Prashant Singh

STUDY FOR PREDICTION OF THE CONVECTION DEVELOPMENT OVER OCEAN

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By

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Table of contents:

Preface

Convection development is one of the areas in meteorology that is challenging to forecast. Thunderstorms can form in less than 20 minutes and have destructive effects. In this study we tried to give prediction of convective thunderstorm with lead time.

A study with primary importance given to the potential value of parameters derived from Radio Sounding and scattrometer wind data for forecasting the thunderstorm associated with convective storms is presented in this work. The main aim of this study is to predict the thunderstorm with a lead time by making use of four parameters i.e. lifted index, K index, Vorticity and divergence respectively. For this study we have used two years data out of which one year data is used for making criteria/finding the threshold value for prediction and one year data is used for verification. It is observed that, six hours prior to the thunderstorm occurrence chosen parameters shows good linearity and less scattering from predicted values.

In this work we used radio sounding data to calculate varies parameter associated with convective thunderstorm like Convective Available Potential Energy (CAPE),Convective Inhibition Energy (CIN), K Index and L index. Also scattrometer data is used to find out Vorticity and Divergence Over the region.

The thesis comprises of four chapters. The content and salient features of each chapter are highlighted in the sections below:

Chapter 1 Gives introduction about the formation of convection development over ocean. Studies based on observations, modeling are also included on convection development over ocean using various parameters.

Chapter 2 Describes in detail about the parameters which we used to give prediction on convection development with a good lead time.

Chapter 3 Provides details of the sources and types of data we used to calculate the parameters used for prediction of convection development over ocean. In this chapter we give calculation details of these parameters.

In **Chapter 4** discussion about a methodology used for prediction of prediction of convection development over ocean. In this chapter we verified our predicted time of thunderstorm occurrence with the threshold values of parameters for deferent slice of time before the thunderstorm. This chapter includes final outcomes of this project.

Conclusions and future scope are presented in **Chapter 5**.

CHAPTER 1

Introduction

Convection development is one of the areas in meteorology that is challenging to forecast. Thunderstorms can form in less than 20 minutes and have destructive effects. Thunderstorms may have large hail, heavy rains, deadly lightning, destructive winds, and possibly tornadoes. The analysis of the atmosphere during times of thunderstorms has prompted meteorologists to develop parameters that would indicate whether or not the conditions are favorable for thunderstorm development. These parameters describe how unstable the atmosphere is or indicate the likelihood of convection. Cold air aloft, warm air at lower levels, and an abundance of moisture all add to the instability of the atmosphere while the turning of the winds with height can influence the severity of thunderstorms. Since forecast models can forecast these factors of the atmosphere, they can forecast the instability also.

Weather is the condition of the atmosphere at a particular time and place. It refers to such conditions of the local atmosphere as temperature, atmospheric pressure, humidity (the amount of water contained in the atmosphere), precipitation (rain, snow, sleet, & hail), and wind velocity. Because the amount of heat in the atmosphere varies with location above the Earth's surface, and because differing amounts of heat in different parts of the atmosphere control atmospheric circulation, the atmosphere is in constant motion. Thus, weather is continually changing in a complex and dynamic manner (Nelson, 2012).

Climate refers to the average weather characteristics of a given region. Climate, although it does change over longer periods of geologic time, is more stable over short periods of time like years and centuries (Nelson, 2012).

The Earth's weather and climate system represent complex interactions between the oceans, the land, the sun, and the atmosphere. That these interactions are complex is evident by the difficulty meteorologists have in predicting weather on a daily basis.

Motive of this work is to predict the development of convective thunderstorm over ocean with a good lead time. This work is done over the ocean near to Sriharikota region, where Satish Dhawan Space Centre (SDSC) is situated from where satellites are launched. For launching satellite at this place we require a fair idea of atmosphere over the ocean with a good lead time.

1.1 Convection development over Ocean

Convection is fluid motion due to bouncy forces. Convection is driven by the static instability that results when relatively dense fluid lies above relatively light fluid (Marshall and Schott, 1999).

In the ocean, greater density is associated with colder or saltier water, and it is possible to have thermal convection due to the vertical temperature gradient, haline convection due to vertical salinity gradient, or thermohaline convection due to the combination.

Since, Sea water is about 1000 times denser than air; the air sea interface from the waterside can be considered a free surface. So-called thermo-capillary convection can develop on this surface owing to the dependence of the surface tension coefficient on temperature. There are experimental indications that in the upper ocean layer more than 2 cm deep, buoyant convection dominate (Solviev and Klinger, 2001).

Over most of the ocean, the near surface region is considered to be a mixed layer in which turbulent mixing is stronger than at greater depth. The strong mixing causes the mixed layer to have very small vertical variation in density, temperature and other properties compared to pycnocline region (pycnocline; boundary separating two liquid layers of different densities. In oceans a large density difference between surface waters and deep ocean water effectively prevents vertical currents.) Convection is one of the key processes driving mixed layer turbulence, though mechanical stirring driven by wind stress and other processes is also important.

Thermal convection is associated with the cooling of the ocean surface due to sensible (Q_T), latent (Q_L), and effective long-wave radiation (Q_E) heatfluxes. Q_T, may have either sign; its magnitude is, however, much less than that of Q_L or Q_E(except perhaps in some extreme situations). The top of thewater column becomes colder and denser than the water below, and convection begins. In this way, cooling is associated with the homogenization of the water column and the deepening of the mixed layer. Warming due to solar radiation occurs in the surface layer of the ocean and is associated with stratification and reductions in mixed layer depth (Solviev and Klinger, 2001).

There are also important geographical variations in convection, with net cooling of relatively warm water occurring more at higher latitudes and a net warming of water occurring closer to the Equator. Deep convection in being more strongly affected by surface wind stress and much less affected by the rotation of the Earth.

Convection directly affects several aspects of the near-surface ocean. Most obviously, the velocity patterns of the turbulent flow are influenced by the presence of convection, as is the velocity scale. The convective velocity field then controls the vertical transport of heat (or more correctly, internal energy), salinity, momentum, dissolved gases, and other properties, and the vertical gradients of these properties within the mixed layer. Convection helps to determine property exchanges between the atmosphere and ocean and the upper ocean and the deep ocean.

1.2 Literature survey

I. Hernandez (2007) has shown that Convective Available Potential Energy (CAPE) and Convective Inhibition Energy (CINE) are sensitive to the choice of the surface air parcel's initial properties. However the relationship of CAPE with the other indices is robust. Also, CAPE values calculated from the COSMIC retrieved temperature and moisture do not correlate well with those calculated by nearby radiosondes, due to fact that the retrieval of COSMIC temperature and moisture (particularly in the lower levels) are very sensitive to retrieval method of RO data. Other convective indices such as K Index (KI), and Lifted Index (LI) calculated from COSMIC soundings, correlate well with those from nearby radiosondes. They provide useful indication of convective potential over ocean. From these data we can eventually obtain horizontal distribution maps of these indices, which can then be provided for aviation use to assess potential threat of unexpected convection and turbulence that could lie ahead of an airplane. When conducting a study of the diurnal cycle of five indices over Hawaii, they all seem to reach a maximum at 00UC (in the afternoon) and shortly after that they reach their minimum for the latter three indices.

II. Sharma et al.,(2009) has analyzed the occurrence and intensity of rainfall with the lifted index(LI),total perceptible water(TPW),average relative humidity(ARH),average refractivity(AR)derived from the radio occultation(RO) data. The stability and moisture indices govern the state of the atmosphere on the synoptic scale. They also provide an initial assessment of the potential for the convection. They inspect the special average time series of the rain rate with calculated value of LI, TPW, ARH and RI of Indian and surrounding region during 3-7 may 2007.In this study, they concluded that without any additional data set, RO data set are sensitive enough to give the signature of intensity and occurrence of rainfall. By applying some condition on calculated parameter, the RO data was giving 90 percent probability of rain occurrence. They concluded that RI is good replacement of LI as moisture parameter.

III. Mahesh et al.,(2011) presented that calculating Lifted Index(LI),K Index(KI), moisture, amount of perceptible water, precipitation rate, relative humidity, U-component of wind and V-component of wind and using artificial neural network design results are effectively utilize for prediction of thunderstorm. Therefore LI and KI may be used as a good predictor.

IV. Blanchard (1998) shows that Comparisons of convective available potential energy (CAPE) with standard instability indices for evaluating the convective potential of the atmosphere such as the lifted index (LI) reveal only moderate correlations. This is because the LI is a measure of single-level buoyancy while CAPE is a measure of both integration depth and the buoyancy. He Concluded that Evaluating NCAPE (NCAPE =CAPE/FCL where FCL stand for depth of free convective layer) can quickly point out whether the CAPE is a product primarily of buoyancy or of the depth of the FCL. Alternatively, the user could evaluate the mean LI over many levels and the depth of the FCL, or CAPE and FCL, or other possible combinations.

CHAPTER 2

Parameters

Weather forecasters use various techniques to predict the occurrence of convective storms that produce thunder and lightning or thunderstorms. Convective storms are a manifestation of the overturning of the entire troposphere or a large part thereof. We used some of these parameters to get prediction time of thunderstorm occurrences and are derived from radio sounding data namely: Convective Available Potential Energy (CAPE), Convective Inhibition (CIN), Lifted Index (LI), and K Index (KI).In this work we also used vorticity and divergence derived from Scatterometer wind data over the ocean to find possibility of convection development over ocean.

2.1Convective Available Potential Energy (CAPE)

The use of CAPE has become very popular as a method to evaluate the convective potential of the atmosphere. In contrast to single-level stability indices, CAPE is a vertically integrated index and measures the cumulative buoyant energy in the free convective layer (FCL) from the level of free convection (LFC; the level at which the parcel temperature exceeds the ambient temperature and parcels are unstable relative to their environment) to the equilibrium level (EL; the level at which the ambient temperature exceeds the parcel temperature and parcels are stable relative to their environment). The formal definition of CAPE (Blanchard, 1998) is

$$CAPE = g\int_{Z_{LFC}}^{Z_{EL}} \left(\frac{T_{vp} - T_{ve}}{T_{ve}}\right) dz$$

…………………...(2.1)

Where T_{vp} is the virtual temperature of the parcel and T_{ve} is the virtual temperature of the environment Z_{EL} is the height of the equilibrium level, Z_{LFC} is the level of free convection, and g is gravity. This definition of CAPE uses the method described by the United States Air Force

(USAF) Air Weather Service (AWS 1961) and more recently by Doswell and Rasmussen (1994) in which temperature is replaced by virtual temperature.

CAPE is, rather, a vertically integrated measure of the parcel buoyant energy with appropriate units of joules per kilogram. Similarly, Fritsch and Chappell (1980) note that the positive area is the buoyant energy that would accrue to a parcel in rising between its LFC and EL. Nonetheless, it has often been used as a proxy for instability and as a substitute for the LI for many years.

2.2 Convective Inhibition (CIN)

CIN is a measure of the ‘‘negative area’’ on the sounding diagram and the amount of work required to lift a parcel through a layer that is warmer than the parcel and allow these parcels to ascend above the LFC.This negative area is often referred to as a lid. CIN is computed in a manner similar to CAPE and is defined as,

$$CIN = g \int_{Z_{SFC}}^{Z_{LFC}} \left(\frac{T_{vp} - T_{ve}}{T_{ve}}\right) dz$$

………………… (2.2)

Blanchard (1998), whereZ_{SFC} is the height of the surface and Z_{LFC} is the height of the level of free convection. Convective inhibition (CIN) can be considered a measure of how unlikely thunderstorm development is, or the energy needed for thunderstorms to develop. The CIN represents the amount of energy which must be expended by a lifting mechanism or surface heating to initiate thunderstorm development. When there is an inversion present or stable layer aloft, the CIN can be signified as the strength of the "cape." If the cape is weak it may be easily eroded early in the morning by heating and the energy would be expended to form a cumulus field. If the cap is too strong (CIN > 200 J/kg) the energy might not be overcome and no development may occur. For favorable thunderstorm conditions, the CIN is neither too strong nor too weak but ranges from 50 J/kg to 150 J/kg. The CIN is the "negative" area between the lifted thermodynamic path and the environmental lapse rate, (Bluestein, 1993).

2.3 Lifted Index (LI)

The lifted index (°C) provides an estimate of the instability in the atmosphere due to the difference between the 500mb level temperature and the temperature an air parcel would acquire when lifted from the surface to 500 mb. A parcel of air will rise freely when it is warmer than its surroundings. When a parcel is "lifted" it obtains an upward vertical velocity which can be a result of a surface front or trough, surface heating (convection).Lifted index is defined as,

$$LI = T_{500} - T_{p500}$$

……………………. (2.3)

where LI (°C) is the lifted index, T_{500} is the 500mb environmental temperature (°C), T_{p500} is the 500mb temperature (°C) which a parcel will achieve if it is lifted dry-adiabatically from the surface to its lifted condensation level (LCL) and then moist-adiabatically to 500mb.

2.4 K Index (KI)

The K index was composed for forecasting air mass thunderstorms or thunderstorms with no dynamic triggering mechanism. To compute this index, first take the 850 mb temperature minus the 500 mb temperature. Secondly, add the 850 mb dew point temperature to this difference. Larger values of this dew point indicate low level moisture present and increase the chance of convection. Finally, we subtract the 700 mb dew point depression for moisture input at the mid-levels. A small dew point depression at 700 mb indicates a possibility for deep convection. If there is no significant moisture at 700mb then there is a greater chance that entrainment of dry air would occur, given a parcel were lifted from beneath the 700 mb level. If entrainment of dry air occurs, the parcel will become less buoyant (Bluestein, 1993).KI is defined as,

$$K = T_{850} - T_{500} + T_{d850} - (T_{700} - T_{d700})$$

………………… (2.4)

WhereT_{850} is the temperature at the 850 mb level, T_{500} is the temperature at the 500 mb level, T_{d850} is the dew point temperature (°C) at the 850 mb level, T_{700} is the temperature (°C) at the 700 mb level, and T_{d700} is the dew point temperature (°C) at the 700 mb level.

George (1960) defined the first term is a lapse rate term, while the second and third are related to the moisture between 850 and 700 mb, and are strongly influenced by the 700-mb temperature–dew point spread. As this index increases from a value of 20 or so, the likelihood of showers and thunderstorms is expected to increase.

2.5 Vorticity

The vertical motion patterns associated with synoptic scale divergence/ convergence are directly connected both with development of surface pressure systems and the development of the vertical motion fields that lead to the creation of cloud/precipitation systems in association with the surface lows.

Vorticity is one of the ways to describe the curved motion of fluid parcels without reference to a center of rotation (Lynch and Cassano, 2006).

$$\xi = \frac{\partial c}{\partial A} = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

…………………. (2.5)

Conceptually, the vorticity could be determined by marking the particles of the fluid in a small neighborhood of the point in respected area, and watching their relative displacements as they move along the flow. The vorticity vector would be twice the mean angular velocity vector of those particles relative to their center of mass, oriented according to the right-hand rule.

Since, the circulation represents the flux of vorticity through a specified area closed circuit; the circulation is often termed the vertex index. Vorticity in solid is calculated as

$$\xi = \frac{\partial c}{\partial A} = \frac{2\pi\delta r.v}{\pi\partial r^2} = \frac{2v}{\delta r} = 2\omega$$

…………………. (2.6)

Vorticity does not cause weather to form, but is related directly to systems that do. Positive relative vorticity is counterclockwise spin that occurs because of "cyclonic" shear or curvature.

This means positive relative vorticity is associated with low-pressure systems. Positive vorticity advection indicates upward vertical motions and divergent flow near the tropopause(Lynch and Cassano, 2006).

Negative relative vorticity (clockwise spin) occurs due to "anticyclonic" curvature. Therefore, it is associated with high-pressure systems and indicates downward vertical motions and convergent flow near the tropopause.

To remember these relationships, use this vorticity rule of thumb: "Curl the fingers of right hand in the direction of spin and thumb points in the direction of vertical motion."

Vorticity is an instantaneous rotation or spin of very small air parcels. When this rotation results simply from wind shear and/or curvature of the contours, we call it relative vorticity. When twice the angular velocity of the Earth is added (Coriolis force) to this rotation, we call it absolute vorticity. Thus, we define absolute vorticity as the sum of the spin of an individual parcel and the spin of the Earth (Lynch and Cassano, 2006).

The prime advantage of using the vorticity is the detection of vertical motion. It must be emphasized that this vertical motion is indicated by the advection of vorticity and not by the vorticity values themselves. This can be proven mathematically by using the vorticity theorem. As an element that can be analyzed, vorticity is a very important tool for tracking and predicting the strength of weather systems (Lynch and Cassano, 2006).

2.6 Divergence

The divergence (flux density) of a wind vector at the point (u, v) is

$$\text{Divergence}=\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right) \qquad \textbf{……………………. (2.7)}$$

This represents a scalar which gives the rate of change of field strength in the direction of field (Lynch and Cassano, 2006).

Positive divergence⇒ Expansion (source)

Negative divergence⇒contraction (sink)

The surface pressure changes are largely controlled by mass changes in the upper troposphere. The troposphere contains 85 percent of the mass and energy transformations in the atmosphere. It is primarily these energy transformations, caused by divergent and convergent forces, which produce our weather.

Horizontal divergence refers to the spreading of air, when horizontal divergence occurs, the air moves away from the center of the column. This result from the air's pushing downward from the top of the column, which adds mass to the column of air. The original column of air then contracts vertically and expands horizontally. That is, the total volume of the air parcel remains constant.

Horizontal convergence refers to the packing of air. Horizontal convergence of a layer near the surface, keeping the volume constant, As the air converges horizontally toward the center of the layer, it creates a flow upward toward the top of the layer of air, which contracts the air layer horizontally and expands it vertically; this is caused by upper-level winds taking mass out of the column.

As indicated, pressure changes at the surface result from changes in mass within the troposphere. The pressure at the surface directly relates to the mass of air in a vertical column above the surface. An increase in this mass increases the surface pressure. A decrease in the mass decreases the surface pressure.

Many separate layers of horizontal divergence or convergence are possible. Therefore, the surface pressure measures the net effect of the convergence and divergence.

CHAPTER 3

Data and Methodology

3.1 Data sources

A.Upper air sounding

This study primarily used data from rawinsonde observations. The benefit of this approach is that it is based on direct observations of the atmosphere. Upper air soundings from all of the sites in the Southeast Asia were retrieved from the website of University of Wyoming's Department of Atmospheric Science (http://weather.uwyo.edu/upperair/sounding.html). The website provides calculations for many different stability indices for each sounding. The main advantage of rawinsonde soundings is that they are launched from Chennai (Madras) Station, which is nearest station for this work.

B. Scatterometer wind data

This dataset is derived under the Cross-Calibrated Multi-Platform (CCMP) project and contains value-added Advanced Microwave Scanning Radiometer EOS (AMSR-E) ocean surface winds from the AQUA platform. The CCMP datasets combine cross-calibrated satellite winds obtained from Remote Sensing Systems (REMSS) using a Variational Analysis Method (VAM) to produce a high-resolution (0.25 degree) gridded analysis. Wind directions from the resulting analysis are assigned to the location and time of the satellite-derived wind speed observations to create this value added dataset. The CCMP data set includes cross-calibrated satellite winds derived from SSM/I, SSMIS, AMSR-E, TRMM TMI, QuikSCAT, Sea Winds, Wind Sat and other satellite instruments as they become available from REMSS. REMSS uses a cross-calibrated sea-surface emissivity model function which improves the consistency between wind speed retrievals from microwave radiometers (i.e., SSM/I, SSMIS, AMSR, TMI, Wind Sat) and those from scatterometers (i.e., QuikSCAT and Sea Winds). The VAM combines these data with in situ measurements and a starting estimate (first guess) of the wind field. The European Center for Medium-Range Weather Forecasts (ECMWF) ERA-40 Reanalysis is used as the first-guess from 1987 to 1998. The ECMWF Operational analysis is used from January 1999 onward. All wind observations and analysis fields are referenced to a height of 10 meters. The ERA-40 can be obtained from the Computation and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR): http://rda.ucar.edu/datasets/ds117.0/. The ECMWF Operational analysis can also be obtained from CISL at NCAR: http://rda.ucar.edu/datasets/ds111.1/. Three products are distributed to complete the CCMP dataset series. L3.0 product contains high-resolution analyses every 6-hours. These data are then time averaged over monthly and 5-day periods to derive the L3.5 product. Directions from the L3.0 product are then assigned to the time and location of the passive microwave satellite wind speed observations to derive the L2.5 product. All datasets are distributed on a 0.25 degree cylindrical coordinate grid. This dataset is one in a series of First-Look (FLK) CCMP datasets and is a continuation and expansion of the SSM/I surface wind velocity project that began under the NASA Pathfinder Program. Refinements and upgrades to the FLK version will be incorporated under a new release (date to be determined) known as Late-look (LLK) and may include additional satellite datasets. All satellite surface wind data are obtained from REMSS under the DISCOVER project: Distributed Information Services: Climate/Ocean Products and Visualizations for Earth Research (http://www.discover-earth.org/index.html). The CCMP project is the result of an investigation funded by the NASA Making Earth Science data records for Use in Research Environments (MEaSUREs) program (http://community.eosdis.nasa.gov/measures/). In accordance with the MEaSUREs program, the CCMP datasets are also known as Earth System Data Records (ESDRs). In collaboration with private and government institutions, a team led by Dr. Robert Atlas (PI; proposal originally solicited by REASoN, and currently funded by MEaSUREs) has created the CCMP project to provide multi-instrument ocean surface wind velocity ESDRs, with wide ranging research applications in meteorology and oceanography.

3.2 Calculation methodology

The stability indices have been calculated from radio sounding from Wyoming University for Chennai (Madras) station. For each radio sounding the various stability indices have been calculated and stored together with the number of lightning strokes recorded in an area around sriharikota during a certain time window.

The data sample covers the period from 01-01-2009 to 31-12-2010. This data sample has been divided into two sub periods, one from 01-01-2009 to 31-12-2009 and a second from 1-01- 2010 to 31-12-2010. Data from the first period are used to determine the parameters in a probabilistic indication model and data from the second period are used to verify the probabilistic model.

Data from an automatic lightning stroke detection system (http://webflash.ess.washington.edu/) have been used to identify days with lightning. The system can detect the occurrence of a lightning stroke and then calculate the position and strength. The number of lightning strokes occurring in an area around sriharikota during a time window of 24 hours from 00 to 23 UTC are counted and stored together with the value of the indices on that particular day.

A. Sounding data amylases

For downloading raw data we used data from university of Wyoming, upper air data and selected date sounding data. (http://weather.uwyo.edu/upperair/sounding.html)

We get calculated data as per above formula mentioned in equation number2.3 and 2.4. From this we calculated lifted and k index for the selected cases of thunder storm. We had data from two soundings per day. We arranged data in two group's first for2009 and next for 2010. We fixed a threshold value from calculated values ofk and lifted indexes from 2009 data and they are given as in the below Table 3.1.

From the above threshold values we wanted to check the behavior instabilityof atmosphere in same region for the next year. For that we put Lifted index (LI) on Y-axis and lead time before the occurrence of thunderstorm on X-axis. Similarly on separate Figure we put K Index (KI) on Y-axis and lead time before the occurrence of thunderstorm on X-axis.

Table 3.1 Threshold value of k and L index against lead time before the occurrence of thunderstorm

B.

Lead Time (Hour)	Li (°C)	Ki (°C)
2	-7.19	42
4	-6.4	39.2
6	-5.19	35.9
8	-4.65	33.4
10	-3.85	32.5
12	-3.85	31.7
14	-3.85	30.1

Scatterometer wind data: We used Scatterometer data to find out vorticity and divergence over the ocean. Wind data over ocean is available at a time interval of 6 hours i.e. 4 times a day. Using u and v component of wind over ocean the vorticity and divergence over the region have been computed using.

$$\text{Vorticity} = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

$$\text{Divergence}=\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)$$

Using GrADS we calculated these raw data of wind over ocean to find out Vorticity and divergence.

The data of vorticity and divergence is calculated as per above methodology (program). The data has been arranged in two group one for the year 2009 and another for the year 2010. We have fixed some threshold value from 2009 data for our calculated vorticity and divergence given in Table 3.2 with respect to lead time before the occurrence of thunderstorm.

<u>Table 3.2 Threshold value of Vorticity and Divergence index against Lead Time before the occurrence of thunderstorm.</u>

Lead Time(Hour)	**Vorticity (S^{-1})**	**Divergence (S^{-1})**
0	5.35E-06	-6.02E-06
2	4.24E-06	-4.01E-06
4	3.50E-06	-3.41E-06
6	2.81E-06	-2.68E-06
8	2.71E-06	-2.53E-06
10	2.63E-06	-3.61E-06
12	1.14E-06	-4.16E-06

From the above threshold values we wanted to check the behavior instability of atmosphere in same region for the next year. For that we have put Vorticity on Y-axis and lead time from the occurrence of thunderstorm on X-axis. Similarly on separate Figure we put divergence on Y-axis and lead time from the occurrence of thunderstorm on X-axis.

CHAPTER 4

Result and discussion

Today, there are a number of parameters available that may be used to characterize pre-convective conditions and predict the beginning of convection. Johns et. al. (1992), have reviewed severe thunderstorms forecasting in detail. According to them, three of the most important factors to examine in determining occurrence of severe thunderstorm events are intense instability, a sufficiently deep humid layer in the lower and middle troposphere and an updraft to initiate convection. The formation of thunderstorms is an interaction between these conditions on different scales.

In this section, the general results of our study are shown. We use the Surface-based Lifted Index and K index as an example.

4.1. Threshold value test for Lifted and K index

Figures 4.1 to 4.8 shows a scatter-Figure of the Lifted Index vs. lead time from the occurrence of thunderstorm. For cases of 2009, LI values could be calculated and compared with LI of 2010 lightning detection data. Low index values are obviously associated with higher thunderstorm probability and vice versa.

At first, we want to fix threshold values for indexes to find out a linear relation between lead time from the occurrence of thunderstorm with Lifted index and K index, and we verified this fixed linear relation to 2010 thunderstorms activity with different lead time range as given in below scatter Figures, where solid line shows relation between threshold value of lifted index, k index and lead time in respective Figures. We figured thelead time in interval of 6hr., 9hr., 12hr., 15hr., before the thunderstorm activity.

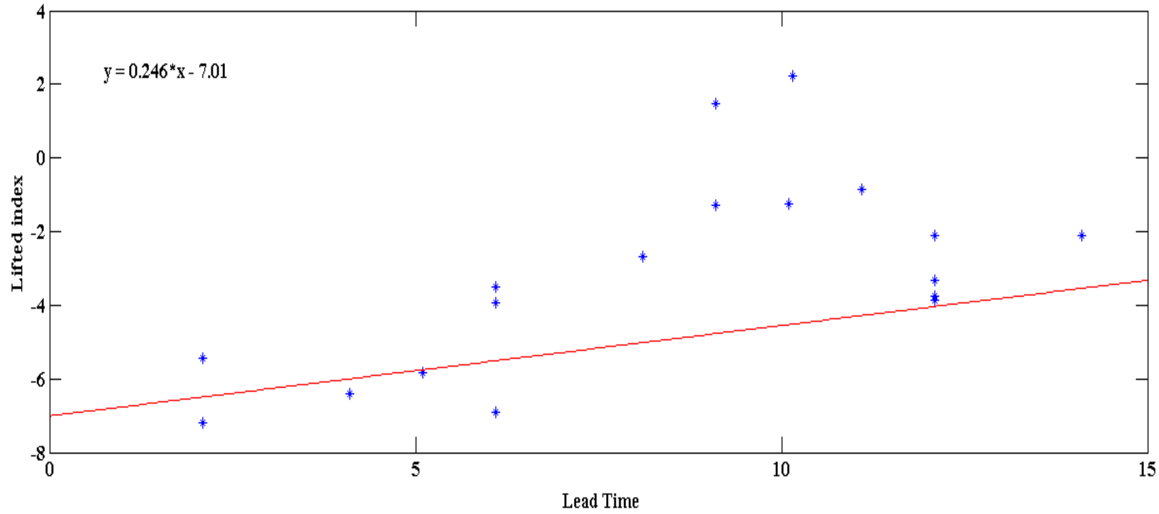

Figure 4.1: Lifted index vs. lead time with interval of 15hr., before the occurrence of thunderstorms.

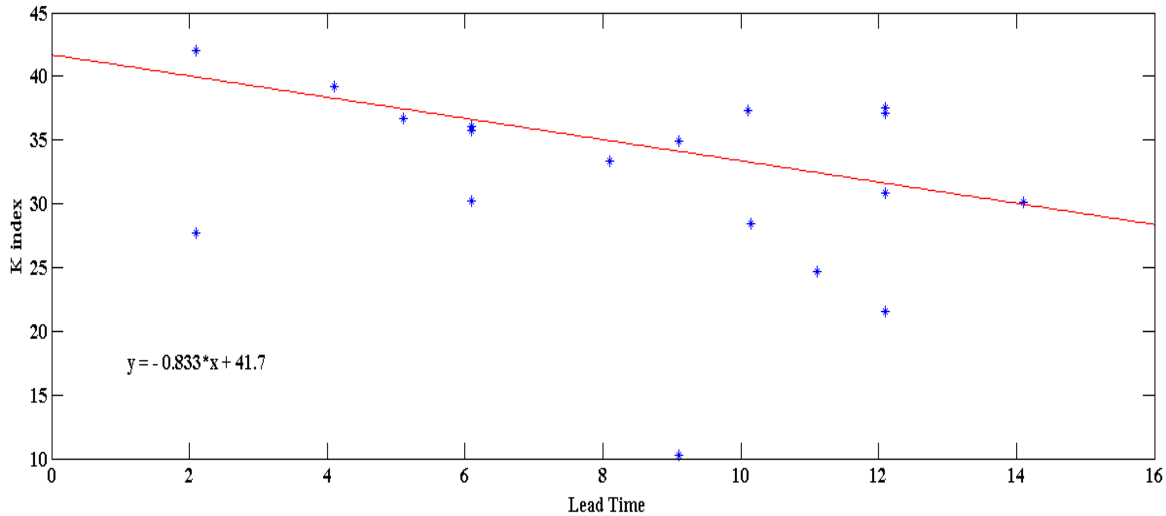

Figure 4.2: K index vs. lead time with interval of 15hr., before the occurrence thunderstorms.

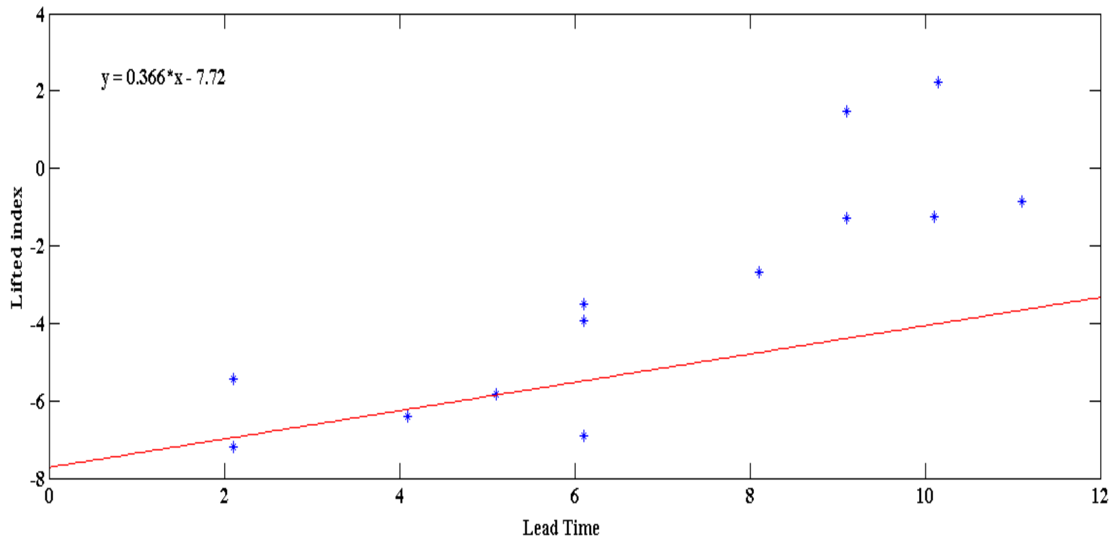

Figure 4.3: Lifted index vs. lead time with interval of 12hr., before the occurrence of thunderstorms.

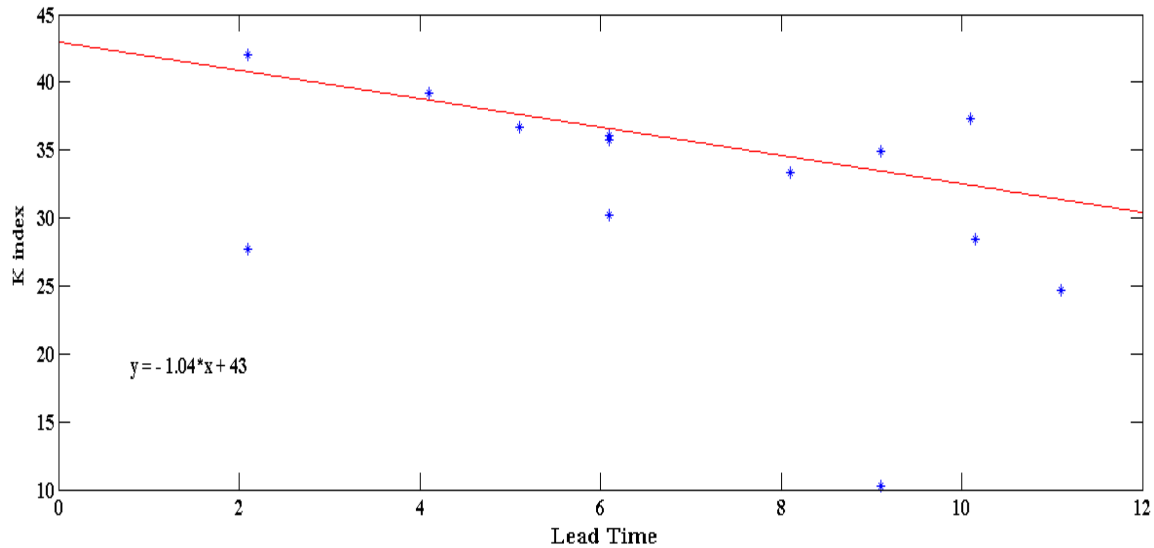

Figure 4.4: K index vs. lead time with interval of 12hr., before the occurrence of thunderstorms.

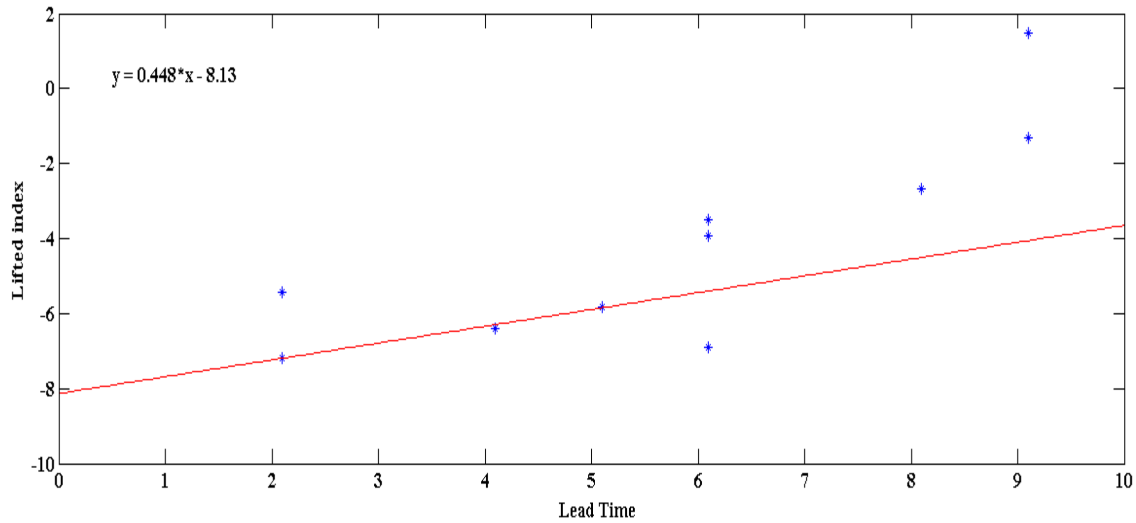

Figure 4.5: Lifted index vs. lead time with interval of 9hr., before the occurrence of thunderstorms.

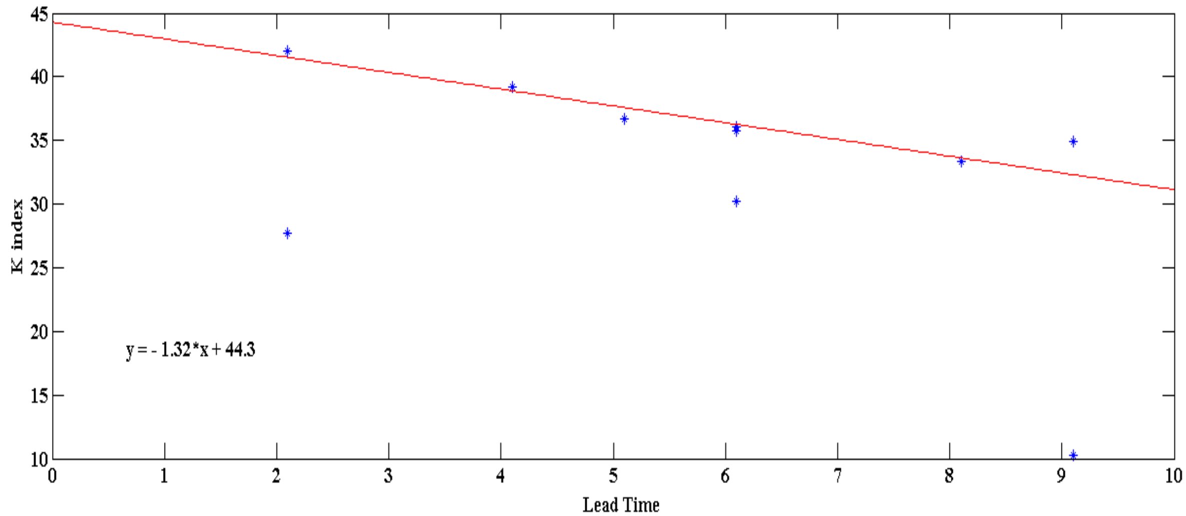

Figure 4.6: K index vs. lead time with interval of 9hr., before the occurrence of thunderstorms.

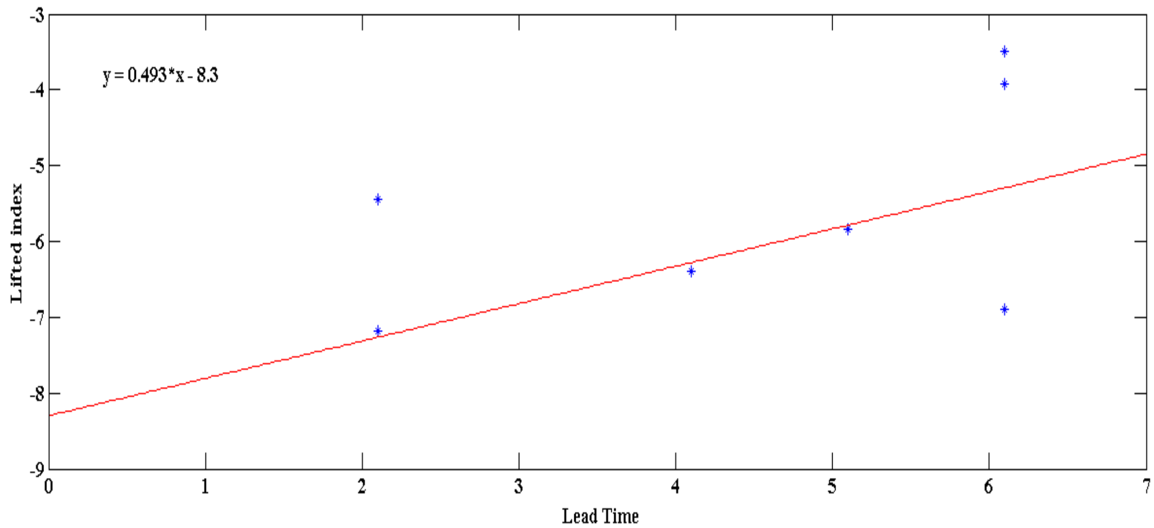

Figure 4.7: Lifted index vs. lead time with interval of 6hr., before the occurrence of thunderstorms.

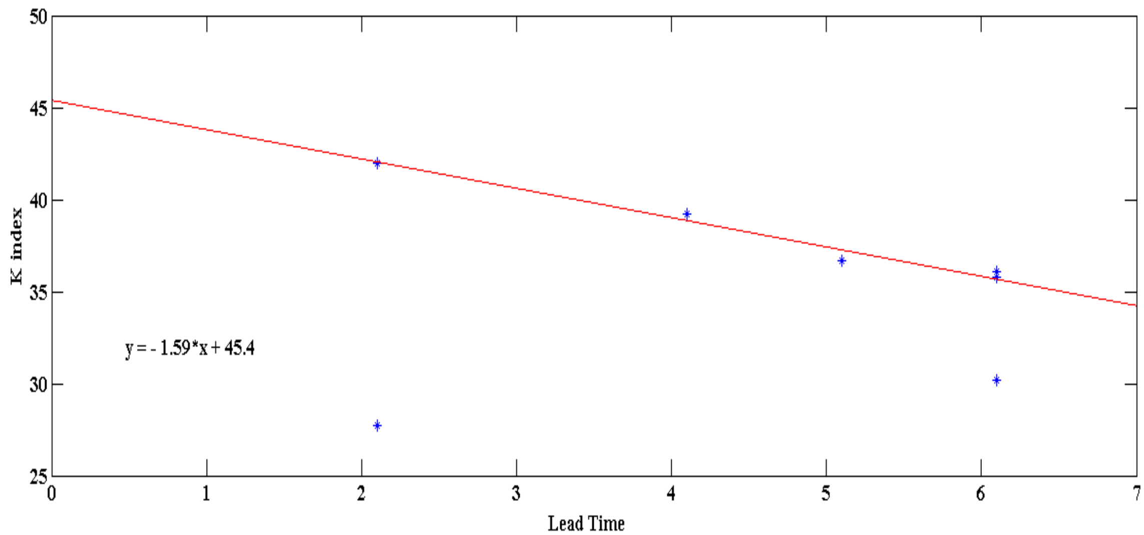

Figure 4.8: K index vs. lead time with interval of 6hr., before the occurrence of thunderstorms.

4.2 Threshold value test for Vorticity and Divergence.

Figures 4.9 to 4.16 shows a scatter-Figure of the Vorticity and time before the occurrence of thunderstorm. For cases of 2009, Vorticity values are calculated and compared with Vorticity values of 2010 lightning detection data. Figure shows that positive values are obviously associated with higher thunderstorm probability and vice versa. Similar finding is also seen for the Divergence.

We fixed threshold values for Vorticity and divergence to find out a linear relation between lead time from the occurrence of thunderstorm and Vorticity /Divergence. After that, we verified this fixed linear relation of vorticity/divergence with time of occurrence of thunderstorm for selected cases of year 2010with different leading time range as given in below scatter Fig. (4.9 to 4.16), where solid line shows relation between threshold values of Vorticity, Divergence with lead time from the occurrence of thunderstorm in respective Figures.

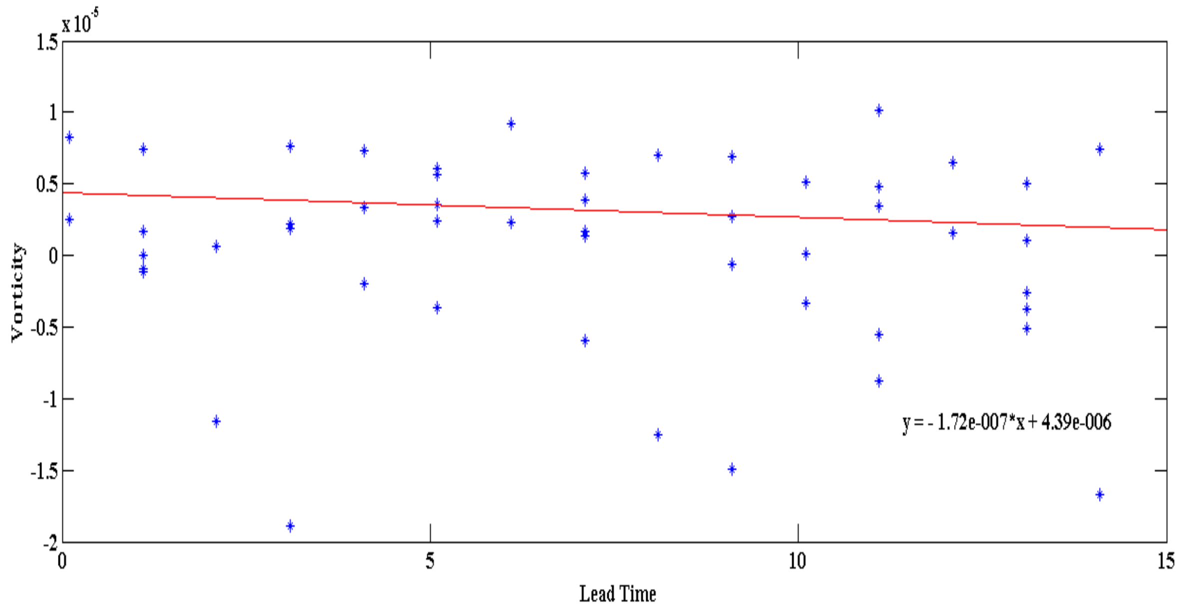

Figure 4.9: Vorticity vs. lead time with interval of 15hr., before the occurrence of thunderstorms.

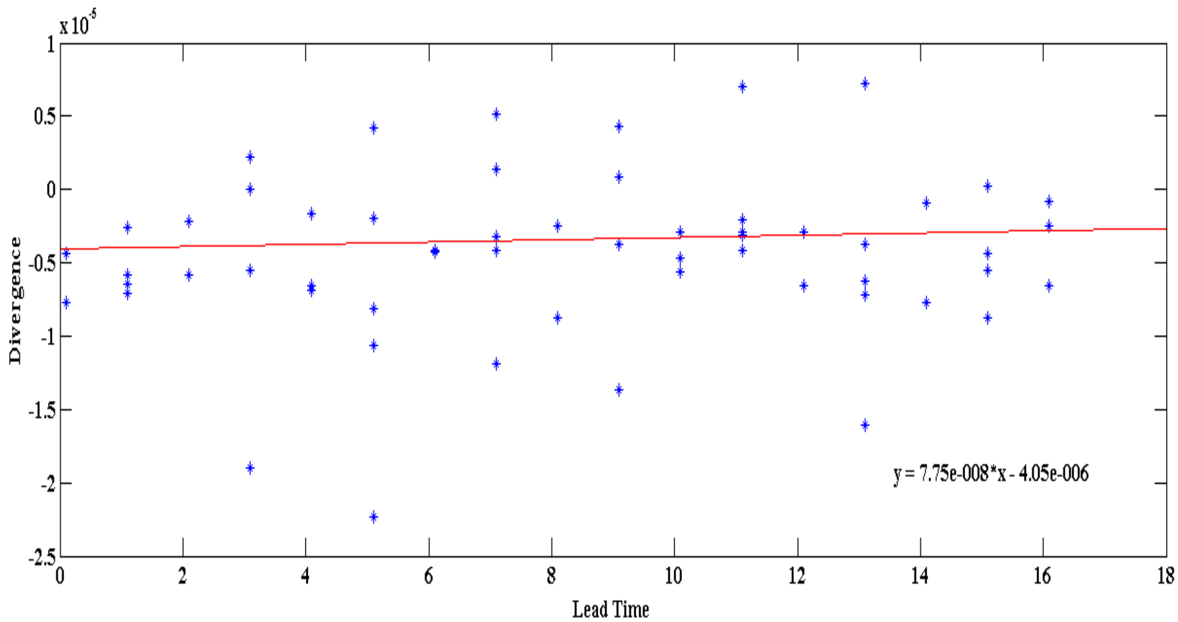

Figure 4.10: Divergence vs. lead time with interval of 15hr., before the occurrence of thunderstorms.

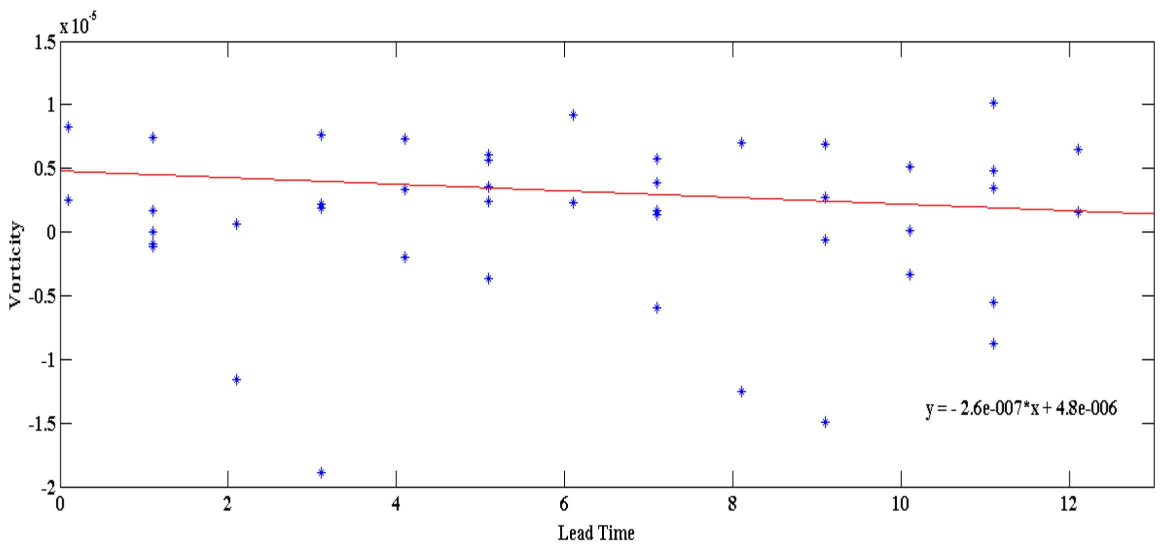

Figure 4.11: Vorticity vs. lead time with interval of 12hr., before the occurrence of thunderstorms.

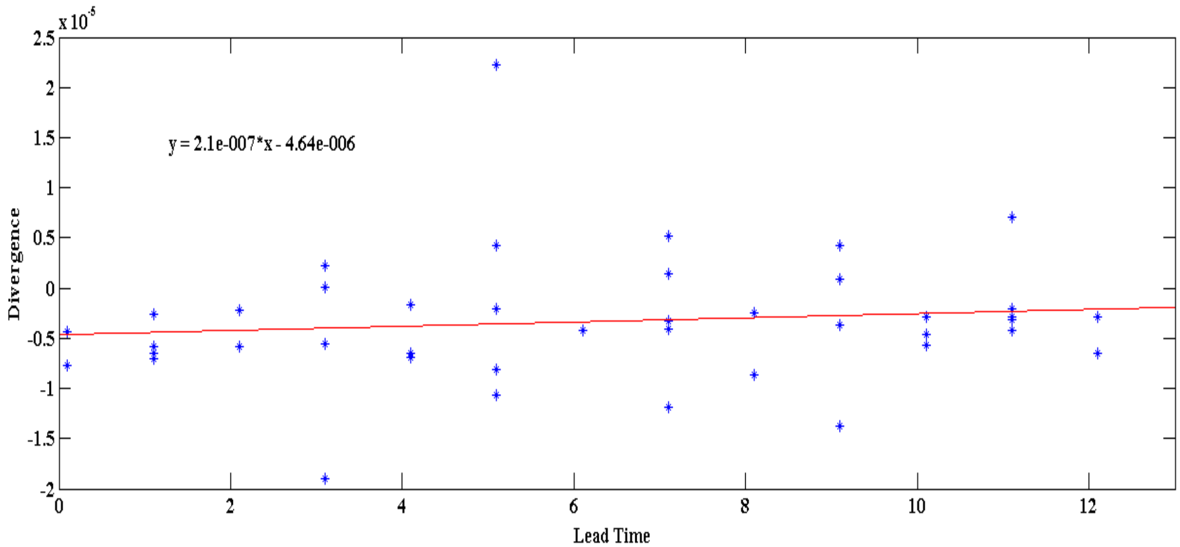

Figure 4.12: Divergence vs. lead time with interval of 12hr., before the occurrence of thunderstorms.

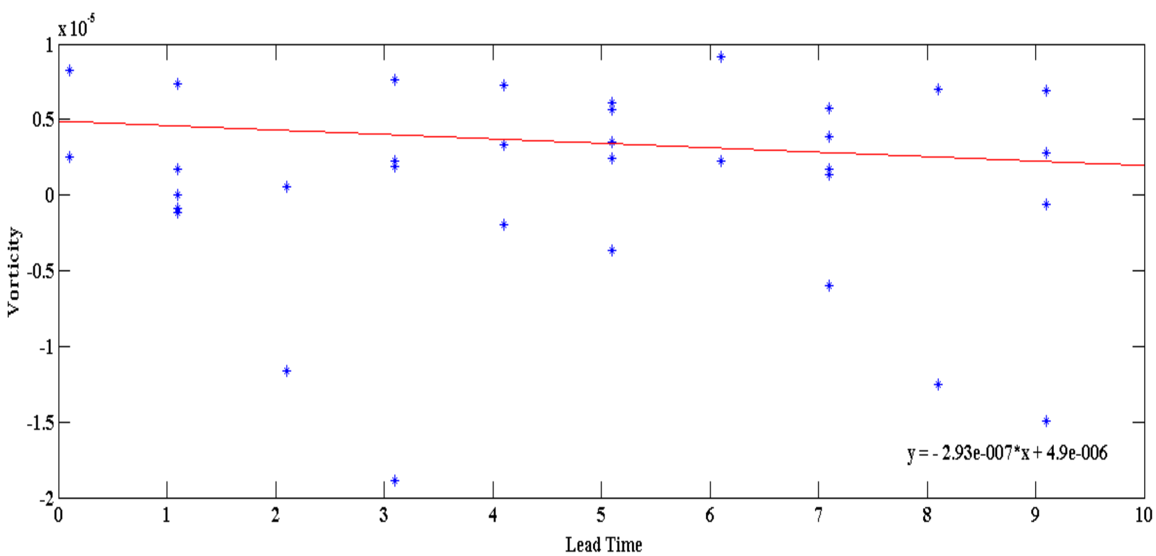

Figure 4.13: Vorticity vs. lead time with interval of 9hr., before the occurrence of thunderstorms.

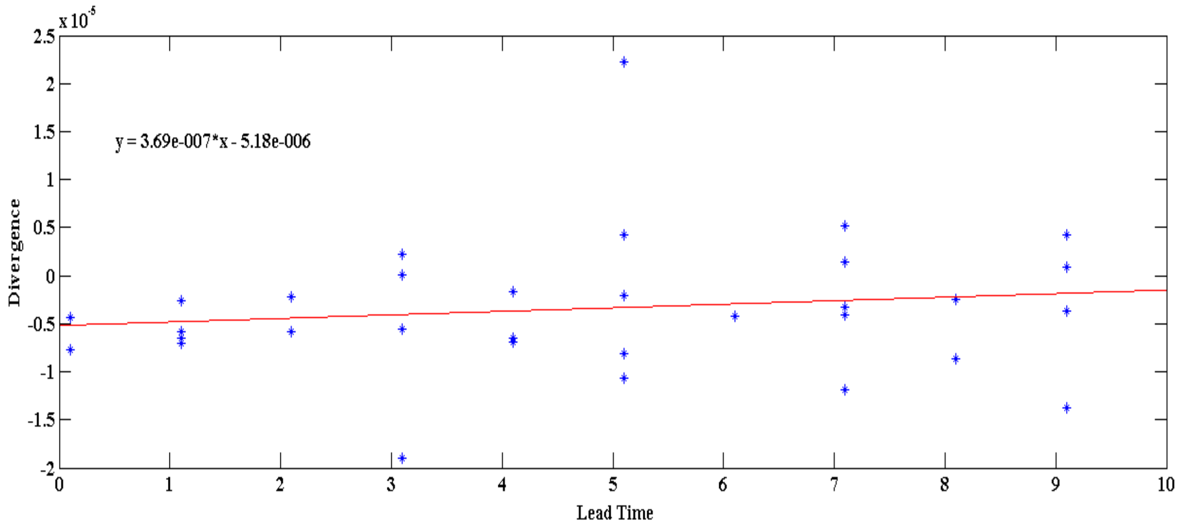

Figure 4.14: Divergence vs. lead time with interval of 9hr., before the occurrence of thunderstorms.

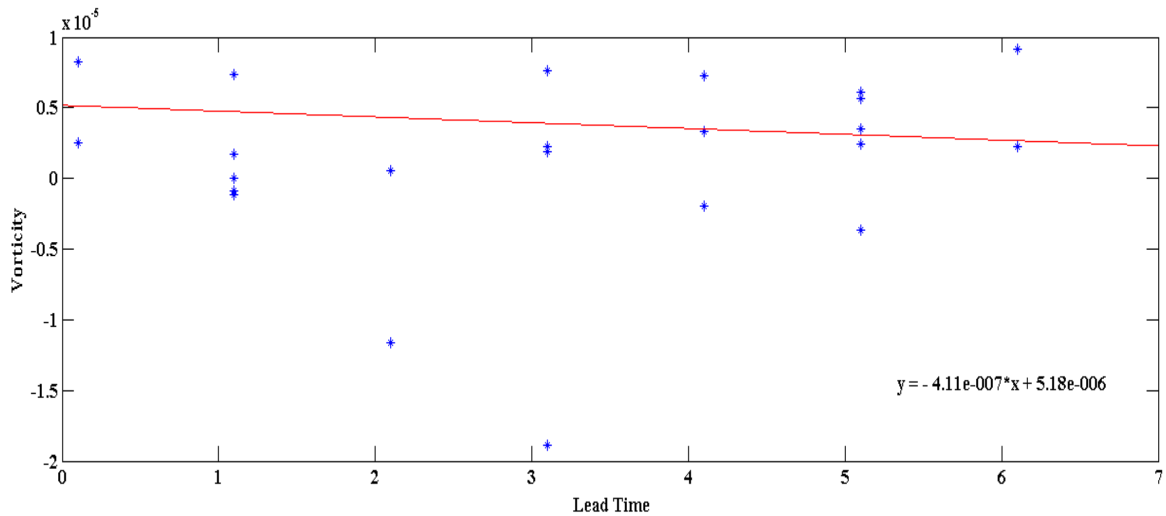

Figure 4.15: Vorticity vs. lead time with interval of 6hr., before the occurrence of thunderstorms.

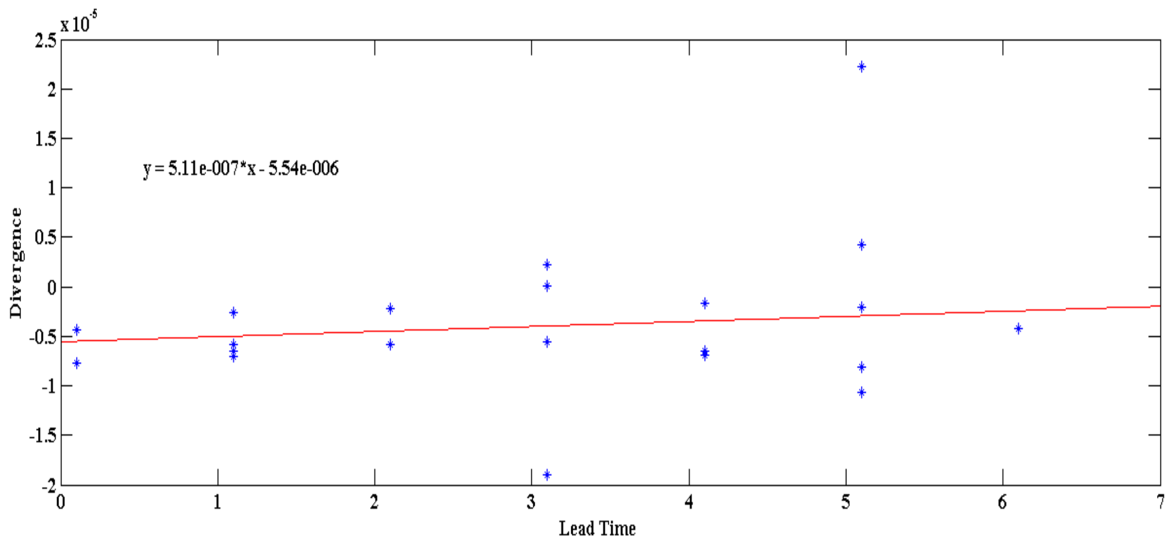

Figure 4.16: Divergence vs. lead time with interval of 6hr., before the occurrence of thunderstorms.

4.3 Discussion

Thunderstorm is a small scale weather phenomenon (10km in scale), thus, predicting the occurrence of thunderstorm at a certain place is very difficult. There are some thunderstorm forecast methods available in the world such as using the instability index, statistical method, and fluid dynamic method. The most widely used thunderstorm indices are CAPE, LI, KI, etc. To make a judgment on whether an index has significant predictive potential or not for a certain region, it is necessary to look into the statistical relation between the index and the thunderstorm occurrence at that region.

In recent years, the value of different thunderstorm indices can beeasily computed using the numerical model outputs and rawinsonde data. Furthermore, several statistical forecast models have been developed based on meteorological variables and instability indices represent the atmospheric state before convection.

In this work, we studied the four parameter i.e. LI, KI, Vorticity and Divergence to find out the possibility of occurrence of thunderstorm over a given region with a certain lead time. Result shows that prediction has a fluctuating relation between predictor and time of thunderstorm between 9 to 15 hr. Hence it becomes slightly difficult to go for prediction of thunderstorm in advance 15 hr. Fig.(4.7 and 4.8) shows that the Lifted index and K index are in good agreement with predicted time of thunderstorm for the period of 6 hr. Fig.(4.15 and 4.16) shows that the vorticity and divergence are also in good agreement with predicted time of thunderstorm for the period of 6 hr.We get a clear picture of time of occurrence of thunderstorm, 6 hours in advance by combining threshold value of all four predictor.

Table 4.1 Result: Threshold value verified for thunderstorm prediction.

Lead Time before the occurrence of thunderstorm (Hour)	Lifted Index (°C)	K index (°C)	Vorticity (S^{-1})	Divergence (S^{-1})
2	-7.19	42	4.24E-06	-4.01E-06
4	-6.4	39.2	3.50E-06	-3.41E-06
5	-5.84	36.7	2.97E-06	-3.01E-06
6	-5.19	35.9	2.81E-06	-2.68E-06

Prediction of convection development is slightly complicated in nature. At the initial step, we tried to look at the linear relation between the parameters which affect the convection development over ocean. For development of thunderstorm, we require a fine condition for uplifting of convected moisture which can be measure by the vorticity. If values of vorticity are positively increasing with time then there is good possibility of uplifting. Simultaneously, for thunderstorm formation, we have to consider the divergence of wind over the ocean. As divergence negatively increaseswith time the possibility of thunderstorm occurrence increases. Present study shows a good agreement of using these conditions to predict the occurrence of thunderstorm with a good lead time. Figures 4.15 and4.16 shows a good agreement between predictor and lead time before the occurrence of thunderstorm.

Instability indexes are suitable for the thunderstorm prediction and finding out the possibility of convection development over ocean. In this study, we consider two instability parameters to predict thunderstorm i.e. lifted index and K index. The negatively increasing lifted index and positively increasing K index provides a fair idea of thunderstorm occurrence over ocean. It is observed that the values of Lifted and k index show a good agreement with fixed threshold values of these indexes with respect to lead time to the occurrence of thunderstorm. Figures 4.7 and 4.8 shows good agreement between predictor and lead time before the occurrence of thunderstorm.

CHAPTER 5

Conclusions

The results show that CAPE and CINE is a good stability indicator but they are very sensitive to condition of moisture. Hence, we are not able to conclude CAPE and CINE in the fixing of thunderstorm predictor.

Correlation between the Lifted index and K index is used to find out the possibility of thunderstorm formation. Threshold value of these indices with a lead time could be fixed and have been verified.

Computed Threshold values of vorticity and divergence over the ocean were fixed to predict convective thunderstorm possibility and it is possible to predict thunderstorms with a good lead time.

Results shows that the Lifted index, K index, vorticity and divergence can be used to fix a threshold value to predict convective thunderstorm over the ocean.

References

1. Holton, James R., and Gregory J. Hakim. An introduction to dynamic meteorology. Academic press, 2012,(86-114,449-475)
2. Lynch, Amanda H., and John J. Cassano. Applied atmospheric dynamics. Wiley, 2006, (119-132).
3. Navy operational ocean circulation and tide models (Department of oceanography, Naval postgraduate school), march 2003.
4. Pickard, George L., and William J. Emery. Descriptive physical oceanography. 5th ed. Oxford: Pergamon Press, 1990.(110-147)
5. Tomczak, Matthias, and J. Stuart Godfrey. Regional oceanography: an introduction. Daya Books, 2003.(175-198).
6. Extra tropical Synoptic-scale process sever convection-Charles A Doswell-III,Lance F Bosart,2000
7. Hemmati, Hamid, ed. Deep space optical communications. Vol. 11. Wiley-Interscience, 2006.
8. Knudsen, B. M., Andersen, S. B., & Gross, A. Contribution of the Danish Meteorological Institute to the final report of SAMMOA, 1999.
9. Kotal, S. D., Roy Bhowmik, S. K., Kundu, P. K., & Das Kumar, A. A statistical cyclone intensity prediction (SCIP) model for the Bay of Bengal. Journal of Earth System Science, 117(2), 157-168(2008).
10. Stoffelen, Ad, and David Anderson. "Scatterometer data interpretation: Estimation and validation of the transfer function CMOD4." Journal of Geophysical Research 102.C3 (1997): 5767-5780.
11. S Mahesh Anand, Ansupa Dash, M S Jagadeesh Kumar, Amit Kesarkar"Prediction and classification of thunderstorms using artificial neural network.-" (2011)
12. Hernandez, Michael Kevin. "Utilizing COSMIC radio occultation soundings to estimate convective potentials over oceans." 12th Conference on IOAS-AOLS. 2008.

13. Emanuel, Kerry A., and Marina Živkovic-Rothman. "Development and evaluation of a convection scheme for use in climate models." Journal of the Atmospheric Sciences 56.11 (1999): 1766-1782.
14. Sharma, Neerja, D. Jagadheesha, P. C. Joshi, and P. K. Pal. "Atmospheric stability estimation using radio occultation data over India and surrounding region." Indian J. Radio Space Phys 38 (2009): 317-325.
15. Banacos, Peter C., and David M. Schultz. "The use of moisture flux convergence in forecasting convective initiation: Historical and operational perspectives." Weather and forecasting 20.3 (2005): 351-366.
16. Marshall, J., & Schott, F. (1999). Open-ocean convection: Observations, theory, and models. Rev. Geophys, 37(1), 1-64.
17. Groenemeijer, Pieter. Sounding-derived parameters associated with severe convective storms in the Netherlands. Diss. MS thesis, Institute of Marine and Atmospheric research Utrecht (IMAU), 2005.
18. Healy, S. B., and J-N. Thépaut. "Assimilation experiments with CHAMP GPS radio occultation measurements." Quarterly Journal of the Royal Meteorological Society 132.615 (2006): 605-623.
19. Michael Kevin Hernandey, Ying HwaKuo, Douglas C Hont. “Utilizing Radio occultation sounding to estimate convective potential over oceans”SOARS, 2007.
20. Blanchard, David O. "Assessing the vertical distribution of convective available potential energy." Weather and forecasting 13.3 (1998):870-877.

List of online References……

- http://www.teachingboxes.org/avc/content/Severe_Weather_Indices.htm
- http://itg1.meteor.wisc.edu/wxwise/AckermanKnox/chap11/TW_Index.html
- http://weather.cod.edu/sirvatka/si.html
- http://www.balloonlife.com/publications/balloon_life/9801/0007/liftedk0007.html
- http://xweb.geos.ed.ac.uk/~rharwood/teaching/phys4/dynamics/ch_10.pdf
- http://tornado.sfsu.edu/geosciences/classes/m201/Vorticity_Eq/Vorticity.htm
- http://tornado.sfsu.edu/geosciences/classes/m302/Divergence.html
- www.springerlink.com/index/l872v51303j71292.pdf
- http://www.meto.umd.edu/~hudson/aosc200.d/Ch2Notes.htm

- http://www.tulane.edu/~sanelson/geol204/oceanatmos.htm
- http://atoc.colorado.edu/~cassano/atoc5050/Lecture_Notes/wh_ch3_part3.pdf
- http://www.atmos.millersville.edu/~lead/SkewT_HowTo.html
- http://www.cs.ubc.ca/~tmm/courses/old533/projects/sancho/proposal/documents/Skew-T-Manual.pdf
- http://wx4cast.blogspot.in/2011/10/how-to-read-skew-t-log-p.html
- http://journals.ametsoc.org/doi/pdf/10.1175/MWR-2861.1
- http://www.remss.com/papers/wentz_JAOT_1991.pdf
- http://cimss.ssec.wisc.edu/iwwg/iww4/p207-213_Stoffelen-OnTheUse.pdf
- http://www.nat-hazards-earth-syst-sci.net/7/327/2007/nhess-7-327-2007.pdf
- http://dspace.library.cornell.edu/bitstream/1813/13084/1/Gottlieb,%20Robert%20-%20Research%20Honors%20Thesis.pdf
- http://www.staff.science.uu.nl/~delde102/Thunderst.Predictors.pdf
- http://www.academia.edu/691701/PREDICTION_AND_CLASSIFICATION_OF_THUNDERSTORMS_USING_ARTIFICIAL_NEURAL_NETWORK
- http://ocw.mit.edu/courses/
- http://www.ufa.cas.cz/dub/storm/ts_mz0.htm
- ftp://texmex.mit.edu/pub/emanuel/PAPERS/ezr99.pdf
- http://www.nc-climate.ncsu.edu/
- www.meted.ucar.edu/cosmic

STUDY FOR PREDICTION OF THE CONVECTION DEVELOPMENT OVER OCEAN

"Climate is what we expect, weather is what we get."

Mark Twain (Samuel Langhorne Clemens)

"Sunshine is delicious, rain is refreshing, wind braces us up, and snow is exhilarating; there is really no such thing as bad weather, only different kinds of good weather."

John Ruskin