Study of Microphysical and Thermodynamic indices in forecasting pre-monsoon thunderstorm over Guwahati during STORM-2009 and 2010

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Abstract : This paper presents thunderstorm vertical structure and microphysical parameters obtained from Micro Rain Radar and thermodynamic instability indices calculated from the radiosonde ascent over Guwahati (26.1445° N, 91.7362° E) during the pre-monsoons. The pre-monsoon convective atmosphere over Guwahati during Severe thunderstorm observations and regional modeling (STORM) field phase 2009 and 2010 is investigated using 12 UTC radiosonde data and micro rain radar. Micro Rain Radar (MRR) images and Skew-T diagrams are also analyzed which support the thunderstorm activities. The convective available potential energy (CAPE) and convective inhibition (CIN) energy show the favorable conditions for the thunderstorm to occur over Guwahati; however, due to physiographic uniqueness of NERI, the values of CAPE, CIN and other thermodynamic parameters show different values during STORM-2009 and STORM-2010. The convective available potential energy (CAPE) and convective inhibition (CIN) energy show the favorable conditions for the thunderstorm to occur in some of the identified stations; however, due to physiographic uniqueness of Indian subcontinent, the values of CAPE, CIN and other thermodynamic parameters show different values in different stations. Moreover, the variation in threshold values of CAPE in different regions makes thunderstorm forecasting difficult which may add uncertainty to loss estimation for risk assessment. A simple outline on thunderstorm risk assessment algorithm development are also highlighted for the quantification of losses, so that the likely probability of occurrences of events with their frequency, location, severity and extent of losses can be modeled and accessed ahead of time for the betterment of the society.

***IndexTerms* - thunderstorms, microphysical characteristics, thermodynamic instability parameters/indices, and algorithm for risk assessment**

I. INTRODUCTION

Thunderstorms are the consequences of cumulonimbus cloud. The base of the thunderclouds initiates from 450 to 600 meters altitudes from the ground surface while the tops frequently reach the altitudes of 12 to 15 kilometers over Tropics. The thunderstorms form over tropics due to upright convection which is a result of uneven heating of the ground surface. The strong updraft leads to release electrical discharge, precipitation or hail from the cloud to surface. These thunderstorms are generally driven by the strong wind and are known as Squalls. The wind speed reaches to 55 to 80 km per hour but sometimes it may attain the speed of 140 km per hour. The rain fall from squall varies from place to place; it increases from west-north to east-south depending on the source of moisture supply. The rainfall lies between few millimeters to 80 millimeter. Microphysical aspect of the thundercloud is a great concern. The drop size distributions had been well represented by the exponential equation and the study portrayed different distribution pattern of rain drops during thunderstorms for different values of rain fall rate (Sekhon and Srivastava, 1971). To figure out the characteristics of rain-drop size distributions different new relationship among the derived products of Doppler radar is established (Steiner, 1991). The different disdrometer datasets comprised measurements taken in Switzerland and Brazil. The study was based upon the specific radar combination of vertically pointing Doppler and polarization radar scanning at low elevations and was derived from consideration of two extensive disdrometer datasets. The important microphysical characteristic of the storms is hail which is quite frequent at the early hour of the season and gradually decreases with time over Gangetic West Bengal. The sizes of hail have been reported to vary pea size to base ball size and it is much common in extra-tropical region. Microphysical characteristics of thunder clouds during pre-monsoon season are explained through VLF atmospherics during tropical thunderstorms (Sarkar*et al*, 1980).The parameters like Gradual Rise of Atmospherics (GRA), Steady Recovery of Atmospherics (SRA), Sudden Enhancement of Atmospherics (SEA) and Integrated Field Intensity of Atmospherics (IFIA) are derived to view the atmospheric conditions during monsoon, pre and post monsoon season. The study shows that the precipitation is associated with the steady recovery of Integrated Field Intensity of Atmospherics (IFIA) during the post-monsoon season while pre-monsoon thunderstorms are related with Sudden Enhancement of Atmospherics (SEA).

Though pre-monsoon thunderstorms give a pleasant weather with rain and a sudden drop in temperature after passage of unbearable heat wave over north-eastern part of the country; rainfall associated with the storm is also helpful for some crops and large number of vegetables and fruits but severe thunderstorms with tomadic intensity affect the life of the people causing casualties and damages to properties every year. 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), Australia (Maki et al.,2001; Sandra et al., 2006), 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 discriminant analysis. Ravi et al. (1999) 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 BhishmaTyagi et al., (2010). 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. Iqbal et al (2010) studied thunderstorm electrical parameters vis-a-vis rainfall and surface air temperatures over Pune. Thunderstorms/lightning generated sprite and associated phenomena was studied by Singh et al., (2010).

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 participated in the **Severe Thunderstorms – Observations & Regional Modeling (STORM) Program** over Guwahati region and 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 and to understand dynamical and microphysical variations of meteorological parameters 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.

II. Data and Methodology

Extensive observations with modern instruments/sensors, viz. Micro Rain Radar (MRR), Laser Disdrometer, Weather Radar, radiosonde, Automatic Weather Stations (AWS) and etc are utilized for better understanding of the physical, dynamic and thermodynamic characteristics of thunderstorms over Guwahati region. 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 Long wave Radiation (OLR)data to understand Hailstorm, thunderstorm and non-thunderstorm precipitating clouds observed during pre-monsoon. ***Table 1***shows an overview of the instruments with an aim to attain the research goals.

As a case study of one thunderstorm (27-05-2010) event and one non-Thunderstorm (22-05-2010) precipitating clouds observations from Micro Rain Radar, Parsivel Disdrometer, Automatic Weather Station, OLR and COSMIC satellite. Here, all the data presented in this paper are in local time, namely the Indian Standard Time which is the Greenwich Mean Time by 5 hours and 30 minutes.

III. Results And Discussion

3.1 Thunderstorm (27thTH May, 2010) study

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. 1992). 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 measurements provided unique in situ cloud-physics data of feeder clouds to severe hailstorms, with coverage from base to the anvil levels.

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. 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.

MRR is one of the remote sensing instruments to estimate the melting layer height and depth. In figure 2 melting layer is shown by a bright band (BB) ~5.5 km, a layer of enhanced radar reflectivity resulting from the difference in the dielectric factor for ice and water and the aggregation of ice particles as they descend and melt. The top of a melting layer is the melting level (or freezing height), commonly accepted as the altitude of the 0°C isotherm surface (Glickman, 2000).

Vertically-pointing micro rain radars can detect Convective and stratiform clouds with melting layer height at intervals of ≤ 1 min within precipitation by using a combination of information on the radar bright band and fall speed gradients (Reddy et al., 2001). The gradient in Doppler velocity associated with the change in particle fall speed as the particle melts from snow into rain provides a clear indication of the melting layer height even in conditions where reflectivity is attenuated. On 27th May, 2010 thunderstorm occurred from 04:00 hrs to 04:30 hrs IST (Figure 2) with a reflectivity profile ranging from 17-24 dBZ observed from ground to 4600 meters, from 05:27 to 07:00 hrs IST we observed a high reflectivity of 54dBZ at the ground and a reduced reflectivity ranging from 16 dBz to 38 dBz with increase in altitude. From 07:20 hrs to 8:30 hrs IST 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 3800 m to 6200 m. For this day precipitation occurred for a total period of 226 minutes with 22 minutes, 90 minutes and 114 minutes for the event1, event 2 and event 3.

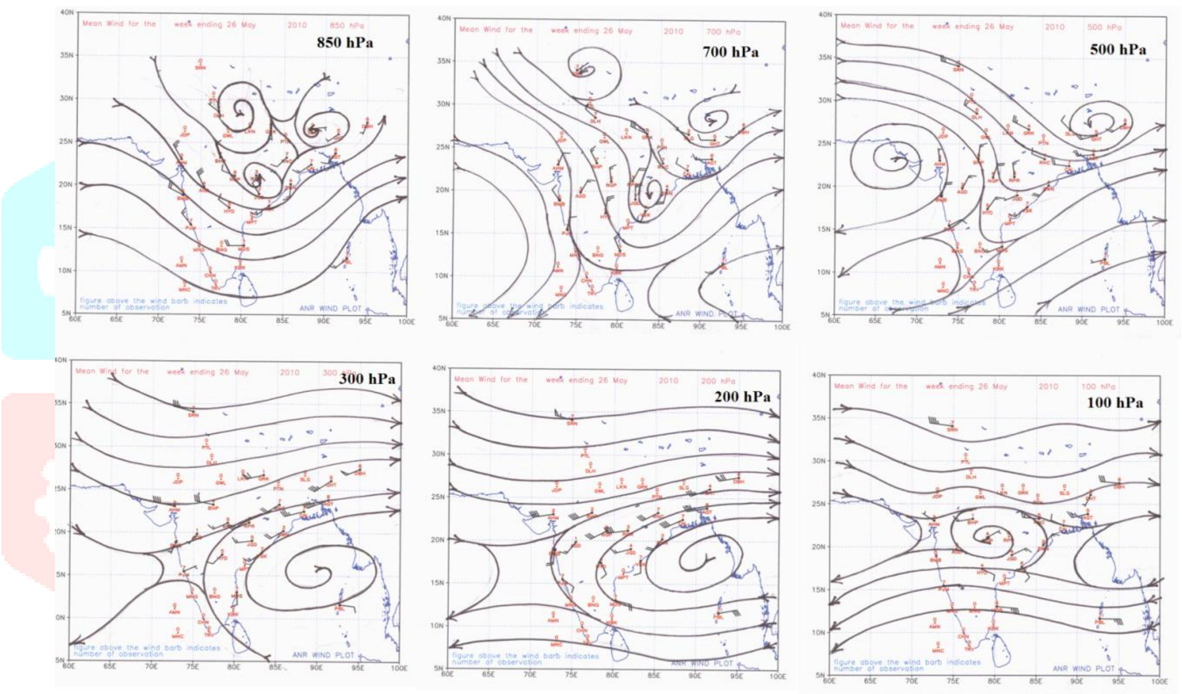


Fig.1: wind chart at different pressure levels of 27thMay, 2010

In the vertical profile of rain rate in event 1 the maximum rain rate is below 5mm/hr and its value reduced in reaching the ground. In event 2 maximum rain rate of 80 mm/hr is observed from 3 to 5.8 k.m and the same intensity is observed at the ground level. In event 3 though the high rain rate of ~70mm/hr is observed at about 5 to 5.5 k.m and the intensity value is reduced while reaching the ground and the observed rain intensity is below 10mm/hr. In the liquid water content (LWC) vertical profile of event 1 its value is about 1 g/m3 and its value has reduced to below 1 g/m3 by reaching the ground. In event 2 LWC ranges from 1- 10 g/m3 in between 3- 5.5 k.m height and the same values are observed from ground to 1.5 k.m height. In event 3 the maximum LWC of 10 g/m3 is observed at about 5 to 5.5 k.m but its values reduced gradually while reaching the ground.

In event 1 of the 27th May, 2010 vertical profile of fall velocity ranged from 6-8 m/s and its value reduced to 4-6 m/s by reaching the ground. In event 2 a higher fall velocity of 10 m/s is observed at the ground when compared to the above ground level. In event 3 fall velocity of 10 m/s is observed in the height range of 4-5 k.m and there is almost negligible fall velocity above 6 k.m height. Radar reflectivity of event 1 is in the range of 15 to 25 dBZ from ground to 6 k.m. In the event 2 a high reflectivity of 45 dBZ is observed at the ground when compared to higher altitudes. In event 3 high reflectivity of 35 dBZ is observed in the range of 4.5 to 5.5 k.m. The main purpose of the AWS is to identify ground level changes in weather parameters corresponding to instabilities if any, as instabilities can be taken as an indication of possible thundercloud formation. Cloud formation requires the presence of humidity. Increase in humidity and vertical motion of air may be considered as indications of lifting which can lead to cloud formation as mentioned by Houze Jr. (1993). A change in RH should be seen reflected in an AT change also. Hence, to ascertain the formation of thunder cloud, interrelated variations between weather parameters on thunder storm days have been examined. Figure 3 shows the variations of four significant weather elements for 24 hours on 27 May 2010.AT shows a prominent reduction with a maximum decrease of 2°C between 030 h and 06:00 h. Exactly at same times and for the same duration RH shows an increase with a maximum increase of 20%.

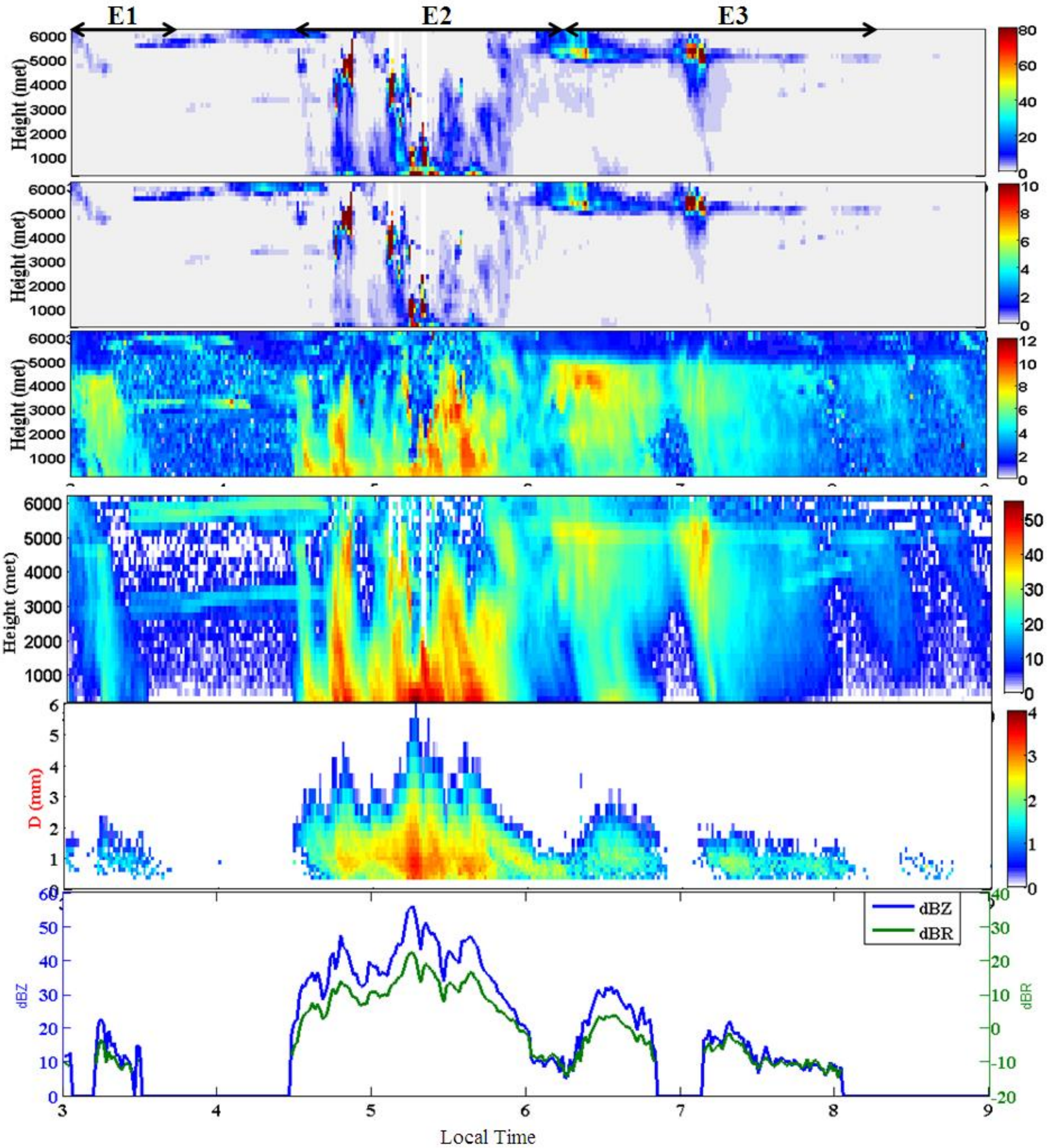


Fig.2: Rain Integral parameters observed on 27th May 2010 during thunderstorm event. Time-height cross section of 1-min. observations of (a) Rain Rate (mm/hr). (b) Liquid water Content(g/m^3) and (c) fall velocity (m/s) (d) Radar reflectivity (dBZ) from Micro Rain Radar observations. Time series of (e) drop size concentration log (N) (mm^{-1}m^{-3}) and (f) Radar Reflectivity (dBZ) and Rain rate [10*log$_{10}$(R), dBR] from Parsivel disdrometer observations.

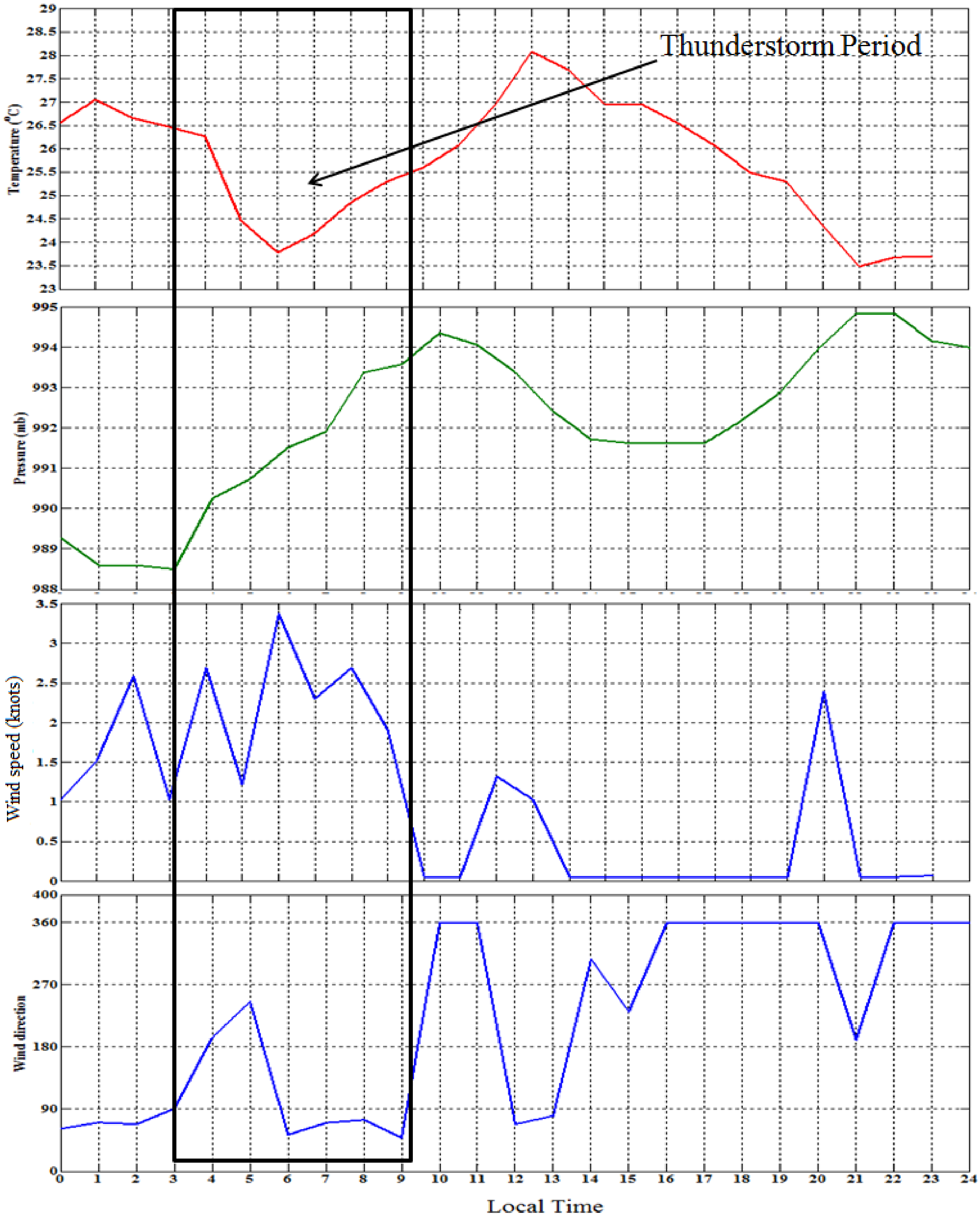


Fig.3: Time series of hourly observed Temperature, Pressure, wind speed and wind direction on 27th May 2010.

3.2 NON-THUNDERSTORM (22TH MAY, 2010) STUDY:

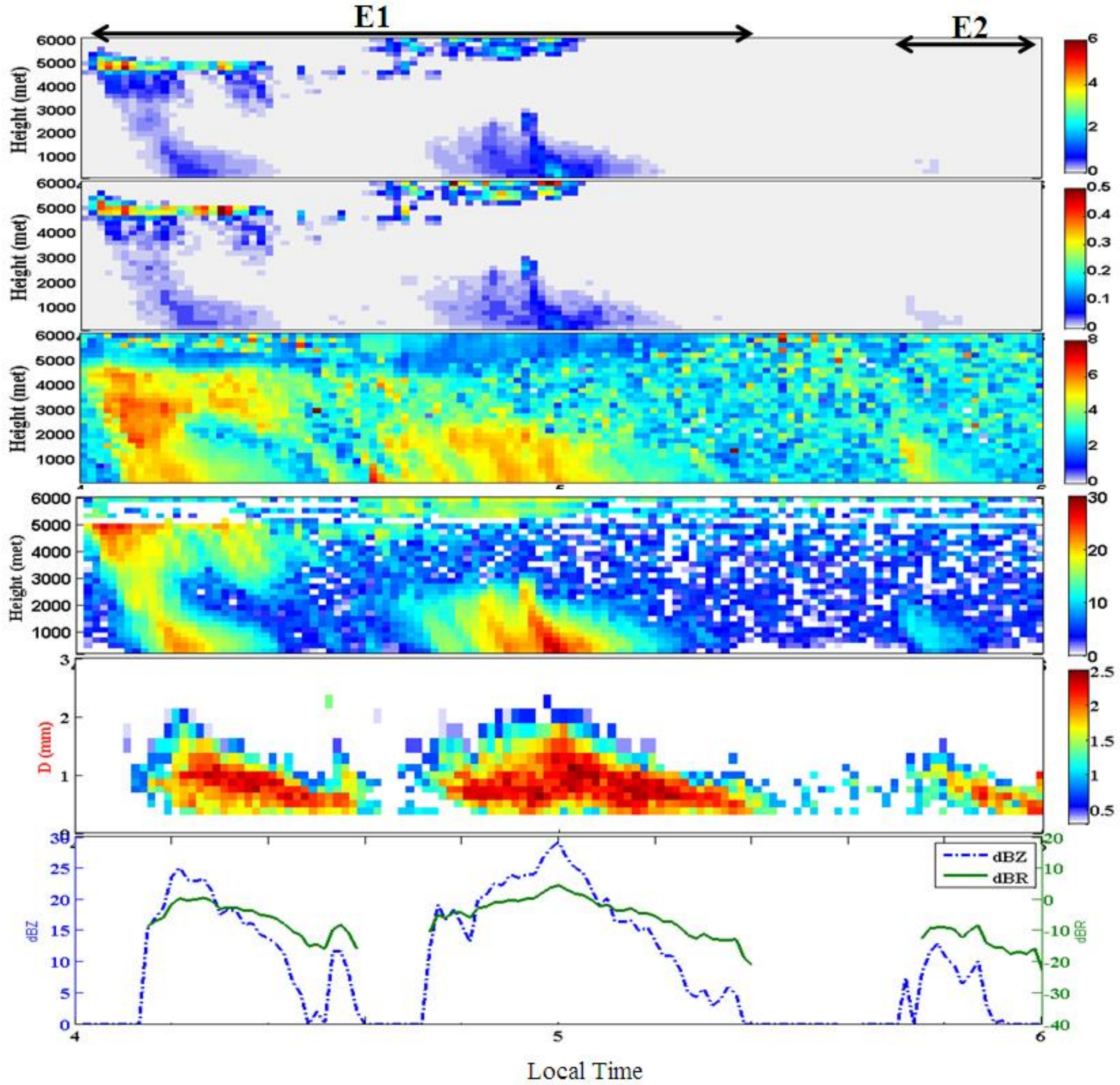


Fig.4: Rain Integral parameters observed on 22 May 2010 during non-thunderstorm event. Time-height cross section of 1-min. observations of (a) Rain Rate (mm/hr).(b) Liquid water Content(g/m^3) and (c) fall velocity (m/s) (d) Radar reflectivity (dBZ) from Micro Rain Radar observations. Time series of (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.

On 22nd May, 2010 Rain occurred from 05:05 hrs to 5:25 hrs IST and from 05:42 to 6:16 hrs IST. During 05:05 hrs to 5:25 hrs IST and enhanced reflectivity value ranging from 20-26 dBz (Figure 4) is observed at ground as well as in the altitude range of 4400 to 5000 meter altitude. And from 05:40 to 6:16 hrs IST reflectivity value ranging from 14 – 28 dBz is observed at the ground and extending vertically up to 2400 meters. In the event 1 of 22nd May 2010 (Figure 4), a maximum of 5-6 mm/hr is observed at an altitude of 5 k.m and intensity value is reduced while reaching the ground in the range of 1 to 1.5 mm/hr. Liquid water content (LWC) is about 0.3 to 0.5 g/m3 in the height range 5-6 k.m is observed and at the ground rain occurred with the LWC value of 0.1-0.2 g/m3.

The Skew-T diagrams (using which it can be can be infer the presence/absence of conditional instability) from Department of Atmospheric Sciences of University of Wyoming are made utilized for the analysis of thermodynamic instability parameters which favor the thunderstorm events. Stability indices presented here are defined based on the 'American Meteorological Society (AMS)'. Details on the different thermodynamic indices are described by Suresh and Litta et.al., Though, several indices signify the Instability parameters used in thunderstorm forecasting and analysis (e.g. Total totals Index, K Index, Showalter index, Lifted index etc.) few of them are mentioned in this study.

3.3 CONVECTIVE AVAILABLE POTENTIAL ENERGY (CAPE)

Convective Available Potential Energy (CAPE) is considered the best index for measuring latent instability in the atmosphere (Darkow 1986) and is a raw estimate of vertical motion. As a representation of the amount of buoyant energy available to accelerate a parcel vertically, CAPE is computed by integration between the environmental temperature curve and the trace of a vertically moving parcel between the level of free convection and the equilibrium level. Still, there are assumptions and problems when using CAPE to assess vertical motion in the atmosphere. Vertical motion estimates need to include the effects of water loading, entrainment, non hydrostatic pressure gradients, and ice processes (Doswell and Rasumussen 1994). In most cases, CAPE is often overestimated due to dry air entrainment and water loading. When CAPE only takes into account the potential amount of energy in the atmosphere, it is likely the most widely used measure of instability and, in a sheared environment, has a great amount of value as a forecast parameter in the prediction of thunderstorm super cells. However, it is recognized that CAPE values related to thunderstorm environments can greatly differ depending upon season and region of interest.

The Convective available potential energy of a parcel is defined as the maximum energy available to an ascending parcel, according to parcel theory. On a thermodynamic diagram this is called positive area, and can be seen as the region between the lifted parcel process curve and the environmental sounding, from the parcel's level of free convection to its level of neutral buoyancy. It may be defined as

$$CAPE = \int_{p_n}^{pf} \left(\alpha_p - \alpha_e\right) dp, \qquad \ldots 1$$

Where, α_e is the environmental specific volume profile, $\alpha_p$is the specific volume of a parcel moving upward moist-adiabatically from the level of free convection, p^f is the pressure at the level of free convection, and $p_n$is the pressure at the level of neutral buoyancy . The value depends on whether the moist-adiabatic process is considered reversible or irreversible (conventionally irreversible) and whether the latent heat of freezing is considered (conventionally not).

CAPE < 0 : Stable
CAPE= 0 to 1000 : Marginally unstable
CAPE=1000 to 2500 : Moderately unstable
CAPE=2500 to 3500 : Very unstable
CAPE > 3500 to 4000: Extremely unstable

The above values are based on a parcel lifted with the average temperature and moisture of the lowest 50 to 1000 m layer (i.e., the boundary layer). The value of CAPE is dependent on the level from which a parcel is lifted. Parcels lifted from the surface usually exhibit a CAPE value than for those lifted using mean boundary layer characteristics.

3.4 CONVECTIVE INHIBITION (CIN) ENERGY

The energy needed to lift an air parcel vertically and pseudo adiabatically from its originating level to its level of free convection (LFC). For an air parcel possessing positive CAPE, the CIN represents the negative area on a thermodynamic diagram having coordinates linear in temperature and logarithmic in pressure. The negative area typically arises from the presence of a lid. Even though other factors may be favorable for development of convection, if convective inhibition is sufficiently large, deep convection will not form. The convective inhibition is expressed (analogously to CAPE) as follows.

$$CIN = -\int_{p_i}^{pf} R_d \left(T_{vp} - T_{ve}\right) d\ln p \qquad \ldots 2$$

Where, p_i is the pressure at the level at which the parcel originates, $p^f$is the pressure at the LFC, R_d is the specific gas constant for dry air, $T_{vp}$is the virtual temperature of the lifted parcel, and $T_{ve}$is the virtual temperature of the environment. It is assumed that the environment is in hydrostatic balance and that the pressure of the parcel is the same as that of the environment.

3.5 SEVERE WEATHER THREAT INDEX (SWEAT):

SW index is used mainly for analyzing the potential for severe thunderstorms and is defined as

$$SW = 20\left(TT - 49\right) + 12D_{850} + 2V_{850} + V_{500} + 150\left[\sin\left(\Delta_{500-850}\right) + 0.2\right] \qquad \ldots 3$$

Where, TT is the Total Totals index (set to zero if less than 49), $V850$ and $V500$ are the 850- and 500-mb wind speeds, and $\Delta V500$ - 850 is the 500-mb wind direction minus the 850-mb wind direction, in degrees. The last term is set to zero if any of the following conditions are not met: i) 850-mb wind direction is in the range from 130 to 250 degrees; ii) 500- mb wind direction is in the range 210 to 310 degrees; iii) the difference in wind directions is positive, or iv) both 850- and 500-mb wind speeds are at least 15 knots. No term in the formula is allowed to be negative. The severe thunderstorm threat is considered to increase from values of about 300 and higher; tornadoes are considered to increase in likelihood from values of about 400 and up .

The shear term in the above SWEAT equation (i.e., last term) is set to zero if any of the following criteria are not met:

1. 850 mb wind direction ranges from 130 to 250 degrees
2. 500 mb wind direction ranges from 210 to 310 degrees
3. 500 mb wind direction minus the 850 mb wind direction is a positive number and
4. Both the 850 and 500 mb wind speeds are at least 15 kts. No term in the equation may be negative; if so that term is set to zero.

SWEAT over 300: Potential for severe thunderstorms
SWEAT over 400: Potential for tornadoes.

These are guidance values developed by the U.S Air Force. Severe storms may still be possible for SWEAT values of 250-300 if strong lifting is present. If convective cell and boundary interactions increase the local shear which would not be resolved in this index. The SWEAT value can increase significantly during the day, so low values based on 1200 UTC data may be unrepresentative if substantial changes in moisture, stability, and/or wind shear occur during the day. Finally, as with all indices, the SWEAT only indicates the potential for convection. There must still be sufficient forcing for upward motion to release the instability before thunderstorms can develop.

3.6. TOTAL PRECIPITABLE WATER CONTENT (TPWC):

The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels, commonly expressed in terms of the height to which that water substance would stand if completely condensed and collected in a vessel of the same unit cross section.

The total precipitable water is that contained in a column of unit cross section extending all of the way from the earth's surface to the 'top' of the atmosphere. Mathematically, if $x(p)$ is the mixing ratio at the pressure level, p, then the precipitable water vapor, W, contained in a layer bounded by pressures $p1$ and $p2$ is given by

$$W = \frac{1}{pg}\int_{p1}^{p2} x dp \qquad \dots 4$$

Where, ρ represents the density of water and g is the acceleration of gravity. In actual rainstorms, particularly thunderstorms, amounts of rain very often exceed the total precipitable water vapor of the overlying atmosphere. This results from the action of convergence that brings into the rainstorm the water vapor from a surrounding area that is often quite large. Nevertheless, there is general correlation between precipitation amounts in given storms and the precipitable water vapor of the air masses involved in those storms .

3.7 THERMO DYNAMICAL PARAMETERS ESTIMATED FROM RADIOSONDE:

Thunderstorm is a mesoscale phenomenon which consists of three stages of evolution, namely, cumulus, mature, and dissipating (Byers and Braham 1949). The presence or absence of conditional instability is one of the favorable conditions for occurrence of a thunderstorm and it is deduced from T–Φ gram (Tephigram). It is quantified by different stability indices. In the present study, Convective Available Potential Energy (CAPE), Convective Inhibition Energy (CINE) and lifted index (LI) have been used for analysis of the thunderstorms. Previous studies (Moncrieff and Miller 1976; Williams and Renno 1993) have highlighted the role of CAPE and CINE in isolate drain fall from mesoscale convective activity. Srivastava and Sinha Ray (1999) have studied the role of CAPE and CINE for occurrence of more convective activities in the month of April 1997.De and Dutta (2005) interpreted CAPE as the maximum amount of potential energy, possessed by air parcel, solely due to convection, convertible to vertical kinetic energy. Sen (2005) has classified the state of atmosphere based on the threshold values of CAPE. Schneider and Sharp (2007) have given The K-index and its variance have been useful predictors of precipitation occurrence/amount and non-severe thunderstorm occurrence, while the Total Totals, Lifted ,and SWEAT indices (and variants thereof) have been valuable severe weather predictors. This section first outlines the definitions of thermo dynamical indices and followed by results obtained with radiosonde data.

Thunderstorm is mesoscale phenomenon which consists of three stages of evolution, namely, cumulus, mature, and dissipating (Byers and Braham 1949).The presence or absence of conditional instability is one of the favorable conditions for occurrence of a thunderstorm and it quantified by different stability indices. In this report we tried to calculate the Convective available potential Energy, Convective Inhabitation Energy and Severe Weather Threat Index (SWEAT).

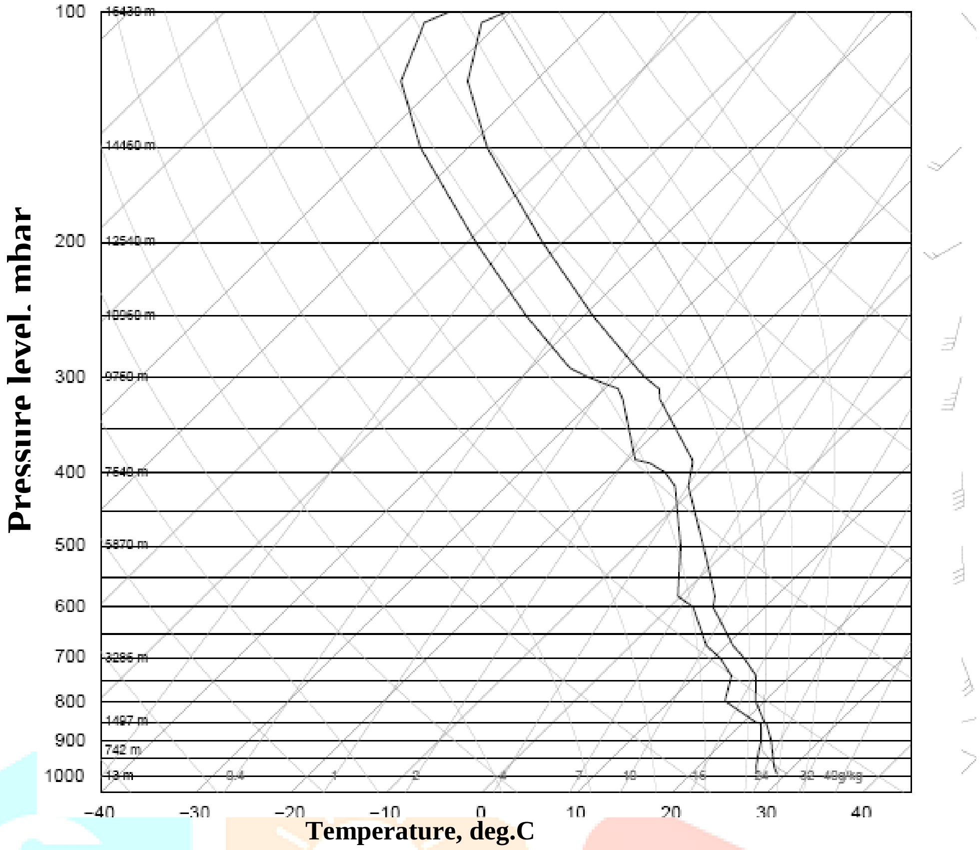


Fig.5:Skew-Tplot at 1200 UTC of 25 May 2009 over Guwahati [from http://weather.uwyo.edu/upperair/sounding.html].

The formation of thunderstorms is an interaction between these conditions on different scales (Doswell, 1987): 'It is proposed that convective systems depend primarily on large scale processes for developing a suitable thermodynamic structure, while mesoscale processes act mainly to initiate convection. Thermodynamic data for this study were extracted from Radiosonde launches from the Regional Meteorological Center (RMC), Guwahati. Various thermodynamical and kinematic parameters such as convective available potential energy (CAPE), convective inhibition energy (CINE), equivalent potential temperature and relative vorticity field are computed.

The skew-*T* plot at 1200 UTC of 25 May 2009 over Guwahati is shown in Figure 6. The plot shows that the atmosphere was convectively unstable at 1200 UTC. The thermodynamic structure over Guwahati is conducive for a thunderstorm occurrence on the evening of 25 May 2009.Convective Available Potential Energy (CAPE) varied considerably during intensive campaign period as shown in Figure 6 and the mean CAPE of 1320 J/kg was observed. The result shows that presence of strong thermodynamic environment is not sufficient for the occurrence of deep convection. Factors like proper dynamic conditions play a very important role in controlling the occurrence of deep convection. The surface warming during the pre-monsoon season destabilizes the atmosphere, but large-scale moist convection, generally, does not take place until CINE becomes close to zero (in the monsoon season, not shown here). Observations during experimental period indicated dissipation of initial cumulus clouds and a failure to develop a significant congests stage until late in the afternoon under the later conditions.

Several research studies (Moncrieff and Miller 1976; Williams and Renno,1993) have highlighted the role of CAPE and CINE in isolated rainfall from mesoscale convective activity. Srivastava and Sinha Ray (1999) have studied the role of CAPE and CINE for occurrence of more convective activities in the month of April 1997. De and Dutta (2005) interpreted CAPE as the maximum amount of potential energy, possessed by air parcel, solely due to convection, convertible to vertical kinetic energy. Sen (2005) has classified the state of atmosphere based on the threshold values of CAPE.Only cases with radiosonde profiles having CAPE greater than 50 J/kg were included in the analysis. This threshold was used to eliminate the large number of zero (or small) CAPE values that are not relevant for severe weather. During thunderstorm, on a few days less CAPE values are observed because of a few radiosondes are launched or launch time may be after the occurrence of thunderstorm. For the present STORM-2010 field campaign the maximum CAPE value of 2600 is observed on 15th April, 2010 (as shown in Figure 6). In other days, the CAPE value in the range of 1300 to 2200 for 21st April, and 9th May 2010 are the observed thunderstorm days. The 18th April, 1st May, 3rd May and 26th May are the days with the CAPE value above zero and below 900 indicating non-thunderstorm precipitating clouds.

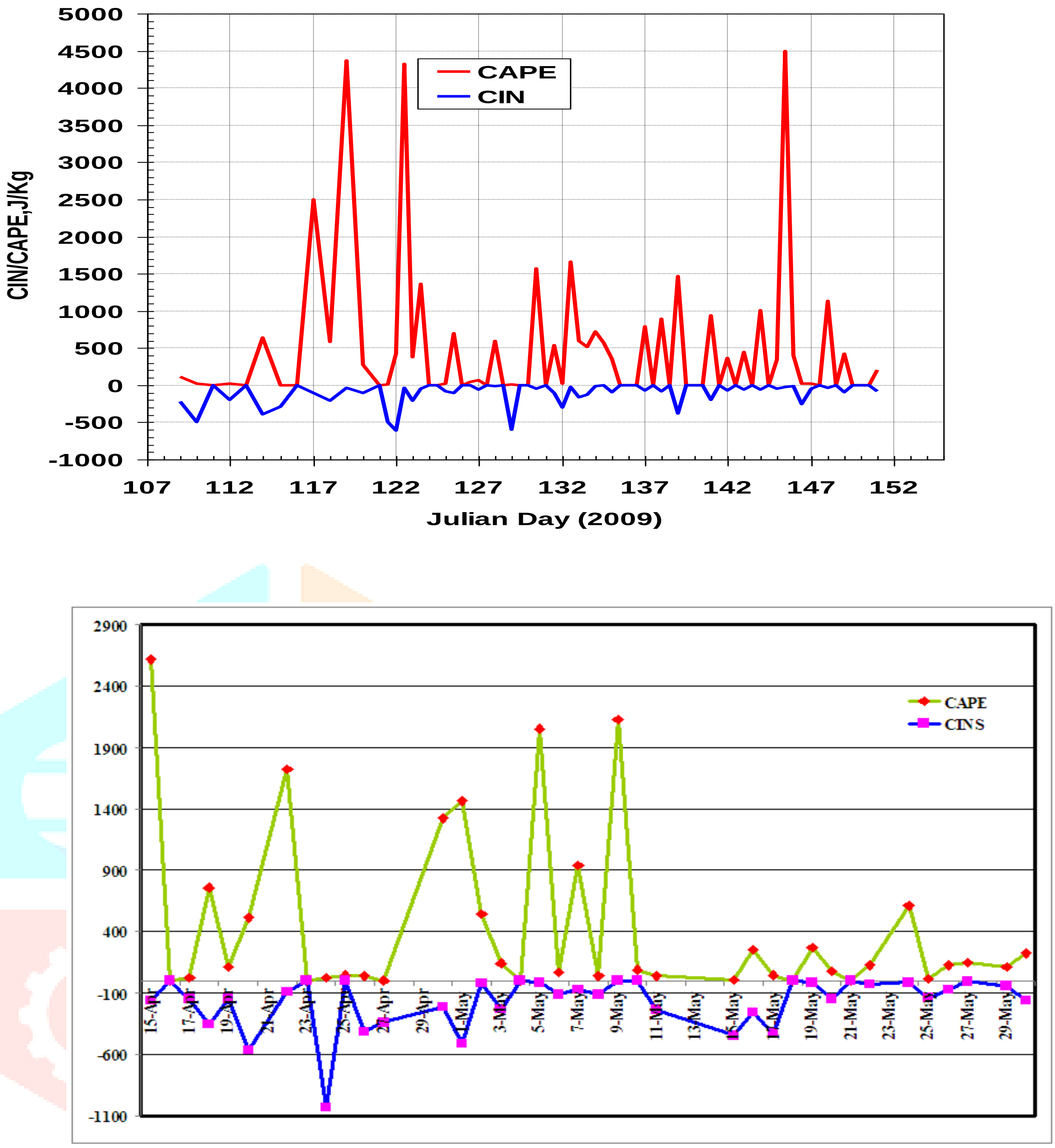


Fig.6: Convective Available Potential Energy (CAPE) and CIN during STROM-2009 and STORM-2010.
(a) from15 April to 31 May 2009 and (b) from 15 April 15 to 31 May 2010

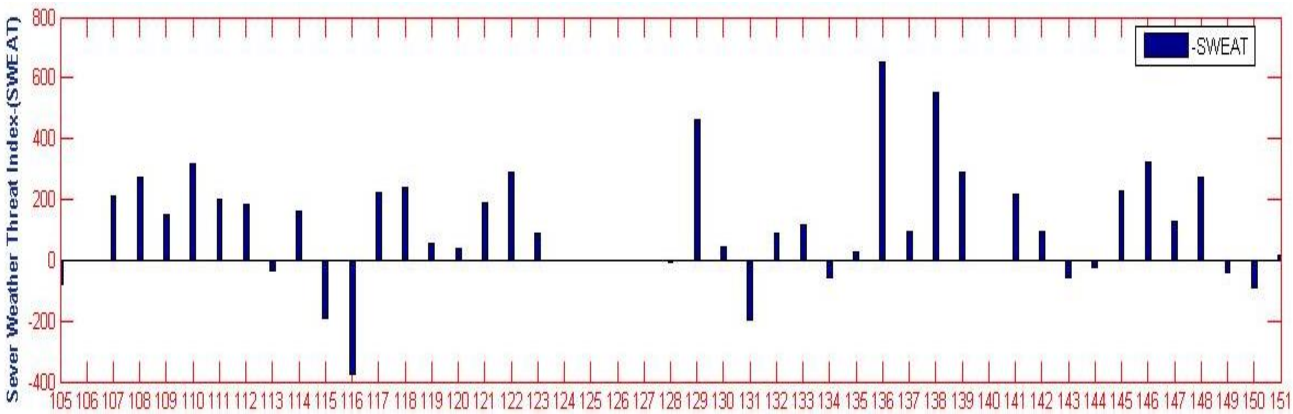
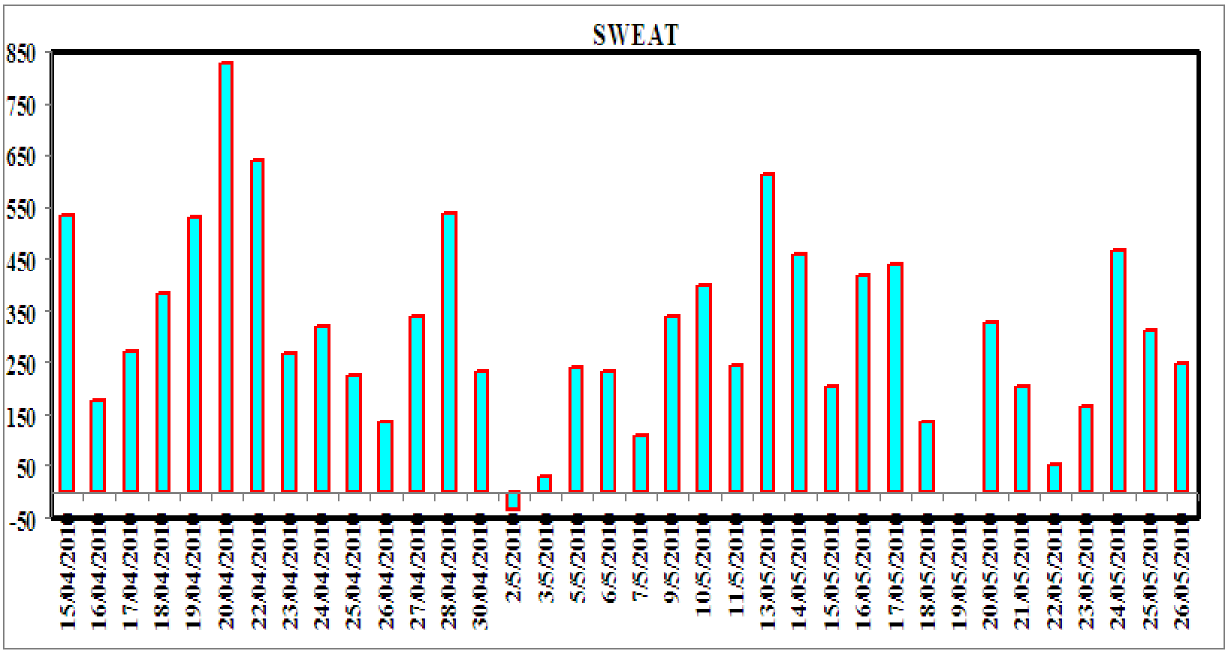


Fig 7: Total Totals Index and Severe Weather Threat Index calculated from Radiosonde data of Guwahati



during STROM -2009 and STORM-2010. (a) from 15 April to 31 May 2009 and (b) from 15 April to 31 May 2010.

Fig.8: Severe Weather Threat Index values of April 15 to 31 May 2010

Figure 8 shows the Severe Weather Threat Index calculated from Radiosonde data of Guwahati during STROM-2009 and STORM-2010.The total totals index is a favorable value for thunderstorm occurrence. The total totals index of > 40 is favorable for the thunderstorm occurrence. From the Severe weather threat index demarcates the TS and NTS precipitating cloud systems. 15th April, 18 to 20 April , 22nd April, 24th April , 27thApril, 9th to 10th May, 13th to 14thMay, 16th to 17th May, 20th May, 24th to 25th May are the days with SWEAT value above 300 and they are the observed thunderstorm days except 18th April , 20th May which are non thunderstorm days.

3.8 Development of Thunderstorm Risk Assessment Model

Based on the realized thunderstorm events over the short period of time during the pre-monsoon season and their adverse impact on the socio-economic conditions and GDP of the nations, the importance of such extreme weather could be well perceived; therefore, it is imperative to forecast and model accurately to know in advance or/well before the time on the severity, location and time of the events for the early warning system/advisories and to access the loss cost due to such severe weather events. Two widely used and accepted approaches to forecast weather are i) the empirical approach and ii) the dynamical approach (Litta et al., 2012). The first approach is referred to as analogue forecasting method in which by using past weather data future events are predicted. The most widely used empirical approaches are regression, Artificial-Neural-Network, stochastic, fuzzy logic and group method (Lorenz, 1969; Kumar et al., 2006). The second approach is based upon governing equations and forward simulations of the atmospheric state using computer technique, and is often referred to as Numerical Weather Prediction (NWP). These governing equations are solved using numerical methods adopting suitable gridding techniques, applying the required initial and boundary conditions in a domain of the study and results are obtained by forward integration of the sets of equations ahead in time for prediction of the weather phenomenon. Numerical modeling studies and research on thunderstorm in India by Vaidya (2007), Chatterjee et al. (2008), Rajeevan et al.(2010) and Litta et al.(2012)have been documented well.

The synoptic charts and the radiosonde ascents provide a broad scale picture of the areas favorable for development and prediction of thunderstorms. At the same time, the radars have proved a boon in the detection of thunderstorm cells including squall lines/tornado and their development with time and space and to prognosticate their movement. Similarly, using satellite technology and images the clusters of cumulonimbus clouds (identified by their high reflectivity, cirriform anvils and the shadows) associated with severe thunderstorms could be analyzed. Analysis of satellite images may help in interpreting subsidence and other weather phenomenon. Thus, thermodynamic instability and radar/satellite techniques are also essential for accurate forecasting of the weather events (thunderstorm). Srivastava et al. (2010) and Sen Roy et al.(2010)have studied the severe weather events using radar data. Hence, the forecasting techniques involve the ground-based sensors output, NWP based methods, Thermodynamics instability indices and Radar/satellite imageries. Importantly, the thunderstorm risk assessment and loss cost to be evaluated by using recently developed algorithm by our research group at Yogi Vemana University, Kadapa(Figure 9). In this paper brief outline on methodological framework of thunderstorm catastrophe risk assessment modeling steps are highlighted. Since such models are mostly proprietary in nature so details literature on this aspects are skeletal. As a first step towards the development of thunderstorm risk assessment model, the frequency of the events may be modeled based on the adjusted historical data. Historical data could be procured from the well certified and accepted data sources or region/country specific recognized nodal agencies, which archive for long period of time and disseminate for research and other applications.

Recent science and technological development in the field of observations, tracking and reporting have led to an apparent increased frequency in thunderstorm occurrences. Moreover, the advancement of DWR and high resolution Satellite products have enabled to provide better detection and reporting of the events and to provide quality data. Even then historical data must be adjusted before a valid thunderstorm risk model may be developed. Thus, the de-trended historical data is considered as better approach for stochastic event set generation for tornadoes, hail storms, and straight-line winds/thunder squall using a smoothing (e.g. smooth bootstrap) procedure that randomly samples from this seed set and spatially perturbs each selected event. The process may also include the temporal and spatial clustering of events so that the simulated event sets could be evaluated against the historical data set for completeness and validation. Importantly, simulated storms can occur where no historical storms have been reported. In a nut shell, in the processes of building the thunderstorm risk assessment model the updated building codes and construction practices plus plant phenology could be integrated with the latest science, computer technology and engineering. So that, both the hazard and vulnerability components of the model offer important modeling innovations, viz. stochastic event simulation (hail, straight line winds, tornadoes), intensity computation model for hazard footprints, different vulnerability functions for different sub-perils of thunderstorms.

Thunderstorm risk assessment algorithm output may include Exceeding Probability (EP) Curve that also include occurrence EP (OEP)/ aggregate EP (AEP), Average annual loss (AAL), Tail value at risk (TVAR), and event-by-event losses with associated uncertainty. Reporting of results could be in total aggregate portfolio, ZIP code, detailed output by policy and site etc. Such model may be useful for reinsurance/insurance companies, Government agencies, financial institutions and others to perform a variety of crucial analyses and provide risk perspectives at site, policy and portfolio level in pricing and managing risk, communicating to stakeholders, including rating agencies, regulators, shareholders, and counterparties.

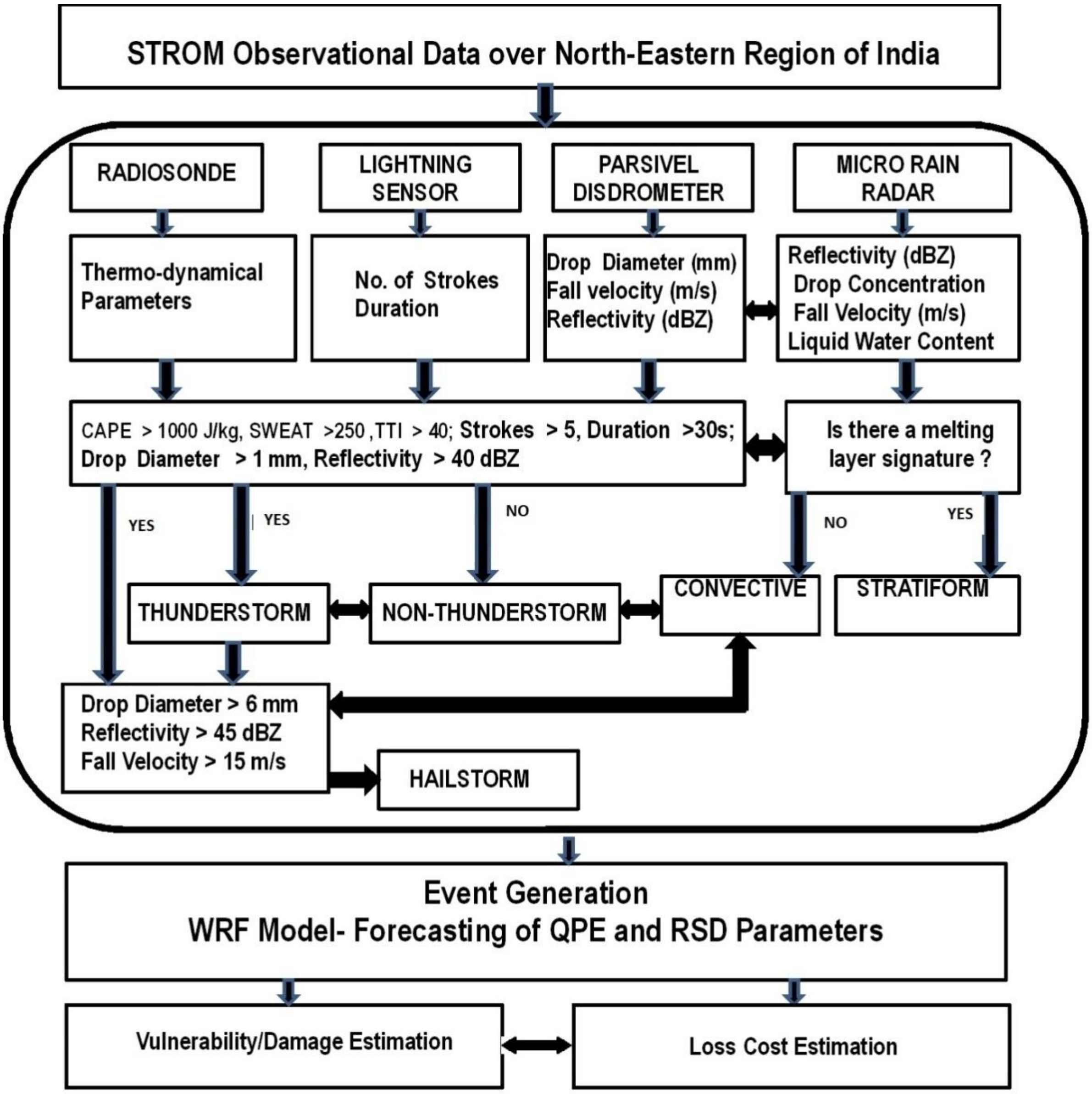


Fig .9. Algorithm showing the thunderstorm risk assessment model development steps/components

IV SUMMARY AND CONCLUSIONS:

North-Eastern Region of India is being bestowed with unique geographical set up, topography and proximity to equator experiences severe thunderstorm of different intensities in different seasons, though frequency of thunderstorm in higher in pre-monsoon season; when the atmosphere is highly unstable because of high temperatures prevailing at lower levels. Severe

Thunderstorms (Nor'westers) a meso-scale disturbance occur frequently in the northeastern Indian subcontinent, and cause devastative damages in this region every year. These meso-scale disturbances mainly occur in the pre-monsoon season (from March to May).From STORM-2009 and 2010 data analysis confirm results of earlier studies and also brought some new results such as maximum frequency observed was along Brahmputra river. 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. It is evidenced that Severe thunderstorms are concentrated downstream of high terrain and pole ward of moisture sources in the form of warm water or rainforest. However, the confluence of continental cold, dry air from northwest at the upper level with warm, moist air masses at lower level from southeast (Bay of Bengal region) creates the conducive environment for the development of the thunderstorm in India. The change of the wind direction with height associated with this configuration implies the presence of significant vertical wind shear, one of the important parameter for severe thunderstorms development. Thus, the atmospheric instability, lower level ample moisture availability, vertical wind shear and vertical lifting constituent the main ingredient in thunderstorm activity.

In this paper, Micro Rain Radar data have analyzed for vertical structure of thunderstorm and non-thunderstorm activities to understand microphysical characteristics. This initiative my help research community to answer some of the important questions relating to thunderstorm viz. exact threshold value of CAPE, exact values of updrafts/downdrafts, relationship/behaviors of synoptic/mesoscale environment with thunderstorms, low- level jets, wind shear and predictability of hailstorm etc. over Indian region and other parts of continents. For this purpose, it warrants establishing the dense network of mesoscale observational stations with continuous automated monitoring system for archiving and dissemination of the data for research and development and different applications. Importantly in this direction an additional network of stations which includes the automatic weather stations, global positioning systems sounding system and Doppler Weather Radars.

Present study also highlights the RS/RW ascent products in terms of thermodynamic instability parameters/indices for the pre-monsoon season over Guwahati of STORM project region for the analyses of the thunderstorm activities. The Skew-T and radar images supporting thunderstorm activities are also analyzed/presented in this regards. It is evidenced that, thunderstorm activity records significant increase in April with the onset of summer conditions over most parts of the country. Physiographic features, insolation and confluence of air masses and advection of moisture under favorable wind regime contribute to high frequency of thunderstorm over these areas. The western disturbances and induced lows in the north and easterly waves plus wind/moisture discounity in south provide conducive environment for the occurrence of thunderstorm over these regions.

Moreover, for better understanding the complex thunderstorm activities for accurate prediction/modeling and for the development of thunderstorm risk assessment model, which is proposed in this study as a next step of research work, may require in-depth knowledge on the various aspects of thunderstorm genesis/development, movement and dissipation mechanisms.The research outcomes of this paper may form the base line information in thunderstorm risk quantification approaches and may also prove useful for the insurance/re-insurance companies, financial institutions, Government organizations and others for decision making, policy issue formulation and their implementation.

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