Chapter - 1

General Introduction

The thunderstorms are typical meso-scale systems controlled and influenced by intense convection. Proper realization and prediction of these weather events is a challenge to the atmospheric scientists. Though, many studies are conducted to understand the dynamical and thermo-dynamical structure of this severe weather phenomenon, but the actual purpose of accurate forecast with considerable lead time has not been delivered as yet, may be, due to lack of close networking of observation system and thus, insufficient understanding. Thunderstorms, in general, connote a perennial feature and occur over different parts of India during different seasons (Manohar et al. 1999). The micro-physical processes leading to the development of these severe storms are also not well-understood due to lack of meso-scale observations. Severe thunderstorms are momentous weather phenomena which impact on various facets of national activities like civil and defense operations, particularly space vehicle launching, agriculture, in addition to this, its damage potential to life and property on the ground and aviation aloft.

The formation of thunderstorms is an interaction among these conditions on different scales (Doswell, 1987). The proper growth of the thundercloud, on the other hand, is supported by pulling mechanism from the upper levels dynamics (Ramaswamy, 1956).
India is confined within 8° N and 37° N latitudes. The tropical easterlies and the mid-latitude westerlies, therefore, influence the weather systems over the subcontinent. Interactions between the tropical and mid-latitude characteristics often occur in this belt. However, the severe thunderstorms occurring over Gangetic West Bengal (GWB) enclosing Kolkata (22° 32'N, 88° 20'E) during the transition period of pre-monsoon season (April - May) are the most devastating when accompanied by lightning flashes, large hail, torrential rainfall, high wind gust and occasional tornadoes.

There are four types of pre-monsoon thunderstorms over north eastern part of Indian subcontinent, viz. A, B, C, and D (IMD T.N. 10, 1944):

- Type A develops over Chota Nagpur Plateau and the adjoining areas (Gangetic Plain in West Bengal, India and Bangladesh), mainly in the afternoon, and subsequently moves in a southeasterly direction.
- Type B originates in the sub Himalayan districts of north Bengal and move southwards. Generally, it occurs during night and early morning.
- Type C originates over the hills of Nagaland, Manipur and Mizoram and travel westwards. It is very rare.
- Type D is very similar to type B but the place of origin is near the Garo hills and Khasi hills. The direction of movement is also from north to south.

Most typical and hazardous types of the thunderstorms are Type A thunderstorms. These storms are termed as Nor'westers, as the approach is mostly from the north.
westerly direction towards the station. The societal and economic impact by Nor’westers made accurate prediction of the weather a great challenge for the professional meteorologists of India. Forecasting Nor’westers over Kolkata (Chaudhuri, 2006; Chaudhuri and Biswas, 2008c) is thus, a prime necessity. It is therefore necessary to take stock of studies that have gone by, make a critical appraisal of them and to distil from them those that will provide inputs for further investigations in the desired direction. Detection of thunderstorm requires a very close network of observatories which is quite impossible. Moreover the lack of adequate data network requires interpolation and extrapolation to create data at the points where data are not available. Interpolation or extrapolation generates error in the input. The traditional methods like numerical weather prediction (NWP) and statistical methods cannot take care of various linguistic variables like “severe”, “high”, “low” etc. that meteorological events need frequently. In this thesis some state of the art flexible computing techniques are adopted for the better understanding of high frequency, nonlinear, mesoscale weather systems like thunderstorms (Abraham et al, 2001; Marzban and Witt, 2001; Benjamin et al, 2007; Chaudhuri, 2008b, Chaudhuri, 2010).

Soft Computing technique (Zadeh, 1965) implies a flexible computing approach that has became highly popular in recent times in recognition of patterns of different objects, which are highly indiscernible in nature. These methods are suitable for working in a non-linear and chaotic environment. They can evolve
themselves for better output and are highly capable of extracting vagueness from an imprecise data series. The principal components of Soft Computing are Fuzzy Logic (FL), Neural Computing (NC), Genetic Algorithm (GA), Rough Set (RS) and Probabilistic Reasoning (PR). This technique has opened up a new line of approach in a number of applied fields, especially where prediction of time series is desired. The prediction is basically a task of pattern recognition. The application of Soft Computing techniques is possible for non-linear and imprecise time series (Chaudhuri, 2010a, b).

Many real world situations can conveniently be described by means of a diagram consisting of a set of points and another set of lines joining certain pairs of these points. Basically a graph consists of a set of vertices $V_i$ and a set of edges $E_j$.

Using Graph theory analysis in meteorology, we can take the vertices of graph as input and output sets and the edges as the logic or reasoning. Thus the obtained output can be matched with target output using different Graph properties. Various methods like paths, walks and cycles, distances, average measures of connectivity, similarity of connection patterns, connectedness and components, cluster indices, ranges and shortcuts, and node and edge cut sets etc. can be effectively introduced in modeling of different real world situations and physical processes. Graph methods can adopt various complexity and non-linearity and the generated errors in conventional methods can be ignored by its flexibility. All graph theory methods are based on a network's connection (adjacency) matrix,
which can be derived from several different sources. In NWP methods the choice of mesh grids and the objective analysis can be done with Graph mathematics. Development of appropriate computational tools, those are useful in handling the challenges of atmospheric analysis, can be possible using Graph mathematics (Chaudhuri, 2007). This study aims to explore the applicability of Graph Theory for forecasting pre-monsoon thunderstorms over Kolkata. The advantage of the approach is that it can adopt all the complexity, non-linearity and inherent chaos of a system in its heuristic framework. Plethora of literature is available which show the applicability of statistical and numerical methods to forecast thunderstorms (Schultz, 1989). For example, Davies (2004) estimated CIN and Level of Free Convection (LFC) associated with tornado and super cell thunderstorm activity. Huntrieser et al (1997) have compared the traditional and newly derived convective indices with their statistical forecast skills over Switzerland. In the present study, Single Spectrum Bipartite Graph (SSBG) model output shows distinct ranges of maximal eigenvalues for severe (2.6±0.12), ordinary (1.88±0.09) and no thunderstorm (1.26±0.03) events. These ranges are used as the reference range for the prediction and the result is validated with the observation of 2007. The model provides 12 to 6 hours forecast (nowcasting) of thunderstorms with 96 % to 98% accuracy (Chaudhuri and Middey, 2009). The significance of the altitudes of lifting condensation level (LCL), convective condensation level (CCL), level of free convection (LFC), freezing level (FL) and
the level of neutral buoyancy (LNB) from the surface level and their intermediate distances are explored in this study using the upper air Radiosonde / Rawinsonde data of 00 and 12 UTC during the pre-monsoon season (April – May) over the station Kolkata. A graph distance matrix is formed with ten years (1997 – 2006) data. The spectral distances and entropies are estimated for various thunderstorm days. The result further depicts that the forecast accuracy through the present method is 98% with one hour lead time whereas the accuracy is 93% with six hours lead time. The forecast is validated with the India Meteorological Department observations for the years 2007, 2008 and 2009 (Chaudhuri and Middey, 2011). Adaptive neuro-fuzzy inference system (ANFIS) has been developed to forecast the surface peak gust speed associated with the pre monsoon thunderstorms over Kolkata (22° 32'N, 88° 20'E) encircling 60 km. area. Neural network and other hybrid soft computing models like ANFIS have already been found to be useful for improving the numerical weather prediction (NWP) model products (Jang, 1993). Moreover ANFIS model have no conflict with numerical weather prediction systems or any other operational forecast systems. Rather, it helps those systems to improve the forecast quality. ANFIS model developed in this study is observed to be useful for nowcasting thunderstorm peak gust speed with lead time up to 12 hours.

Identification of the most significant stability indices relevant for the occurrence of Nor’westers using statistical and soft computing method is done. The forecast
quality detection parameters are computed for the available indices during the period from 1997 to 2006 to select the most relevant indices with appropriate ranges for the genesis of Nor’westers. The skill of LI (Lifted Index, CIN (Convective Inhibition) and CAPE (Convective Available Potential Energy) within the stipulated ranges indicates that the parcel temperature of 5 to 12° C more than the environmental temperature, inhibition energy within 150 Jkg⁻¹ and the available energy in the atmosphere within a broad range of 2000 to 7000 Jkg⁻¹ make the environment suitable for the prevalence of Nor’westers. A composite stability index, Nor’wester Prediction Index (NPI) is formulated with the most significant indices (LI, CIN, and CAPE) to forecast Nor’westers. The forecast with NPI is validated for Nor’westers of Kolkata with the observation from 2007 to 2009. The NPI is used for real time forecast of Nor’westers during the pre monsoon season of 2010.

Convective features and lightning flash activity are studied over two different locations in India with contrasting terrain features. Lightning Imaging Sensor (LIS) database from 1998 to 2008 have been analyzed during pre-monsoon months (March, April and May). The eastern sector, Sector A (West: 85.94°, North: 24.55°, South: 21.41° and East: 89.3°) covering Gangetic West Bengal adjoining part of Bihar and Orissa and the north-eastern sector, Sector B (West: 90.08°, North: 26.6°, South: 24.41°, East: 94.04°) covering Assam, foot hills of Himalaya. The genesis and dynamics of thunderstorms over these two sectors are
completely different. Lightning activity is higher in Sector B than Sector A. Though the lightning frequency is comparatively less but the associated radiance is higher in Sector A than Sector B. Special reference to the stations Kolkata (22.65° N, 88.45° E) and Gauhati (26.10° N, 91.58° E) belong to Sector A and Sector B respectively are made for thunderstorm and lightning features. It is found that the radiance increases linearly with Convective Available Potential Energy (CAPE) value and high correlation coefficient reveals that lightning intensity can be predicted with CAPE values. The sensitivity of lightning activity to CAPE is higher at elevated station Gauhati (elevation: 54 m) than station Kolkata (elevation: 6 m). Moderate Resolution Imaging Spectrometer (MODIS) data product are used to obtain Aerosol Optical Depth and Cloud Top Temperature and employed to find their response to lightning radiance.

The study of boundary layer is imperative because this is the portion of the atmosphere where the impact of severe weather on environment and various facets of national activities like civil and defense operations, particularly space vehicle launching, agriculture, in addition to this, its damage potential to life and property on the ground affects the socio-economic scenario of a region. The characteristic of boundary layer structure is investigated in this study by observing the vertical variation of fluxes of heat, moisture, momentum, kinetic energy and Richardson number during the pre-monsoon season (April - May) at Kharagpur (22° 30' N, 87° 20' E) with 50 m and at Ranchi (23° 32' N, 85° 32' E).
with 32 m tower data on thunderstorm and non-thunderstorms days. The upper air synoptic features are also analyzed during these thunderstorm and non-thunderstorm days. The temporal variation of fluxes within the boundary layer and the kinetic energy at different logarithmic heights are observed to vary significantly between thunderstorm and non-thunderstorm days. The heat and momentum fluxes show maximum peak while the moisture flux shows a sudden fall just before the occurrence of thunderstorms. The wind field depicts to play a very crucial role at the inland station, Kharagpur which is in the proximity of Bay of Bengal than the station Ranchi situated over hilly terrain of Chotanagpur. The micrometeorological study of the boundary layer with tower observations reveals a significant finding pertaining to forecast thunderstorm genesis. A moist convective index which is the ratio of the potential temperature ($\theta$) and equivalent potential temperature ($\theta_e$) is found to be confined within a critical range between 0.85 and 0.90 just before the occurrence of thunderstorms at both the stations. The moist convective index may thus, aid in the operational forecast of thunderstorm genesis.

The similarities and dissimilarities in the characteristics of tropical and extratropical thunderstorms are studied with reference to the two stations, Kolkata ($22.6^\circ$N, $88.4^\circ$E) and Denver ($39.47^\circ$N, $104.32^\circ$W). Most severe thunderstorms occurred over Kolkata during pre-monsoon months (April-May) and over the station Denver, warmer months of June, July and August are prone to severe
thunderstorm events. Records of storm events are collected during the period of 1999 to 2010. Sounding data are analysed for the both stations during thunderstorm events and clear demarcations in the ranges of significant dynamic and thermodynamic parameters are observed. Next Generation Radar (NEXRAD) products by National Weather Services (NWS) and Doppler Weather Radar (DWR) products are studied for Denver and kolkata thunderstorms respectively.