The thunderstorms are typical mesoscale systems dominated by intense convection. During April and May, the eastern parts of the country get affected by higher frequency of severe thunderstorms, locally named as ‘Nor’westers’ as it travels from northwest to southeast direction. Severe thunderstorms associated with squalls, lightning, hail, heavy rain cause extensive damage to standing agriculture crops, high rise buildings as well thatched huts, high tension electric poles and wires, and cause flash floods, resulting in loss of life and property. An accurate location specific and timely prediction is required to avoid loss of lives and property due to strong winds and heavy precipitation associated with these storms. Forecasting thunderstorms is one of the most difficult tasks, due to their rather small spatial and temporal extension and the inherent non-linearity of their dynamics and physics. The improvement in prediction of these important weather phenomena is highly handicapped due to lack of mesoscale observations and insufficient understanding. Realizing the importance of improved understanding and prediction of
this weather event, an attempt is made to study these severe thunderstorm events during the pre-monsoon season using empirical and dynamical approaches. The most widely used empirical approach for weather prediction is ANN. The recent advances in neural network methodology for modeling nonlinear, dynamical phenomena along with the impressive successes in a wide range of applications, motivated to investigate the application of ANNs for the prediction of thunderstorms. The second approach is based upon equations and forward simulations of the atmosphere (NWP). The most commonly known NWP models namely NMM and ARW models are used for this study.

The capabilities of six different learning algorithms using MLPN in predicting thunderstorm affected parameters over Kolkata (22.52°N, 88.37°E) were studied and their performances were compared. The ANN model was found to be efficient in fast computation and capable of handling the noisy and unstable data that are typical in the case of weather data. The results indicated that MLPN model with LM algorithm well predicted thunderstorm affected surface parameters. The developed ANN model with LM algorithm was applied to derive thunderstorm forecast from 1 to 24 h ahead at Kolkata. The studies of advanced prediction of these parameters showed that 1 and 3 h MLPN models were able to predict hourly temperature and relative humidity adequately with sudden fall and rise. The results of these analyses demonstrated the capability of
ANN model in prediction of severe thunderstorm events over eastern Indian region and will be helpful for real time thunderstorm forecast.

The sensitivity experiments have been conducted with NMM model to examine the impact of different initial conditions, CPSs and microphysics schemes in capturing the severe thunderstorm events occurred over Kolkata during May 2006, 2007 and 2009. Three sets of initial conditions (19 May 2006 at 0000 UTC, 19 May 2006 at 1200 UTC and 20 May 2006 at 0000 UTC) were experimented using NMM model for a thunderstorm event on 20 May 2006. The trends shown by various meteorological fields of the third experiment (20 May 2006 at 0000 UTC as initial condition) were in good agreement with each other and very much consistent with dynamic and thermodynamic properties of the atmosphere for the occurrence of a severe thunderstorm. Another sensitivity experiments are conducted with NMM model by changing the CPSs such as KF, BMJ, GD, AS schemes and explicit scheme for two severe thunderstorm cases (20 May 2006 and 21 May 2007) at Kolkata and validated the model results with observation. In all experiments, the setups were identical except for the use of different convective schemes. Hence differences in the simulation results may be attributed to the sensitivity of the convective schemes. This study shows that the prediction of thunderstorm affected parameters is sensitive to convective schemes. The GD scheme has well predicted the thunderstorm activities, in terms of time, intensity and the region of occurrence of the events, as
compared to other convective schemes and also explicit scheme. One more sensitivity experiment has been conducted for a severe thunderstorm event on 15 May 2009 with three microphysics schemes namely FERR, WSM6 and THOM to examine the sensitivity of the simulations to different cloud microphysics. The results show that the NMM model with FERR scheme appears to reproduce the cloud and precipitation processes more realistically than other schemes for the prediction of severe thunderstorm event. The studies found suitable options as 24 h simulation for initial conditions, GD scheme for CPS and FERR for microphysics scheme. These options are used for further studies of thunderstorms with NMM model.

A comparative study with two numerical models namely NMM and ARW were done for the prediction of severe thunderstorm events during May 2009. Both models were able to broadly reproduce several features of the thunderstorm events, such as spatial pattern and temporal variability over east region of India. Comparison of model simulated thunderstorm affected parameters with that of the observed showed that NMM has performed better than ARW in capturing the sharp rise in humidity and drop in temperature. NMM model has predicted well the genesis, intensification and propagation of the squall line, which is in good agreement with that of the observed, while the squall line movement was slow in ARW. The statistical analysis of surface parameters indicates the superiority of NMM model in simulating the thunderstorm over
Kolkata on these severe thunderstorm cases. This suggests that NMM model has the potential to provide unique and valuable information for severe thunderstorm forecasters over east Indian region.

The performance evaluation of computational models namely ANN, ARW and NMM models were done to predict severe thunderstorm events using thunderstorm affected parameters like surface temperature and relative humidity over Kolkata. Thunderstorm prediction is inherently complex process, so it is impossible to wait 100% accurate forecast results since we cannot measure all factors that may be local scales. From the results we can see that, the ANN models are not able to predict the sharp jumps and dips of surface parameters during the thunderstorm hour as it is a complex physical process. NMM model is able to predict these fluctuations adequately with reasonable accuracy. It is concluded from the results that, NMM model is good for thunderstorm prediction temporally and spatially since it is a short-lived mesoscale phenomenon which cannot be much easily predicted from historical data.

### 7.1 Future Directions

There are strong requirements in India for improved forecasting of rapid and severe thunderstorm over east and northeast Indian region. Even if a reasonable mesoscale analysis can be obtained, imbalances between the dynamic and thermodynamic fields can lead to model spinup which could degrade, e.g. short-term precipitation forecasts, a key requirement
for mesoscale systems. Thus improved mesoscale analyses will rely on the development of assimilation methods which will include alternative methods to replace current analysis approaches in which only data at or near the synoptic times are used. More comprehensive work will be carried out to improve the mesoscale model performance with modified initial condition through sophisticated 3DVAR/4DVAR assimilation system using ample amount of special high quality observations.

It is clear that high impact weather systems such as thunderstorms, heavy precipitation or tropical cyclones have a high level of uncertainty associated with them. It is therefore more appropriate to provide forecasts of these features in terms of the development of mesoscale ensemble prediction systems (EPS). This will require further research on development of appropriate means of generating initial perturbations and accounting for model uncertainties. Nowcasting and very short range forecasting are concerned with the weather monitoring and forecasting of weather for the shortest time scales, ranging from 0 to 6 hours. These methods are expected to shift from the traditional specialized techniques to an utilization of more general NWP output products. This will be made possible through access to future more powerful computers, through the application of mesoscale NWP models at grid resolutions of the order of 1 km or less and through application of mesoscale assimilation techniques.

The Thunderstorm prediction systems are more likely decision support system than expert systems because they need guidance and
predictions must be evaluated by human interference. The future directions for improving these severe weather events over Indian region can be summarized as follows:

- Comprehensive mesoscale data assimilation utilizing conventional and non-conventional observations from multi-observation platforms.

- Prediction of life cycle of thunderstorm along with associated hazards using very high resolution (1-0.3 km) state-of-the-art mesoscale models.

- Role of physical processes in particular deep convection, cloud microphysics, planetary boundary layer, land surface processes with high resolution mesoscale model and special observational datasets.

- Understanding of cloud microphysics, aerosol concentration and atmospheric electricity in association with severe thunderstorms.

- Systematic error evaluation and bias correction of NWP models in simulation of severe thunderstorms.

- Improve prediction of intensity and time of occurrence of severe thunderstorms by using dynamical-statistical approaches.