Study of Rainfall Distributions over Bangladesh associated with Tropical Disturbances in the Bay of Bengal

M. Phil Thesis

By

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Declaration

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TO

MY PARENTS, HUSBAND AND KIDS

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ABSTRACT

Tropical cyclone is the most disastrous natural phenomenon for Bangladesh. Only preparedness can reduce the losses of lives as well as properties. Rain, one of the three means of destruction due to Tropical cyclone, is closely related with the Tropical cyclone. From its birth to death tropical cyclone produces rain, but the amount and region of rainfall at different stage of the tropical cyclone is different. Keeping this information in mind, in this dissertation, we have studied the rainfall distribution over Bangladesh with the movement of the tropical disturbances in the Bay of Bengal that crossed the Bangladesh coast. As our interest was limited over Bangladesh only, we have chosen those events whose eventual landfall was in the Bangladesh coast from the database created with the help of Bangladesh Meteorological Department (BMD). The main objective of this study is to identify the relationship between the amount of rainfall that is observed in different meteorological stations all over Bangladesh and the track of the tropical disturbances affecting Bangladesh. For that purpose rainfall data of 30 stations located all over Bangladesh is analyzed. We have plotted the isolines to identify the rainfall pattern over Bangladesh map along with the track of the disturbances. Then these figures are analyzed to identify the relationship between the rainfall and the track of the disturbances.

In this study, 17 cyclonic disturbances of different categories, 8 Severe Cyclonic Storms with a core of hurricane wind (SCS (H)), 2 Severe Cyclonic Storm (SCS), 3 Cyclonic Storm (CS), 3 Deep Depression (DD) and 1 depression, have been considered that occurred during 1974 to 2001. The analysis shows that heavy to very heavy rainfall occurred on the front-right quadrant of the track on the day and the day before the system approached the Bangladesh coast.

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CHAPTER ONE

Introduction

CHAPTER 1

INTRODUCTION

Bangladesh stands at the northern tip of the Bay of Bengal, which is the part of the North Indian Ocean. North Indian Ocean is one of the seven basins in which the tropical cyclones form. Most of the tropical cyclones (about 87%) that occur in this basin forms in the Bay of Bengal and the rest form in the Arabian Sea. Though only about 7% of the global tropical cyclones form in the Bay of Bengal, they are the most deadly (Neumann, 1993). The low flat coastal terrain and the funneling shape of the coast line can lead to devastating losses of life and property due to the surge from a storm of even of moderate intensity. The great killer cyclone, the Backergonj cyclone of 1876, killed about 200,000 people. If one considers the then population of this part of the world then it can be considered as the most devastating. The cyclone of 1970, which also took 200,000 lives. It is due to lack of preparedness so many lives were lost. In 1991 another devastation occurred. The Chittagong cyclone took 138,000 lives and the monetary loss was about 10 billion taka ($1.5 billion). Very recently, on 15th November 2007, the cyclone Sidr took lot of lives also. Officially about 2000 people were killed by it, though unofficial number is far more. The Sundarban which acts as the barrier of the South-Western part of the Bangladesh was also severely damaged by Sidr. It can be simply said that if there was no Sundarban then the life toll were many times of that occurred.

According to Riehl (1954) that part of the world where most of the times the weather sequences differ distinctly form those of middle latitudes, the dividing line between easterlies and westerlies in the middle troposphere, serves as rough guide of the boundary of the tropics. Cyclonic events, whatever its intensity may be, of these regions are generally termed as tropical cyclone. Bay of Bengal, which is a part of North Indian Ocean, lies in the tropical belt and so the cyclonic events in this Bay are generally termed as tropical cyclone.

Recent studies have contributed to improved understanding of how month-to-month and season-to-season variations of wind and thermodynamic factors are associated with large variations in seasonal tropical cyclone frequency and intensity. Examples include: Gray (1988), Gray and Sheaffer (1991), Landsea and Gray (1992), Gray et al. (1992), Joseph and Liebmann (1991), Hastenrath (1986, 1990) and Nicholls (1985, 1992).

There are countries in the tropical zone that contain some of the highest population densities in the world, through the whole tropics there has been extraordinary growth in recent years, mainly due to industrial development and tourism. There has not been, however, a correspondingly rapid increase in forecast performance associated with tropical cyclones.

Tropical cyclones develop from persistent but migratory rain disturbances usually in an oceanic circulation environment (Simpson and Riehl, 1981). These disturbances constitute an array of towering cumulus and associated altostratus clouds covering an area 200 to 600 km in diameter. In the disturbed areas, pressure tends to be slightly lower than the environment, and the air movement often acquires a wavelike cyclonic curvature. Only a small percentage of the migratory disturbances produce dangerous windstorms. However, when the processes at work in this benign setting cause surface pressures to fall, the wavelike character of circulation first grows in amplitude and then forms a nearly circular vortex, and winds tend to increase to destructive speeds.

In the 1930s, Dunn (1940) developed a procedure for identifying and tracking migratory tropical disturbances and the progress of there development by following the movement of 24-hour pressure change patterns. In the 1940s, Riehl (1948) described the dynamics of the wave system that generally embraces and supports the well-developed rain disturbances and identified a number of necessary conditions for the development of the wave circulation into a cyclone. In the 1950s Malkus and Riehl (1960) successfully answered a number of questions concerning energy sources and transformations required developing and maintaining the cyclone. In the 1960s, the weather satellite supplied for the first time a means of continuously monitoring the movement and development of tropical disturbances and for accumulating a meaningful climatology of them (Simpson et. al. 1969).

In the late 1970s, W. M. Gray and his collaborators used many years of data from aircraft flights through hurricanes to derive a different physical basis for initiating the pressure falls that lead to hurricane development (Gray, 1978). Riehl (1954) discussed the life cycle, surface structure, upper air structure and many other properties of a tropical cyclone. He also discussed some theories of its formation. Some other theories also evolved afterwards. Anthes (1982) also has discussed various features of tropical cyclones. He also discussed some physical processes related to the tropical cyclone.

Karmakar (1998) has complied available records of events occurred in the Bay of Bengal and Arabian Sea. Alam et al. (2002) discussed the events occurred in the Bay of Bengal basin statistically and found the bimodal occurrences in this basin. Analyzing the crossing of the tropical cyclones through different coastal boundaries of the Bay of Bengal in different seasons Alam et al. (2003) discussed the vulnerability of different seasons.

Tropical cyclone structure forecasting has received considerably less attention than has motion forecasting. This is also a more difficult problem since the dynamics are more highly nonlinear and occur on smaller scales under conditions that make them very difficult to observe. Analysis and forecasting techniques are therefore highly empirical. Although high resolution numerical models may provide useful forecasts in the future, empirical methods are expected to provide the backbone of the forecasting effort.

As with any type of weather forecasting, predicting tropical cyclone structure involves analysing the present conditions and estimating how they will change, i.e. monitoring and forecasting. In the absence of aircraft reconnaissance information, monitoring tropical cyclone structure is usually a problem of inferring intensity, size, and rainfall from frequent satellite imagery and reconciling the estimated structure with infrequent in situ observations from land stations, ships, and rawinsondes. Aircraft reconnaissance data simplify the analysis, but still leave considerable difficulties. Structure change forecasts are made using short-term indications from satellite cloud signatures and longer-term indications from synoptic conditions. These indications are based on a blend of forecaster experience and conceptual models of tropical cyclone dynamics.

Tropical cyclogenesis is a continuous process that may span several days, rather than a sudden event. At the beginning of this process a tropical cyclone does not exist and at the end one clearly does. During this time, the incipient tropical cyclone acquires a low-level mesoscale circulation and associated organized convection and the two (together with the surface heat fluxes) begin to co-operate to amplify the system further. The forecaster's task during this period is to monitor the area of responsibility for regions of collocated persistent convection and low-level cyclonic circulation(s). Such suspect areas are intensively watched for evidence of organization in the convection. Formation forecasts are made by evaluating large-scale factors, which are known to inhibit or enhance development.

Forecasting the future location of a tropical cyclone is universally considered to be the most important function by tropical cyclone warning centres (McBride and Holland, 1987). This level of importance is reflected in the large number of forecast techniques that have been developed using a wide range of approaches, from empirical through statistical and dynamical. Until recently, technique development, together with improved observing methods in some basins, had resulted in a slow, but steady decrease of forecast error of approximately 1% per year (Neumann, 1981). At the same time the resolution and initialisation of tropical cyclones in numerical models have been considerably improved.

Substantial improvements are still possible and to be expected, however. Mean forecast errors increase almost linearly to 72 hours, are approximately 30% of the cyclone displacement over the same time, and, when normalised by climatology and persistence, have a small initial skill that increases with time (Pike and Neumann, 1987; Leslie et al., 1990). The distribution is skewed towards large forecast errors, so that the median error is significantly better than the mean. Eliminating these large errors would produce a major improvement in forecasting.

The ultimate limit on forecast errors seems to be much lower than the current level. Bell (1979) compared the best track analyses from several western North Pacific cyclone warning centres (during a period of both aircraft and satellite observations) and found that the uncertainty in the initial location lay around 40 km. Simple extrapolation of this uncertainty level using CLIPER, or the commonly noted linear error growth rate, provides forecast errors that are half those of current forecast techniques. This simple analysis indicates that the current forecast errors may be twice the level dictated by predictability limits.

Continued research is required to elucidate the fundamental processes and to provide a solid foundation for future technique development. Improvements in observations are essential, especially those required to better locate tropical cyclones and define their outer circulation and near environment. Improvements in numerical models can be expected to provide further improvements in forecast skill. In particular, improvements will come from better model resolution, the use of synthetic observations to fill in gaps, better assimilation of the cyclone and its environment, and the use of coupled atmosphere/ocean models. Coupling numerical model and statistical forecasts will continue to provide further improvements.

The term habitation layer was coined by Bob Simpson (Simpson and Riehl, 1981) to describe the thin layer of the atmosphere in which we live. In this region, the atmosphere is interacting with the underlying surface, with resulting quite complex winds that are gusty, suffer large perturbations around local obstructions, and may contain microbursts and downbursts. The interaction between ocean and atmosphere also occurs in this region, with resultant generation of very high wind waves and coastal storm surges.

The storm surge is a long gravity wave with a length scale similar to the size of the generating tropical cyclone, and lasts for several hours depending on the cyclone size and speed of movement. The surge usually consists of a single passing wave that elevates or depresses the still water height. In some special situations, especially for cyclones moving parallel to the coast, secondary waves or resurgences can form behind the tropical cyclone.

The ocean response to tropical cyclones is quite different in deep water and in shallow, offshore water. In deep waters, far from a coast, the surface wind stress from a tropical cyclone creates a rotating mound, or vortex, of water by diffusing momentum downward. The ocean elevation is small; approximately the hydrostatic uplift in response to the low central pressure and some minor long term Coriolis effects. Dynamic effects become pronounced as the tropical cyclone approaches a coast. On entering the shallow waters of a continental shelf, conservation of the potential vorticity of the mound requires development of marked divergence. Channelling by local bathymetry, and reflections from the coast also contribute to substantially amplify the surge height. Unlike the short-wavelength, propagating wind-waves, a translating surge wave does not break in shallow waters. As viewed by an observer facing out to sea, a tropical cyclone has onshore winds, with positive surge, to the right (left) in the Northern (Southern) Hemisphere, and offshore winds, with negative surge, to the right (left). Tropical cyclone size, translation speed, residence time on the continental shelf, and angle of attack to the coast, together with local offshore bathometry and inland topography all play significant roles in surge generation and inland flooding.

The intensity is a vital factor of tropical cyclone. In terms of the sustained wind speed the intensity of tropical cyclones are categorized. Fletcher (1955) has given a very simple formula ($V_{max} = 17\sqrt{P_0 - P}$) in terms of the pressure drop to estimate the wind speed. But that formula is not found unique for all the basins. Choudhury and Ali (1974a) have done a preliminary investigation on the estimation of maximum sustained wind associated with Bay of Bengal cyclones. A formula similar to Fletcher's formula ($V_{max} = 13.6\sqrt{P_0 - P}$) has been proposed by Meherunnesa and Choudhury (1981) for the Bay of Bengal cyclones. Choudhury and Ali (1974b) have developed a model to predict the maximum surge height associated with cyclones affecting Bangladesh.

Choudhury (1978), on using the method of image, suggested that the track of the Bay of Bengal cyclone would follow the equation of a rose petal. Debsarma (1998), on using parabolic regression, developed a model to obtain cyclone track. But Hossain and Alam (1999) showed that the tracks of Bay of Bengal cyclones follow cubic curves rather than a quadratic one. However, these models do not serve the purpose fully for predicting the tropical cyclone intensity and tracks.

Tropical cyclones develop over the warm waters of tropical oceans where the observing stations are sparse. Since observing stations frequently do not exist in areas of formation of cyclones, they can be traced in its very early stage of formation by satellites and RADARs. The main objective of the cyclone forecasting is the prediction of cyclone track and intensity of the storm. The hurricane damage and loss of life can be significantly reduced if precautionary measures are taken in time following the prediction.

Tropical cyclones typically do not evolve in climatologically fixed conditions but rather in environments that exhibit favorable weekly to seasonal scale deviations from the long-term background climatology. Although the role of the environment has been known and accepted in varying degrees by tropical cyclone specialists for many years, the full extent of this role is only now becoming better understood and appreciated.

The damages due to a cyclone are caused through three means i) high winds ii) torrential rains and iii) storm surge. Nothing can be done against them. Only safety measures can be taken to reduce the losses, both in terms of lives and assets. Reduction of losses, in terms of lives, can be achieved through proper preparedness against the incoming danger. The proper preparedness depends mainly on two factors i) proper information about the degree of danger and ii) proper information about the time when the danger situation will occur. Information about the degree of danger includes the severity of cyclone i.e. whether it will arrive as a depression or cyclone or sever cyclone or severe cyclone with core of hurricane wind. The location and time of its arrival are also important.

If a cyclone hits a place which has no habitant then there is no possibility of losses of lives but if it hits a populous place then preparedness for saving lives properties is very important. But the preparedness depends on in timely information not only in terms of intensity of the cyclone but also its arrival time, because the height of the actual tidal surge has dependency on the normal tide also. If cyclones arrive the time of high tide then the surge height will be maximum and the destruction will be much more than if that arrived at the time of low tide. The tropical cyclones provide heavy rainfall. From the very formative stage of tropical cyclones they produce rains. In the formative stage rain can occur far away from the birth place. With the change of the location as well as maturity the pattern of rainfall changes. Keeping this information in mind our intension is to study the rainfall distribution over Bangladesh associated with tropical disturbances in the Bay of Bengal.

In chapter two detail information regarding the tropical cyclone is furnished through literature review. In chapter three we have discussed the methodology of the research work work. In chapter four we have presented the results and discussion and in chapter five we have made the conclusions.

CHAPTER TWO

Literature Review

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The term cyclone is derived from the Greek word Kyklos. Technically a cyclone is an area of low pressure where strong winds blow around a centre in anti clockwise direction in the Northern Hemisphere and clockwise direction in the Southern Hemisphere. On the basis of latitudinal positions the cyclones are classified as (a) Tropical cyclone and (b) Extra tropical cyclone. The tropical cyclones are nomenclatured by different local names in different regions, viz. Hurricane , Cyclone, Baguio , Typhoon , Willy - Willy etc. The tradition of naming the individual tropical cyclones with the name of girls and other names also persists since 1941.

Tropical cyclones form from initial convective disturbances known as cloud clusters. As they evolve from a loosely organized state into mature, intense storms, they pass through several characteristic stages. A uniform terminology does not exist to describe these stages over the different regions of the globe. General agreement exists that a key stage in the formation process is when the system reaches sustained surface winds exceeding 17.5 m/s (34 kt). Such systems are referred to as tropical cyclones. Another agreed threshold is sustained surface winds of 33 m/s (64 kt), which is referred to as severe tropical cyclones.

The mature tropical cyclone has a characteristic structure on two horizontal scales. The large- scale tropospheric vortex may extend over 1000-2000 km from the region of minimum surface pressure at the centre. Embedded within this large scale circulation is the region containing the eye, the eye wall cloud and the central core of maximum winds, the horizontal extent of the core is on the order of 100 KM.

Sometimes, tropical cyclone formation is refereed to the transition from the cloud cluster stage to the tropical cyclone stage with winds speed exceeding17.5 m/s. Further changes in the maximum wind speed are referred to as intensification.

The devastation of cyclone occurs by three different means (i) strong wind (ii) tidal surge and (iii) rainfall. Heavy rainfall due to tropical cyclones affects a large area. The cause of heavy rainfall in different regions is different. There are generally three heavy rainfall bands (i)the eye wall of the cyclone (ii) spirally cumulonimbus bands and (iii) the band associated with the inverted trough. The core heavy rainfall occurs around the eye wall within 50km of the cyclone centre, whereas the spiral rain band can produce torrential rains over hundreds of kilometer. Li (1982) found that the spiral rain bands at different stages of development of a cyclone have varying propagation direction. As a result remote region from the center may face rains in different times.

In cyclone that makes landfall in China, it was found to develop inverted trough heavy rains within a northern trough after its land fall. Water vapor convergence, ascending motion and low level convergence are found in various regions of the inverted trough.

In addition to the above three regions heavy rainfall may occur far away from the cyclone center in certain weather situations. If a parcel of a moist air approaches to the westerly trough it will move upward along the frontal zone and can produce heavy rains in some remote place from the cyclone centre. Numerical simulations by Jiang and Dang (1993) of remote heavy rain events have shown that if the typhoon circulation is removed from initial field, little precipitation will occur in front of the westerly though, thus it was concluded that such remote heavy rains were induced by the poleward vapour transport associated with typhoons.

Land water interaction and mountains have dramatic impacts through the frictional forces, upward motion, heat and moisture fluxes on the tropical terrains and mountains have different characteristics of rainfall due to cyclones. The intensity of rainfall in the front right quadrant is generally found to be more.

Approximately 80 tropical cyclones occur throughout the world each year, and about two thirds of these reach the severe tropical cyclone stage. Preferred regions of formation are over the tropical oceans. No formations occur within about 2.5° latitude of the equator, where Coriolis force is almost absent. Most of the formations (87%) occur between 20°N and 20°S. Tropical cyclones are seasonal phenomena, and most basins have a maximum frequency of formation during the late summer to early fall period. The Southern Hemisphere peak occurs in January to March and the Northern Hemisphere peak is from July to September. Neumann (1993) classified the areas of formation into seven "cyclone basins" and they are North Atlantic, Eastern North Pacific, Western North Pacific, North

Indian, South West Indian (<100^{0}E), South East Indian/Australia (100-142^0 E) and South West Pacific/Australia (>142^0 E).

The seasonal distribution of the location of formation is governed by two major factors. One is the sea-surface temperatures (SST). The highest values of SST occur during the late summer. The second factor in the seasonal distributions is related to the seasonal variations in the location of the Inter Tropical Convergence zone (ITCZ) which extend semi-continuously around the globe, and occurs as a convergence line between the trade winds from the Northern and Southern Hemispheres, or as a convergence zone is westerly monsoon flow.

In this latter configuration, the monsoon westerlies usually have trade easterlies on their poleward side. The shear line separating the monsoon westerlies from easterlies is known as the monsoon trough or monsoon shearline and is a climatologically preferred region for tropical cyclone formation. The only region of cyclone formation not associated with a monsoon trough is the North Atlantic.

2.2 Life Cycle of Tropical Cyclones

The life span of tropical cyclones with full cyclonic intensity averages at about 6 days from the time they form until the time they enter land or recurve into the temperate zone. Some storms last only a few hours; a few as long as two weeks. The evolution of the average storm from birth to death has been divided into four stages (Tarakanov, 1980).

Formative stage: Tropical storm form only in pre-existing weather systems. Deepening can be a slow process, requiring days for the organization of a large area with diffuse winds. It can also produce a well-formed eye within 12 hours. Wind speed usually remains below hurricane force in the formative stage. Unusual fall of pressure over 24 hours by 2 - 3 hPa or more takes place in the centre of the vorticity concentration.

Immature Stage: A large number of formative cyclones die within 24 hours. Others travel long distances as shallow depressions. Wind of cyclonic force forms a tight band around the centre. The cloud and rain pattern changes from disorganized squalls to narrow organized bands, spiraling inward. Only a small area is as yet involved, though there may be a large outer envelop. The eye is usually visible but ragged and irregular in shape.

Mature Stage: The force of cyclonic winds may blow within a 30 – 50 km radius during immature stage. This radius can increase to over 300 km in mature storms. On the average, the mature stage occupies the longest part pf the cycle and most often lasts several days. The eye is prominent and circular and the cloud pattern is almost circular and smooth. The eye is prominent and circular and the cloud pattern is almost circular and smooth. The surface pressure at the centre is no longer falling and the maximum wind speeds no longer increasing. At this stage, heating from convective clouds furnishes the largest amount of energy for cyclone maintenance. Pressure gradient is largest at the surface. Wind speed range is between 128 – 322 km/hr.

Terminal stage: Nearly, all cyclones weaken substantially upon entering land, because they lose the energy source furnished by the underlying ocean surface. The decay is especially rapid where the land is mountainous. Movement of a cyclone over land cuts of the surface energy source and increases the surface friction, especially when the land is mountainous. Some cyclones die out over sea and this event can be related to their moving over a cold ocean current or being invaded by a surface cold airmass behind a cold front or by a cold centre at high levels moving over their top.

2.3 The Mature Cyclone

A clean demonstration of the cyclone as a working engine can be obtained by forming a composite picture in all its facets from the ocean surface to the upper troposphere.

2.3.1 Pressure

Within 200 km of the cyclone centre, the pressure field and its isobars are very nearly circular and symmetric around the eye. The most reliable and widely used surface instrument yielding quantitative data is the barometer. Ordinary, surface pressure varies little more than .3% (3mb) in the tropics. The central pressure of cyclones, however, may be 5% or even 10% below average sea-level pressure. A cyclone with 950 mb central pressure is always rated a severe storm.

2.3.2 Cloud Pattern

Cloud photographs obtained from weather satellite have reveled that a cyclone seedling initially appears as a cluster of rain clouds. A mature cycle has a well-organized cloud pattern. It is possible to deduce the wind speed from the size and degree of organization of this cloud. The clouds, especially at the outer edges, form long streets that spiral inward. The most intense part is situated off centre to the right of the direction of motion, which is toward north-northwest. Usually central dot denoting the eye is visible.

2.3.3 Wind fields

When a cyclone lies embedded we may term a steering current of large scale, the speed of the steering current and of vortex are largely additive. To the right of the direction of motion of the centre, the direction of vortex motion and steering current coincide. On the left beside there are opposed to each other. Thus speeds are almost invariably higher to the right than to the left of the direction of motion in moving cyclone. Streamlines spiral inward to the ring of strongest wind. The spiral observed in all cyclones.

2.3.4 Precipitation

Individual rain gauge measurements give only a poor approximation of precipitation in cyclones. The wind drives rain horizontally and picks up water already fallen to the ground. Even slight topographic features such as buildings, lakes and small hills influence precipitation. Rainfall at any station depends on its location with respect to cyclonic path, intensity and celerity.

2.3.5 The eye of the cyclone

The centre of the cyclone is revealed as a 'singular point"; pressure stops falling, wind stops blowing hard, rainfall ceases, clouds lighten or disappear so that the satellite photograph shows a central small hole, and the ocean moves are confused. Eye diameter varies from 5 to over 60km, depending on rate of strong propagation. Though the eye is usually pictured as circular, it some times becomes elongated. Some times it is diffused with a double structured appearance. Modern observation specially radar, have proved that an eye does not remain in steady state but is constantly undergoing transformation.

2.4 Tropical Cyclone Formation

2.4.1 Climatological Conditions for Tropical Cyclone Formation

The first global climatology of tropical cyclone genesis by Gray (1968, 1975, and 1979) demonstrates that the distribution of genesis may relate to six environmental factors;

i) large values of low level relative vorticity.
ii) a location at lest a few degrees poleward of the equator, giving a significant value of planetary vorticity;
iii) weak vertical shear of the horizontal winds;
iv) sea-surface temperatures (SSTs) exceeding 26°C , and a deep thermocline;
v) conditional instability through a deep atmospheric layer ; and
vi) large values of relative humidity in the lower and middle troposphere.

The first three factors are factions of the horizontal dynamics, while the last three are thermodynamic parameters. Gray defined the product of (1), (2) and (3) to be the dynamic potential for cyclone development, whiles the product of (4), (5) and (6) may be considered the thermodynamic potential. As discussed by Gray (1975) and McBride (1981), the thermodynamic parameters vary slowly in time and would be expected to remain above any threshold values necessary for tropical cyclone development throughout cyclonic season. On the other hand, the dynamic potential can change dramatically through synoptic activity. Thus, it was hypothesized by Gray that cyclones form only during periods when the dynamic potential is perturbed to a value above its regional climatological mean.

Frank (1987) reduced the list to four parameters by combining (1) and (2) into the absolute vorticity at low levels deleting (5) and adding mean upward vertical motion to (6). Following Palmen (1948), it has been generally accepted that tropical cyclones only form when the underlying sea surface temperature (SST) exceeds 26^0C. Palmen hypothesized that the temperature criterion is one of threshold rather than proportionality. Through a more comprehensive study, Raper (1992) concluded that higher SST's has no direct impact on the frequencies of tropical cyclones.

2.4.2 Large Scale Conditions associated with Tropical Cyclone Formation

Tropical cyclones form only over tropical oceans where upper air observations are sparse, which has made it difficult to document the structure and evolution of the flow during the formation process. Consequently, much of the early understanding of formation was gained from case studies based on innovative use of the existing data networks (e.g. Riehl, 1948; Hubert, 1955; and Yanai, 1961). Subsequent studies that exploited improved observational systems have led to further refinement and detail in documentation of the tropical cyclone formation process. However, no well-accepted closed theory of formation exists.

The observational studies have isolated a number of synoptic-scale aspects that have an important role in the formation process:

i) Tropical cyclones form from pre-existing disturbances containing abundant deep convection;

ii) The pre-existing disturbances must acquire a warm core thermal structure throughout the troposphere;

iii) Formation is preceded by an increase (spin-up) of lower tropospheric relative vorticity over a horizontal scale of approximately 1000 to 2000 km;

iv) A necessary condition for cyclone formation is a large-scale environment with small vertical shear of the horizontal wind;

v) An early indicator that cyclone formation has begun is the appearance of curved banding features of the deep convection in the incipient disturbance;

vi) The inner core of the cyclone may originate as a mid-level meso-vortex that has formed in association with a pre-existing mesoscale area of altostratus (i.e., a Mesoscale Convective System or MCS); and

vii) Formation often occurs in conjunction with an interaction between the incipient disturbance and an upper-tropospheric trough.

2.4.3 Pre-existing disturbance

We observe universally that tropical storms form only within pre-existing disturbances. An initial disturbance, therefore, forms part of the starting mechanism. A weak circulation, low pressure and a deep moist layer are present at the beginning. The forecaster need not look into areas which contain no such circulation's. These statements by Riehl (1954) have stood the test of time. The structure of these tropical "cloud clusters" has been documented by many authors (e.g. Ruprecht and Gray, 1976a, b; Johnson and Houze, 1987). The cloud clusters have an upper tropospheric warm core and mean (averaged over a 4° latitude-longitude square) upward velocities of about 100 hPa/day (McBride and Gray, 1980; Lee, 1989). Although the diameter of the convective area is typically only a few hundred km, the rotational circulation's associated with the systems usually extend over a diameter of approximately 1000 - 1500 km.

2.4.4 Lower-tropospheric warm core

Although tropical cloud clusters have a warm core in the upper troposphere, they typically have a cold core below approximately 700 hPa, or generally below the level of maximum cyclonic circulation. Thus, a major theme of the early observational studies was the mechanism for transformation from a cold core to a warm core in the lower troposphere (Riehl, 1948; Hubert, 1955; Yanai, 1961). A transformation from cold core to warm core was observed by Davidson et al. (1990) prior to the formation of two tropical cyclones during the Australian Monsoon Experiment (AMEX). These two cyclones were well observed as they formed within an approximately 600-km diameter array of six rawinsonde stations. Approximately 2-3 days prior to cyclone formation, the vorticity maximum migrates downward to approximately the top of the boundary layer (900 hPa), which implies the establishment of a lower-tropospheric warm core. The physical mechanism for this downward migration of the mid-level vortex toward the surface, and thus into contact with the oceanic heat and moisture source, is one of the missing links in our understanding of tropical cyclone formation.

2.4.5 Small vertical wind shear

One of the environmental factors associated with the mean seasonal and geographical distributions of tropical cyclone frequency is small vertical shear of the horizontal wind. For example, Gray (1984a) and Shapiro (1987) have found inverse relationship between frequency of cyclones in the North Atlantic Ocean and seasonal mean vertical wind shear. It is also generally accepted that a small vertical wind shear is a necessary condition for an individual pre-existing disturbance to develop into a tropical cyclone. The physical reasons usually given for the importance of small (or even zero) shear is to accumulate moisture and temperature anomalies in a vertical column above the incipient disturbance.

By contrast, the presence of large vertical shear is said to "ventilate" the column by advecting the warm core aloft away low-level circulation center. Some support for this idea is provided in the numerical simulations of Tuleya and Kurihara (1981), Kurihara and Kawase (1985) and Tuleya (1988). In those studies, the vertical wind shear had to be such that a strong vertical coupling exists via the phase speed of the incipient (low-level) disturbance and the upper level winds. This coupling serves to keep the warm area above the disturbance and thereby maintains a favorable condition for growth of the disturbance.

2.4.6 Curved cloud features

Although the horizontal scale of the pre-existing convective cloud cluster is usually of the order of 500 km, it may range from as small as 200 km too as large as 1500 km. A persistent cloud cluster consists of many Mesoscale Convective Systems (MCSs) that are continually evolving on time scales of 6-18 hr. This MCSs are associated with a number of cumulonimbus elements that feed moisture to a deep altostratus deck.

Dvorak (1975, 1984) states that the convective elements form into curved cloud lines or bands approximately 36 hr prior to classification as a tropical cyclone. According to Dvorak, "a T1 classification is made when curved cloud lines or bands indicate that a system center has been near to or within a deep-layer convective cloud system for a period of at least 12 hours. It is the close association of moderately curved cloud lines or bands and a sizeable amount of deep-layer convection that signals cyclogenesis." This configuration can appear in various forms.

2.4.7 Mid-level mesoscale vortex

Mesoscale Convective Complexes (MCC's) were first identified as long-lived convective weather systems in the middle latitudes by Maddox (1980), Maddox (1991) and Sanders (1981). Similar systems have been identified in other regions of the world (Houze et *al.*, 1981; Velasco and Fritsch, 1987). The MCSs can be identified as the large areas of cloud with temperatures lower than - 70°C, which signifies the presence of long-lived altostratus decks. A pre-cyclone cloud cluster may contain one or more MCSs.

In mid-latitude MCCs with an intensifying Mesoscale Convective Vortex (MCV), the system becomes stronger, persists longer, and induces heavy precipitation (Bosart and

Sanders, 1981). In some cases the vortex appears to be responsible for subsequent development of MCCs Menard and Fritsch (1989).

Velasco and Fritsch (1987), and Chen and Frank (1993) have hypothesised that "if an MCC forms or propagates into a large-scale environment favourable for tropical cyclogenesis, the MCC - generated warm-core vortex may play a catalytic and crucial role in initiating tropical storm development" (Velasco and Fritsch, 1987). Such a hypothesis appears to be consistent with the study of Zehr (1992) based on satellite data, operationally analysed wind fields and reconnaissance aircraft data in the Western North Pacific. In the early stages, the vorticity maximum is in the middle troposphere between 700 and 300 hPa and no appreciable vorticity is detected near the surface. In the TEXMEX studies, the surface flow is divergent below the mesovortex. McKinley and Elsberry (1993) and Ritchie (1993) note that the pre-cyclone cloud cluster may contain a number of "secondary" mesovortices that appear to be directly related to altostratus areas with strong convection.

These preliminary observations suggest that the central core of the cyclone may begin as a small vortex at middle levels that extends downward toward the surface and increases in horizontal scale.

Zehr (1992, 1993) and Emanuel (1993) have divided the formation process into two or more stages with an important transition point being the formation of the persistent mesoscale vortex. In Zehr's stage 1, a mesoscale vortex is embedded within the pre-existing disturbance (cloud cluster) circulation. During stage 2, the central pressure of that vortex decreases and the tangential wind increases to result in a minimal tropical cyclone.

2.4.8 Interaction with upper-level disturbances

Case studies by many authors (Riehl, 1948; Bath *et al.*, 1956; McRae, 1956; Fett, 1968; Ramage, 1974; Sadler, 1976, 1978; McBride and Keenan, 1982) have demonstrated an apparent initiation of the formation process through interaction with surrounding upper-tropospheric synoptic systems, particularly upper level troughs. In particular, Sadler (1976, 1978) showed that cyclone formation in the western North Pacific frequently occurs in association with intense cyclonic cells embedded within a large-scale climatological feature known as the Tropical Upper Tropospheric Trough. McBride and Keenan (1982) showed that rapidly developing tropical cyclones in the Australian region were associated with slowly moving troughs in the upper troposphere displaced by approximately 5° longitude on either side of the developing disturbance. On the other hand, slowly developing cyclones were associated with fast moving upper-level troughs, which usually lay over the disturbance at the time of classification as a tropical cyclone.

2.5 Cyclones of North Indian Ocean

Although only about 7% of the global tropical cyclone (Neumann, 1993) occur in the North Indian Ocean they are most deadly. The shallow waters of the Bay of Bengal, the low flat coastal terrain and the funneling shape of the coastline can lead to devastating losses of life and property due to the surge from a storm of even moderate intensity. The Buckerganj cyclone of 1876 and the Bhola cyclone of 1970 each killed more than 200,000 people in Bangladesh. More than 138,000 people were killed by a storm surge of cyclone 1991 in Bangladesh.

About 10 cyclones (Karmakar and Shrestha, 1998) form in the North Indian Ocean basin each year, with variation from 3 to 16 during the period 1891-1991. The average annual frequency of cyclonic storms is about 3. The annual number of cyclonic storms is about 26.56% of the annual number of cyclonic disturbances. The average annual number of severe cyclones is about 1.48 which is 14.81% (Karmakar and Shrestha, 1998) of the annual number of cyclonic disturbances. Alam et al. (2002, 2003) observed that the average 7.77 storms and depressions and 3.46 storms formed in the Bay of Bengal during 1974 – 1999. The average annual number of cyclonic disturbances is about 2. That indicates five to six times more tropical cyclones occur in the Bay of Bengal as in the Arabian Sea.

The seasonal variation of tropical cyclones in the Bay of Bengal has a bimodal distribution with the primary maximum in November and a secondary maximum in May. That is, the intervening period of the summer monsoon is a relatively suppressed period of tropical cyclone formation. McBride (1986) attributed this suppression to the close interrelation between tropical cyclones and monsoon depressions. The two types of systems have almost identical structure of the larger scale vortex, and both systems form over warm tropical oceans. During the May and June cyclone season, system develops this large scale vortex structure in the monsoon trough and remain over the ocean long enough to develop an inner core structure and so become topical cyclones. When the monsoon trough is located further north and closer to land in August, the systems still form over warm waters, but they then track northwest into the Indian subcontinent and so remain monsoon depressions (i.e. with no inner – core structure).

Most North Indian Ocean cyclones form within the monsoon trough. Formation may occur either as reintensification of westward–propagating disturbances or from in situ disturbances that develop within the trough. The zone of formation shift meridionally between 5°-20°N following the annul migration of the monsoon trough. Mandel and Neumann (1976) analyzed the cyclones that formed in the North Indian Ocean during 1877 to 1974 in a grid of 2.5° latitude longitude box. It reveled from their analysis that the box from 87.5 to 90° E and 20° to 22.5° N faced most of the cyclone and the next highest events were over its left box.

2.6 Tropical Cyclone Tracks

The ability of tropical cyclones to maintain warm core characteristics as they move out of the tropics also is a function of a number of factors including sea surface temperatures (SSTs), environmental flow characteristics (such as vertical shear and equatorial extent of westerlies), and land/water configuration.

In the eastern North Pacific tropical cyclones typically encounter cold SSTs (<22.5°C) at low latitudes (e.g. Frank, 1987) and dissipate before recurvature into the westerlies. By comparison, relatively warm SSTs in the western North Pacific and the North Atlantic allow tropical cyclones to be sustained well into the subtropics, even after recurvature into the westerlies.

Southern Hemisphere SSTs, on the average, are lower than those of the Northern Hemisphere for the same latitude and tend to be intermediate between the two extremes cited above. This, together with the more equatorward extent of westerlies typically result in poleward moving tropical cyclones losing their warm core characteristics at lower latitudes than for similar systems in the Northern Hemisphere.

2.6.1 Cyclone track prediction

Cyclone track prediction techniques are grossly classified as

a) Simple techniques

b) Statistical models and

c) Dynamical models

Persistence, climatology and analog technique fall in the simple track prediction category. There are number of Statistical models to predict Cyclone tracks. Barotropic models and baroclinic models of regional and global scales are of dynamical types.

It may be assumed that the entire tropical cyclone system has considerable inertia that can not be turned rapidly. If the vortex, large scale flow, and the interaction process do not change, future motion should resemble the past motion and thus persistence model developed. In climatological track prediction models it is assumed that the present storm will move with the average direction and speed of all past storms near that location.

A combination of persistence plus climatology may be expected to provide an improvement over the separate techniques. A statistical combination of CLImatology and PERsistence (CLIPER) developed for the Atlantic region by Neumann (1972) has been extended to other basins (Leftwich and Neumann, 1977; Xu and Neumann, 1985). Predictors such as the present latitude and, longitude, the components of the recent motion of the storm and the intensity are used. Least squares to fitting of the basic predictors and various polynomial combinations is used in CLIPER derive regression equations for future latitudinal/longitudinal displacements in 12-h increments.

The basic assumption of the analog techniques is that a given storm will move in the mean speed and direction of all storms that occurred in that region within some time interval centered on the current day. The analog technique also includes a persistence aspect. In the HURRicane ANalog (HURRAN) scheme by Hope and Neumann (1970) each selected analog is translated to the position of the existing storms and started at the heading and speed of the current storm. The predictand in the statistical models is the tropical cyclone components motion over some future time interval. Statistical models derive their variance reducing potential from one or more of four sources of predictive information: "climatology; persistence; analyzed environmental data; or numerically forecast environmental data". When synoptic data is used the model then it is termed as Statistical- synoptic (e.g. NHC-72) and when dynamical models data is used then the Statistical model is termed as Statistical – dynamical model (e.g. NHC-73). NHC -83 has a hybridized form of CLIPER type, Statistical synoptic and statistical dynamical model.

Barotropic models have their capability to achieve higher horizontal resolution to better resolve the storm structure and the interaction between the vortex and its environment. The barotropic model is useful for situation in which the lower tropospheric flow in the tropics is more barotropic and limited period of times. To achieve higher horizontal resolution to better resolve the strong structure and the interaction between the vortex and its environment barotropic model is preferred. A barotropic model is useful for situation in which the lower troposheric flow in the tropics is more barotropic for limited periods of time. VICBAR developed by Hurricane Research Division of U.S.A is a barotropic model and used for operational track forecasting Bureau of Meteorology Research Center of Australia also uses its own barotropic model. It is found that with respect to CLIPER both of them works better.

Baroclinic models are of two categories (i) regional models and (ii) global models. Many countries have their own regional baroclinic models and they are of different resolution. One of the major problems of the regional baroclinic model is to assign its lateral boundary conditions. In some situation the lateral boundary conditions are assigned through its global counter part.

On the other hand major meteorological research centre has their own global models. Most of these global models handles all over the environmental factors that have their role to the local weather for example land ocean interaction, land use pattern, topography, sea surface temperature, incoming and outgoing solar radiation along with pressure, wind field temperature etc. The global models differ in terms of resolution also in terms of the model physics. With the enhancement of number of layers along the verticals and the number of grid points in the Lat-long direction the requirement of computational capacity goes higher and higher. So forecasters use low resolution global models to assign boundary conditions to a high resolution regional model.

2.7 Rainfall distribution around a tropical cyclone

Rainfall is found to be strongest in the inner core of a tropical, within a degree of latitude of the center, with lesser amounts farther away from the center (Riehl 1954). Most of the rainfall in hurricanes is concentrated within its radius of gale-force winds. A chart was developed by Riehl in 1954 using meteorological equations which assume a gale radius of about 210 statute miles i.e.300 km, for a fairly symmetric cyclone, and does not consider the effect that hills and mountains would have on the rainfall distribution, or vertical wind shear. Rain is a source of precipitation which forms when separate drops of water fall to the Earths surface from clouds. Larger tropical cyclones have larger rain shields, which can lead to higher rainfall amounts farther from the cyclone's center. This is generally due to the longer time frame rainfall falls at any one spot in a larger system, as long as forward motion is similar to that of a smaller system. Some of the difference seen concerning rainfall between larger and small storms could be the increased sampling of rainfall within a larger tropical cyclone when compared to that of a compact cyclone; in other words, the difference could be the result of a statistical problem.

Quantitative prediction of tropical cyclone rainfall is very difficult for the following reasons:

i) Rainfall itself is difficult to measure accurately, which hinders both operational analysis of rainfall and the development of improved forecasting aids;
ii) Current errors in track prediction mean that accurate rainfall estimates cannot necessarily be transformed into precise predictions, this is especially a problem when a cyclone is moving near regions of significant orography;
iii) Interactions between tropical cyclones and other weather systems are themselves complicated and poorly understood, so that heavy rain in areas of large-scale ascent and high humidity are difficult to predict;
iv) Even within clearly defined threat areas, mesoscale processes, which are poorly understood and difficult to monitor, may determine the distribution of heavy rainfall.

As with other aspects of tropical cyclone structure forecasting, operational numerical models generally lack the resolution and physical processes to predict rainfall accurately and explicitly but they are rapidly being improved. They may be especially useful in determining threat areas in complicated situations.

Research on tropical cyclone rainfall has tended towards intensive examination of a few cases. Improvements in forecasting ability, especially of regional peculiarities, would be well served by the development of a simple archive of the relevant synoptic features and resulting rainfall for a wide variety of cases. Were this available, forecasters would be able to classify each new situation within the range of typical patterns and perhaps make a more accurate prediction of the heavy rain threat area.

2.7.1 Rainfall Measurement

Rainfall is very difficult to measure accurately, especially for small areas, heavy rain, and short periods of time. Following methods are commonly used:

Rain Gauges: Rain gauges are very simple and direct. Unfortunately, convective rainfall is extremely variable in the horizontal, so a rain gauge network must be very dense. Otherwise a local extreme can be misinterpreted as the amount for an entire region. High winds such as found in tropical cyclones may also cause turbulence around the gauge and lessen its catch unless special shielding is used. Rain gauge networks are of most value in providing the ground truth, however limited, for indirect radar and satellite estimates.

Radar: Radar can continuously cover a 200 km radius circle over all conditions, unless blocked by terrain. It is less prone to sampling problems than gauges because of its continuous spatial coverage and implicit averaging over an area determined by the pulse length and beam width. Radar measures the strength of radio pulses scattered back to the radar by precipitation particles, which is related to their size and type (rain, snow, hail) by a rather complex equation. The size and type of particles is in turn related to rain rate by a less clearly known relationship, based on empirical 'Z-R relationships' (Batten, 1973) determined by comparing radar and rain gauge measurements. The relationship varies according to the radar and type of weather system.

Satellite Imagery: Satellite imagery can be used to estimate rainfall by empirical relationships based on the shape, texture and (infrared) black-body temperature of the tops of clouds. Although the relationships are not overly accurate, the large area and frequent time coverage make this a useful initial estimate of tropical cyclone rainfall over the ocean.

Satellite Microwave Measurements: Satellite microwave measurements use either radiometers measuring upwelling microwave radiation, or active "radars" in space, which work on the same principle as ground-based radars. Several systems are currently being tested and show significant promise for quantitative determination of tropical cyclone rainfall. Their operational use is untested at this stage, however.

2.7.2 Rainfall Analysis and Forecasting

Because of the meteorological complexity, measurement limitations, and lack of objective aids, analysis and forecasting of heavy rain associated with tropical cyclones can at best be indicative of likely outcomes. A suggested mode of operation is to first classify the situation as uncomplicated or complicated.

Uncomplicated situations satisfy the following conditions:

i) The tropical cyclone is relatively well developed;

ii) The tropical cyclone is a day or less from landfall and is moving rapidly enough such that its precipitating region will pass over a given point completely within a day or less;

iii) There are no topographic features within the path of the tropical cyclone which are significant enough to appreciably alter the rainfall;

iv) There are no significant nearby weather systems, including frontal zones, jet streams, or upper-level cut-off lows, which are likely to interact with the tropical cyclone during its passage inland.

Unfortunately, the majority of forecast situations near landfall involves rapid changes in the character and structure of the precipitation as the system moves inland and interacts with orography and other weather systems. Simple extrapolation procedures will not work very well and the situation is therefore complicated. About the best the forecaster can do in advance is identifying a general threat area based on the locations of the tropical cyclone and surrounding weather systems. The actual locations of heavy rain must then be identified as the event proceeds in order to identify areas which are accumulating dangerous amounts of rainfall. In the absence of dominating terrain, mesoscale processes such as the development of new convective cells at the merger of old convective outflow boundaries generally determine where within the threat area the heavy rain actually falls. If these mesoscale focusing mechanisms are quasi-stationary, extremely heavy rain may fall even though the convective elements are moving quickly.

2.8 Tropical Cyclone Speed

Wide ranges in tropical cyclone translational speeds are observed, both within and across ocean basins. Some of the more significant aspects of translational speeds are:

i) Predominance of slow tropical cyclones over the north Indian basin and the more equatorial portions of the Southern Hemisphere west of 160^0E;

ii) A marked lack of slow tropical cyclones over the North Atlantic and the western North Pacific basins;

iii) The fastest cyclones predominate only in the high latitudes of the North Atlantic and the western North Pacific basins, where average speeds occasionally exceed 40 kt (75 km h^{-1}), but a qualification is needed here on the inclusion of extratropical systems;

iv) A comparatively small range of speeds are observed over the eastern North Pacific basin.

2.8.1 Direction of Tropical Cyclone Motion

The mean directions of motion show that the classical recurvature patterns occur over the North Atlantic and the western North Pacific basins, and to a lesser extent in the southwestern Indian Ocean. The cyclones over the eastern North Pacific typically dissipate before recurvature into the westerlies. In both the north Indian Ocean and northern and western Australia regions cyclones often encounter land and dissipate before or during recurvature. The near-equatorial approach of mid-latitude westerlies in the southwest Pacific leads to a predominantly eastward motion of tropical cyclones.

2.8.2 Variability of Tropical Cyclone Motion

Analyses of tropical cyclone position forecast errors by Neumann and Pelissier (1981) and Jarrell et al. (1978) demonstrate that they are highly dependent on the tropical cyclone translational speeds and variability thereof. The greatest forecast errors are typically associated with rapidly moving or highly variable tropical cyclones. Thus, indications of the steadiness of cyclone motion, combined with knowledge of the mean translational errors provide a useful means of comparing forecast errors.

The vector speeds are always less than the scalar speeds and the proportion of speed reduction compared with the scalar means indicates the degree of variability in tropical cyclone motion. Thus, the western part of the eastern North Pacific basin has highly consistent tropical cyclone motions, whereas the recurvature latitudes of the North Atlantic and the western North Pacific as well as the equatorial regions of the Southern Hemisphere experience highly variable motion. A climatological measure of speed variability therefore can be obtained by algebraically dividing vector speeds by scalar speeds. Such a measure is often referred to as a steadiness or constancy index (Miller et al., 1988).

The global variation in tropical-cyclone motion steadiness, as defined by the above index multiplied by 100 and rounded off the nearest integer value. Note that the higher the index, the more consistent the motion, and perfectly steady cyclones would rate 100. Three ranges of steadiness have been arbitrarily defined with indices greater than 90 being rated high; 60-90 indicate average steadiness and systems below 60 are rated as erratic.

Noteworthy the regions of erratic motion (some less than 40) in the Australian / southwest Pacific region and the remarkably consistent tracks in the eastern North Pacific basin. Relatively low steadiness values also are found over the recurvature latitudes of the North Atlantic and the western North Pacific basins.

2.9 Tropical Cyclone Intensity

The Dvorak (1984) analysis is the worldwide standard for tropical cyclone intensity monitoring in the absence of aircraft reconnaissance and is the most common method of intensity forecasting as well. An important part of the technique is a climatological development rate, which provides a basis for estimating intensity changes.

Research by Holliday and Thompson (1979) indicates that 75% of all western North Pacific tropical cyclones deeper than 920 hPa have experienced a period of rapid intensification of 42 hPa d^{-1} or more. Extreme deepening rates of nearly 100 hPa d^{-1} have been observed. All tropical cyclones, even the weaker ones, should therefore be regarded as potentially serious.

One conceptual model of tropical cyclones at sea is that they are self-amplifying systems. They will intensify until they reach a Maximum Potential Intensity (MPI) unless their surroundings disrupt them, as is frequently (and fortunately) the case. The potential intensity is primarily a function of Sea Surface Temperature (SST) and tropopause temperature (Emanuel, 1988), so passage over colder water (or land) reduces the MPI. Strong vertical shear of the environmental flow is the most common factor limiting intensification in tropical and subtropical latitudes at sea. Tropical cyclones with a compact core of maximum winds and strongest convection are thought to intensify more rapidly, as are those that are well below their potential intensity. Another commonly held view is that interactions with upper-level troughs, either of tropical or subtropical nature, may further tropical cyclone intensification under the right conditions.

The threat of rapid intensification resulting in a very destructive tropical cyclone should therefore be considered greatest for compact, well-organised circulations with warm SST, a high tropopause, and relatively low vertical shear of the environmental flow. The Dvorak method contains detailed procedures for evaluating the satellite signature of a tropical cyclone in terms of its current and near-future intensity. Work sheets designed to modify the Dvorak forecast development rate based on other information are then presented and discussed.

2.10 Tropical Cyclone Warnings

There are two general types of tropical cyclone warnings: those for land areas and coastal waters and those for the high seas (sometimes referred to as marine warnings). Each Member of a regional body is normally responsible for its land and coastal waters warnings. There are some exceptions, however, for example, the United States National Hurricane Center in Miami, Florida (NHC), issues warnings for Haiti, Aruba and the Netherlands Antilles, St. Barthelemy, St. Martin and their coastal waters.

2.11 Prevention

In 1947 a group of scientist under the leadership of the Nobel laureate Irving Langmuir seeded a hurricane with ice nuclei to test it could be modified and make less destructive. Because of the risks involved in trying to change the behavior of hurricanes approaching land, only half a dozen hurricane-seeding tests have been conducted. The most encouraging ones were carried out on August 18 to 20, 1969, when hurricane Debbie was seeded with silver iodide by aeroplanes of Project Storm fury, a joint research program of the National Oceanic and Atmosphere Administration and the U.S Navy. Following both periods of seeding, the peak winds within the hurricane decreased substantially at the aircraft flight level of about 3600m. Mathematical analysis by project scientist indicated that ice-nuclei seeding of a hurricane outside the zone of maximum winds should cause a reduction of peak speed. These results persuaded some scientists that it might be possible to weaken hurricanes by seeding them, but there still are many uncertainties. It is considered essential that more experiments over the open ocean be performed before seeding hurricanes about to populated areas.

CHAPTER THREE

Methodology

CHAPTER 3

METHODOLOGY

3.1 General Procedure

For our study purpose rainfall data as well as the cyclonic events of Bay of Bengal is required. We have collected rainfall data for different cyclonic periods from the Climate Division of Bangladesh Meteorological Department (BMD). The BMD database is created station wise. For a particular station the database consists of year, month and the daily amount of rainfall.

With the help of BMD, a database of the cyclonic events of the Bay of Bengal has been created. As we are interested to analize only the events through which the Bangladesh coast of the Bay of Bengal are affected we have sorted the data base to select only those events. For the purpos of sorting the events which struck between 88 to 92.75^{0}E longitude were selected first. The dates of the events were then listed. A computer programme is then developed to make the tables in which amount of rainfall is tabulated from the rainfall database for all the stations for the dates identified earlier. The dates are selected considering the date in which the particular event was traced by BMD till it crosses the coast. For individual events a table comprising different stations, for the individual days along with the amount of rainfall is prepared. For the purpose of study of the rainfall distribution over Bangladesh these tables are used to draw the spatial distribution of rainfall using the software *surfer*.

We have selected 17 cyclonic events of different intensities that formed in the Bay of Bengal and crossed the Bangladesh coast during 1974 – 2001. The selected 17 cyclonic events are of following categories:

Sl. No.	Category	No. of Cases
1.	Severe Cyclonic Strom a core of hurricane intensity SCS(H)	8
2.	Severe Cyclonic Strom (SCS)	2
3.	Cyclonic Strom (CS)	3
4.	Deep Depression (DD)	3
5.	Depression (D)	1

On the basis of the occurring of rainfall a figure is drawn for each day. Thus for different events the number of figures are different. The discussion is being done for a particular event.

3.2 Classification of Tropical Cyclones

Cyclonic disturbances in the North Indian Ocean are classified according to their intensity. The following nomenclature is in use:

1. Low: Wind speed <31 km/hr.
2. Well marked low: Wind speed equals to 31 km/hr.
3. Depression: Wind speed ranges from 32-48 km /hr.
4. Deep depression: Wind speed ranges from 49-62 km/hr.
5. Cyclonic Strom: Wind speed ranges from 63-88 km/hr.
6. Severe Cyclonic Strom: Wind speed ranges from 89-117 km/hr.
7. Severe Cyclonic Strom a core of hurricane intensity: Winds ≥118km/hr.

3.3 Classification of Rainfall

The classification of rainfall used by the BMD/WMO is given below:

Type of rain	Range in mm/Day
Light rain	4.57 – 9.64
Moderate rain	9.65 – 22.34
Moderately heavy rain	22.35 – 44.19
Heavy rain	44.20 – 88.90
Very heavy rain	≥88.90

CHAPTER FOUR

Results and Discussions

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Track and Rainfall distribution due to SCS (H)

4.1.1 Rainfall distribution and Movement of Cyclone of 5 December 1981

Fig 4.1.1 (a-e) represents the rainfall distribution over Bangladesh during 7 to 11 December of 1981 along with the track of the associated cyclone, which was formed in the Bay of Bengal on 5^{th} December 1981 and crossed Bangladesh coast on 11^{th} December.

At 09 Bangladesh Standard Time (BST) of 6 December the system was a deep depression stage and located at 11^0N, 87^0E, though it was noticed 15 hours before as depression but did not have a definite centre and it moved towards west. In the next 24 hours i.e. by 09 BST of December 7 the system moved towards north-north west and centered at 11.5^0N, 84.5^0E. Within this period further intensification took place and the system became CS. From 12 BST of 7 December to 18 BST of 7 December the system moved in the north easterly direction without any change in its intensity and its centre arrived at 13^0N, 85^0E. In the next 12 hours the system moved towards north and intensified to SCS. In the next 9 hours the system moved towards north easterly direction without change in its intensity and its centre arrived at 15^0N, 87^0E. Form 15 BST of December 8 to 18 BST of December 09 the system moved towards north and located at 17.5^0N, 87^0E. Within the period further intensification took place and the system became SCS (H). In the next 6 hours it moved towards north east with the same intensity and its centre was located at 18.5^0N, 88^0E. In the next 9 hours it moved towards north-north east with the same intensity. From 09 to 18 BST of 10 December the system moved to the northerly direction without any change in its intensity and its centre was located at 20.5^0N, 88.5^0E. In the next 3 hours the system weakened and moved towards north easterly direction and its centre arrived at 21.2^0N, 89^0E. At 06 BST of December 11 it crossed the Sundarban coast as deep depression (DD).

There was no rain over Bangladesh on 1^{st} and 2nd day when depression formed in the Bay of Bengal and transformed into DD. On 3^{rd} day moderate rainfall occurred at Comilla when the deep depression transformed into CS in the Bay and the direction of movement of the cyclone was northwest. On 4^{th} day light rain occurred at Cox's Bazaar when the CS transformed into SCS and the direction of movement of the cyclone was

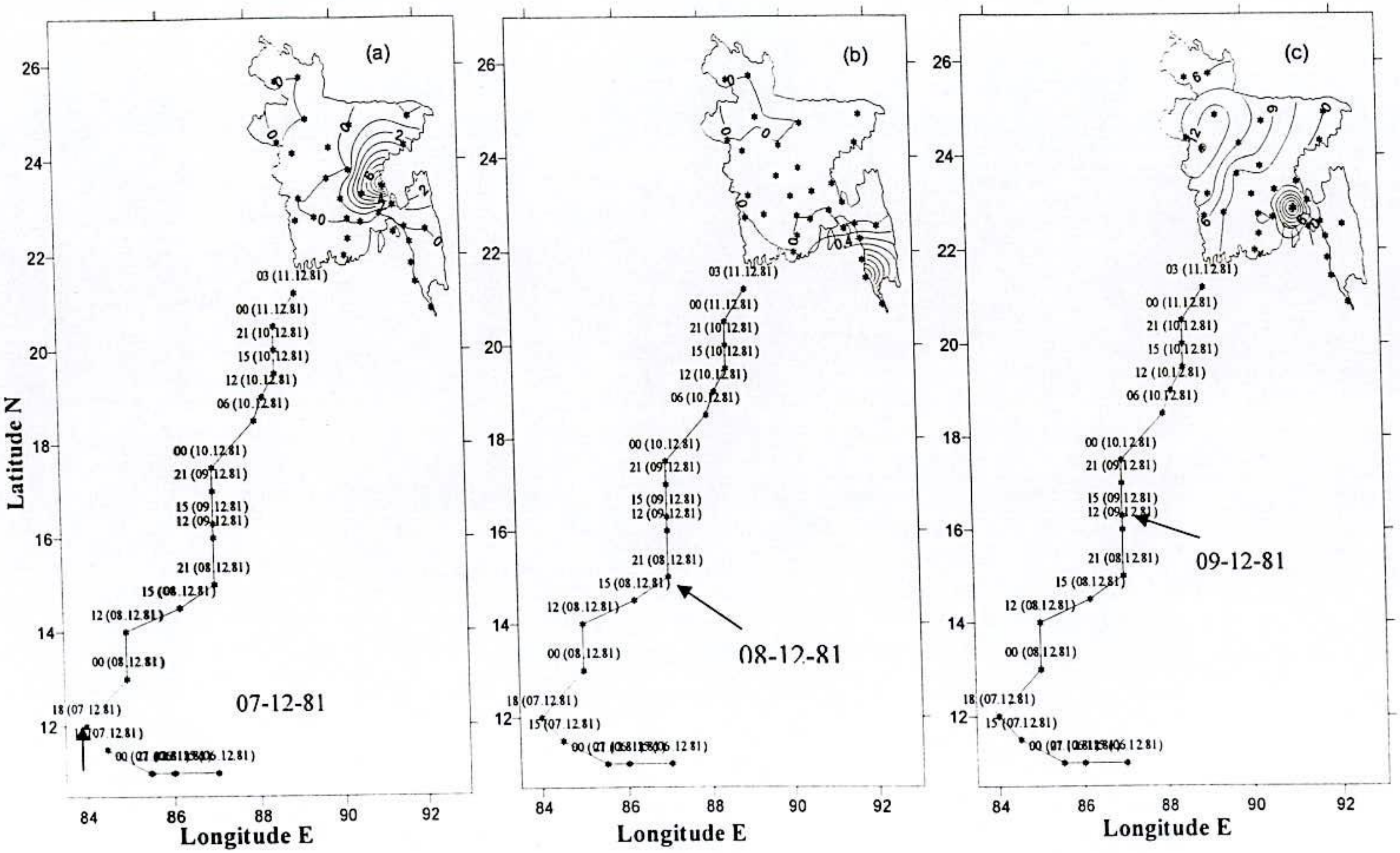

Figure 4.1.1(a-c): Rainfall distribution over Bangladesh during December 7-9, 1981 due to SCS(H) of 5-11 December 1981, along with its track.

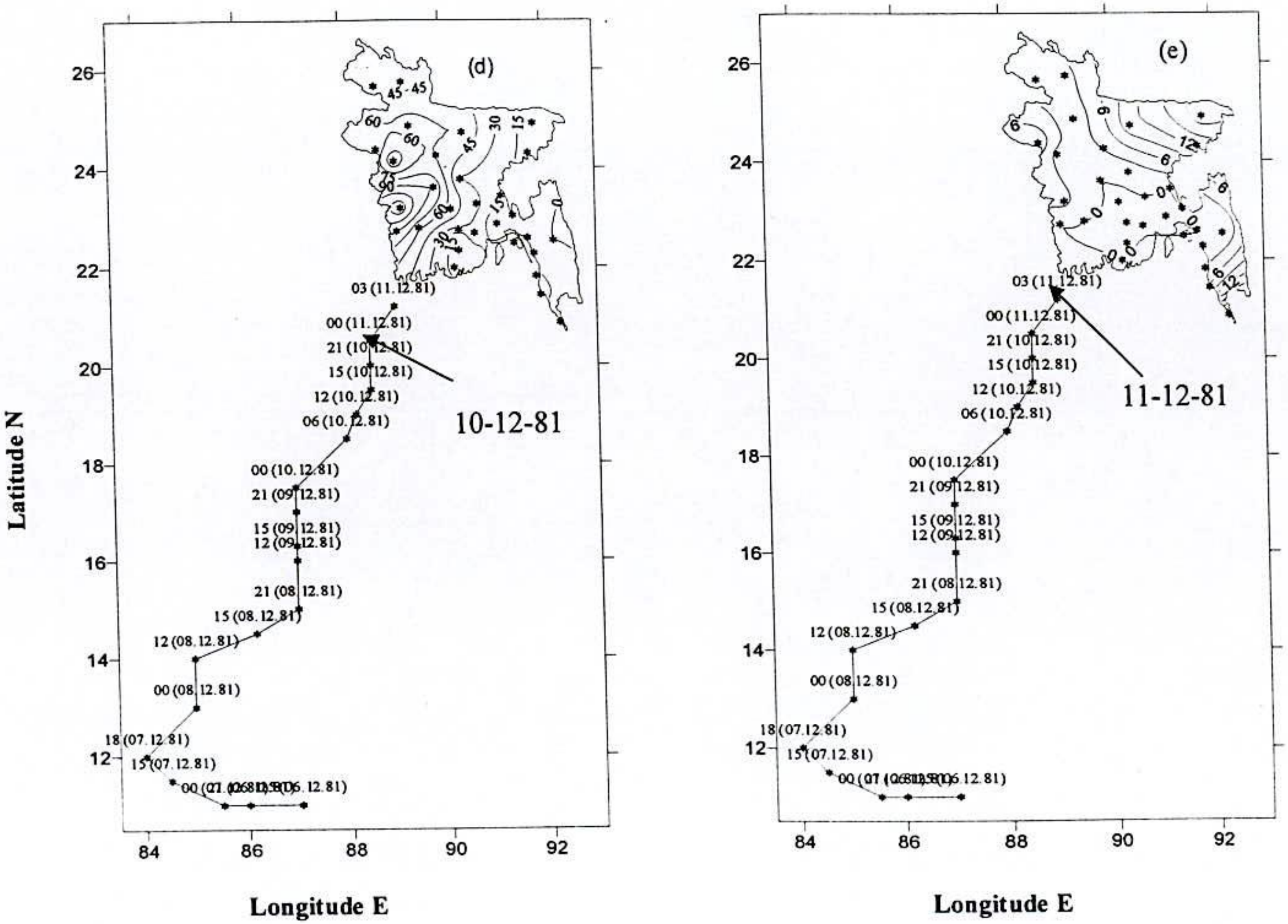

Figure 4.1.1(d-e): Rainfall distribution over Bangladesh during December 10-11,1981 due to SCS(H) of 5-11 December 1981, along with its track.

towards northeast. On 5th day moderately heavy rainfall occurred at Maijdi Court and moderate rainfall occurred at Bogra, Ishwardi, Jessore regions when the SCS transformed into SCS (H) and the direction of movement of the cyclone was towards north. On 6th day very heavy rainfall occurred at Satkhira, Jessore, Faridpur regions and heavy rainfall occurred at Bogra, Mymensing, Rajshahi, Khulna regions and moderately heavy rainfall occurred at Rangpur, Dinajpur, Ishwardi, Dhaka, Chandpur, Barisal, Bhola, Sandwip regions and moderate rainfall occurred at Comilla, Feni, Khepupara, Cox's Bazaar regions. On 7th day cyclone crossed the Sundarban coast and moderately heavy rainfall occurred at Teknaf and moderate rain occurred at Mymensing, Sylhet regions.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 133mm, which is the maximum one for this event, is observed on December 10 at Chittagong.

4.1.2 Rainfall distribution and Movement of Cyclone of 15 May 1997

Fig 4.1.2 (a – e) represents the track of the cyclone that formed in the Bay of Bengal on 15th May 1997 and crossed the Bangladesh coast and the rainfall distribution over Bangladesh during 15 to 19 May of 1997.

At 18 BST of May 15 the system was first detected as depression and was located in the central Bay of Bengal with center at 7.5^0N, 90.5^0E. In the next 15 hours it moved towards north east and intensified to CS. From 21 BST of 16 May to 03 BST of 17 May the system moved in the North easterly direction without any change in its intensity and its centre reached at 11^0N, 90^0E. From 09 BST of 17 May to 00 BST of 19 May the system moved towards north and its centre reached at 19.3^0N, 90.3^0E. Within this period further intensification took place and the system became SCS. In the next 8 hours the system moved in the north-north easterly direction without any change in its intensity and its centre reached at 20.2^0N, 90.9^0E. In the next 4 hours it moved towards north easterly direction without any change in its intensity. In the next 4 hour its intensity remained the same and it further moved towards north-north east and crossed the Sitakundu coast on 18 BST of May 19.

Moderate rain occurred at Sylhet on 1st day when depression formed in the Bay of Bengal and the direction of movement was towards northwest. On 2nd day moderately heavy rainfall occurred at Chandpur, moderate rainfall occurred at Sylhet, Rajshahi,

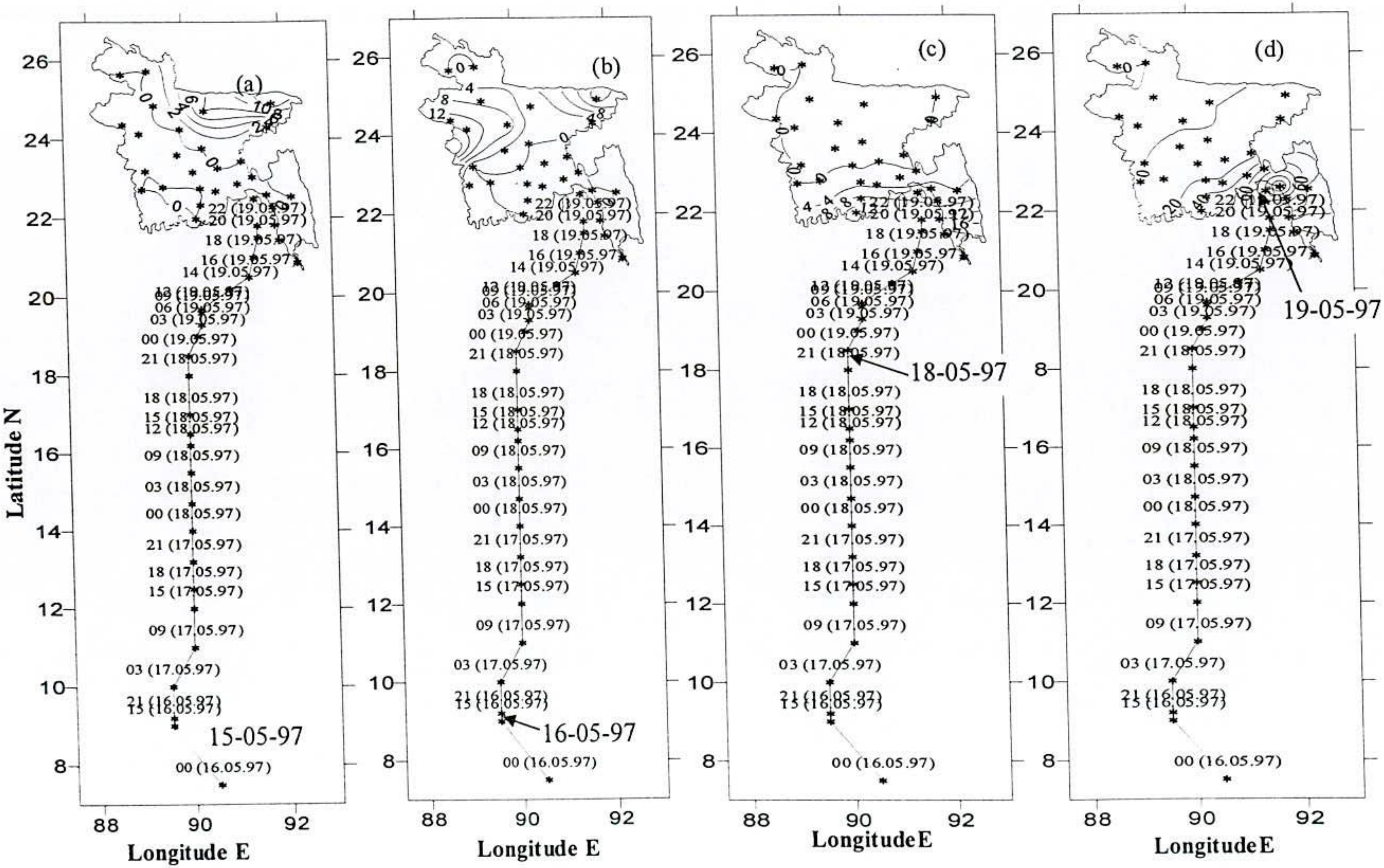

Figure 4.1.2 (a-d) : Rainfall distribution over Bangladesh during May 15,16,18,19, 1997 due to SCS(H) of 15-19 May 1997, along with its track.

Ishwardi and Tangail regions when the depression transformed into DD and the direction of movement of the cyclone was towards north. On 3rd day there was no rain in Bangladesh though the system transformed into SCS and the direction of movement of the cyclone was towards north. On 4th day moderately heavy rainfall occurred at Teknaf and moderate rain occurred at Cox's Bazaar and light rain occurred at Kutubdia, Khepupara, Sitakundu, Sandwip regions and the direction of the movement of the cyclone was towards north. On 5th day cyclone crossed in the Sitakundu coast and very heavy rainfall occurred at Sitakundu, Sandwip regions and heavy rainfall occurred at Teknaf, Cox's Bazaar, Khepupara, Chittagong, Feni regions and moderately heavy rainfall occurred at Kutubdia, Rangamati, Patuakhali, Maijdi Court, Bhola regions and moderate rainfall occurred at Barisal, Srimongal and light rainfall occurred at Chandpur, Madaripur and Comilla regions.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 149mm, which is the maximum one for this event, is observed on May 19 at Sitakundu.

4.1.3 Rainfall distribution and Movement of Cyclone of 17 May 1998

Fig 4.1.3 (a-d) represents the track of the cyclone that formed in the Bay of Bengal on 17th May 1998 and crossed the Bangladesh coast and the rainfall distribution over Bangladesh during 17 to 20 May of 1998.

At 12 BST of 17 May the system was first traced as depression and located in the south west Bay of Bengal with centered at 13^0N 85^0E. Form 12 BST of 17 May to 06 BST of 18 May the system moved in the east- north east direction without any change in its intensity and its centre arrived at 14.5^0N, 88.5^0E. In the next 12 hours its intensity remained the same and it further moved towards north with centered at 15.5^0N, 88.5^0E. In the next 6 hours i.e. by 00BST of 19 May it moved towards north east and its centre was located at 16.5^0N, 89.5^0E. Within this period further intensification took place and the system became DD. In the next 9 hours i.e. 09 BST of 9 May further intensification took place and it moved towards north-north east. In the next 2 hours the system again intensified further and became SCS and the direction of movement of the cyclone towards North east and its location was 19.8^0N, 90.5^0E. In the next 7 hours the system moved towards North and its location was at 20.5^0N, 90.5^0E. Within this period further

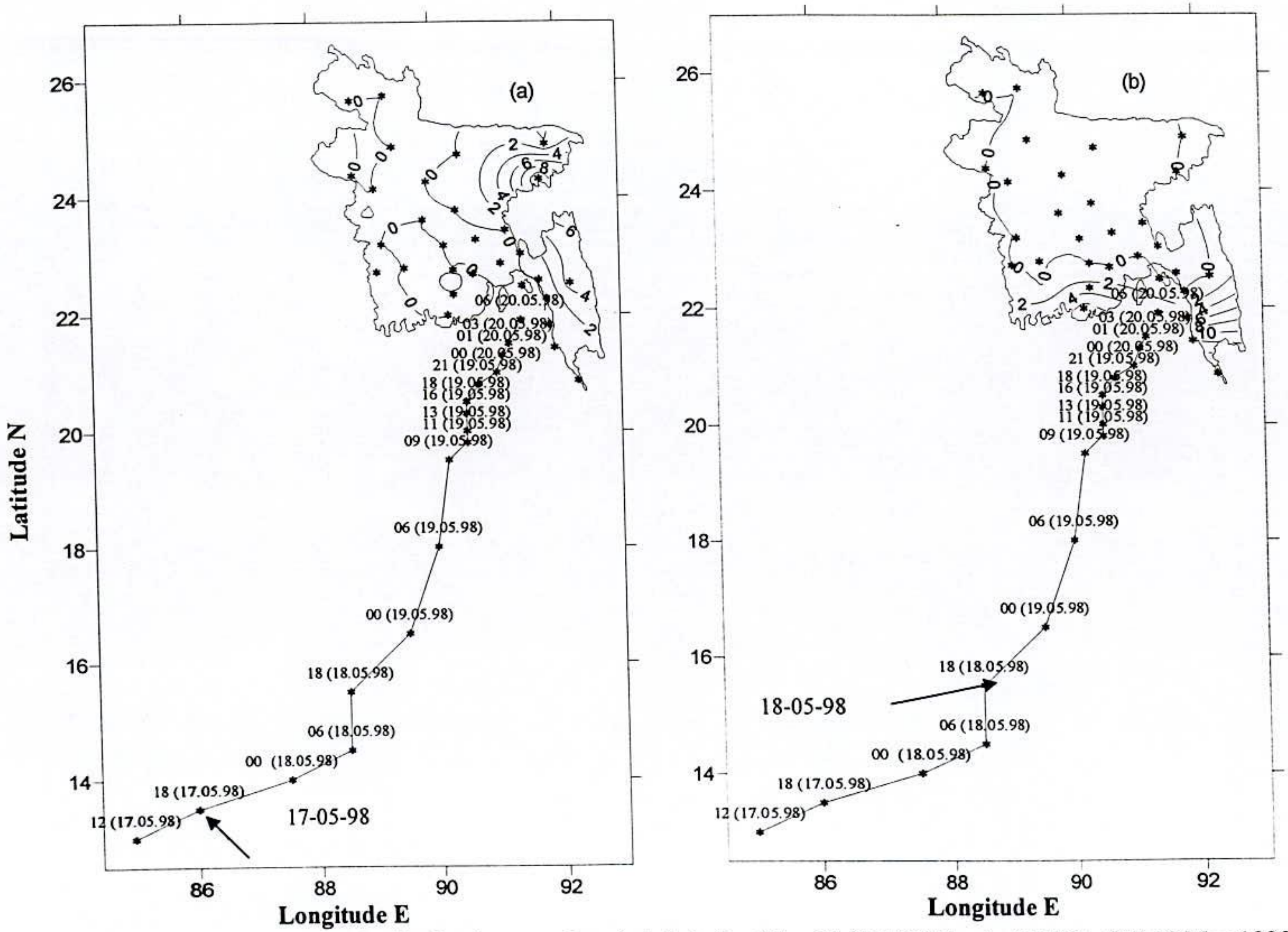

Figure 4.1.3 (a-b) : Rainfall distribution over Bangladesh during May 17-18,1998 due to SCS(H) of 17-20 May 1998, along with its track.

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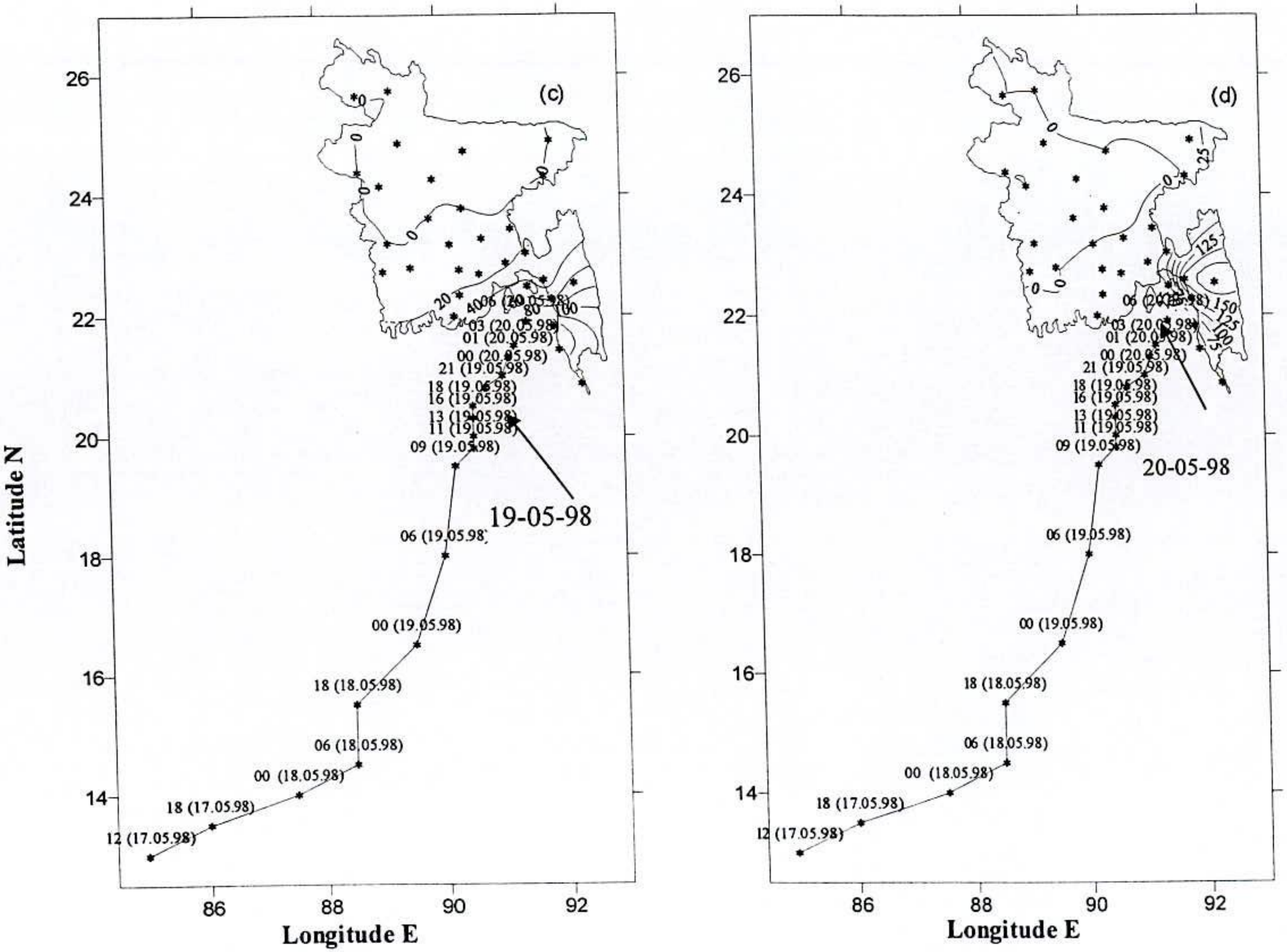

Figure 4.1.3 (c-d) : Rainfall distribution over Bangladesh during May 19-20,1998 due to SCS(H) of 17-20 May 1998, along with its track.

intensification took place and the system became SCS (H). In the next 6 hours its intensity remained the same and it further moved towards north east. From 00 BST of 20 May to 06 BST of 20 May the system moved the north- north easterly direction without any change in its intensity and its centre arrived at 21.9^0N, 91.4^0E. At 08 BST of 20 May it crossed the Sitakundu cost.

Moderate rainfall occurred at Srimongal on 1st day when depression formed in the Bay of Bengal at 13^0N, 85^0E and the direction of movement of the cyclone was towards east northeast. On 2nd day moderate rainfall occurred at Cox's Bazaar, Teknaf regions and light rain occurred at Khepupara and the direction of movement of the cyclone was towards north. On 3rd day very heavy rainfall occurred at Kutubdia, Cox's Bazaar, Teknaf regions and heavy rainfall occurred at Sandwip, Rangamati, Chittagong regions at moderately heavy rainfall occurred at Feni, Sitakundu, Khepupara regions and moderate rainfall occurred at Satkhira, Khulna, Bhola, Maijdi Court, Patuakhali regions when the depression transformed into SCS and the direction of movement of the cyclone was North east. On 4th day cyclone crossed in the Sitakundu coast and very heavy rainfall occurred at Sitakundu, Rangamati, Chittagong, Teknaf, regions and heavy rainfall occurred at Kutubdia and moderately heavy rainfall occurred at Feni, Cox's Bazaar regions.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 204mm, which is the maximum one for this event, is observed on May 20 at Rangamati.

4.1.4 Rainfall distribution and Movement of Cyclone of 17 November 1992

Fig 4.1.4 (a-c) represents the track of the cyclone that formed in the Bay of Bengal on 17 November 1992 and crossed Teknaf – Mayanmar coast on 21st November and the rainfall distribution over Bangladesh during 17 to 21 November 1992.

At 09 BST of 17 November the system was first traced as depression and was located in the central Bay of Bengal with centered at 9.5^0N, 92.5^0E. In the next 21 hours it moved towards west and intensified to CS. From 06 BST of 18 November to 06 BST of 19 November the system moved towards north-north west direction and its centre arrived at 16^0N, 86^0E. Within this period further intensification took place and the system became SCS (H). From 06 BST of 19 November to 15 BST of 20 November the system moved towards north easterly direction without any change in its intensity and its centre reached

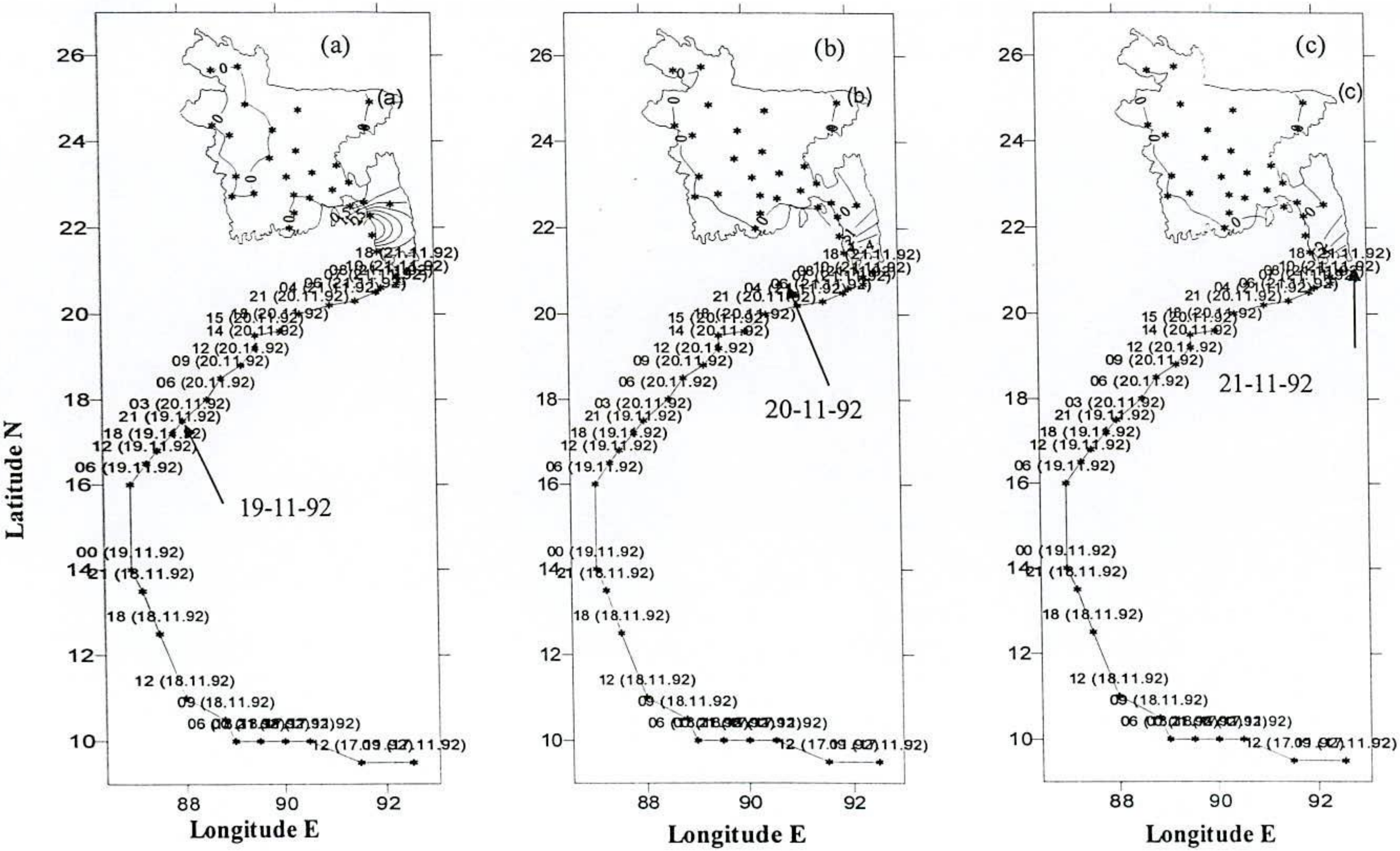

Figure 4.1.4 (a-c) : Rainfall distribution over Bangladesh during November 19-21,1992 due to SCS(H) of 17-21 November 1992, along with its track.

at 19.5^{0}N, 89.5^{0}E. In the next 3 hours its intensity remained the same and it further moved towards north east. From 21 BST of 20 November to 10 BST of 21 November the system moved towards north east and its centre arrived at 20.7^{0}N, 92.3^{0}E. Within this period the system weakened and at 18 BST of 21 November it crossed Teknaf- Mayanmar coast as depression.

There was no rain in Bangladesh on1st and 2nd day when depression formed in the Bay of Bengal and transformed into SCS (H). On 3rd day i.e. 19 November 1992 light rainfall occurred at Kutubdia, Cox Bazaar, Chittagong, Rangamati regions and the direction of movement of the cyclone was towards north-north east. On 4th day (20.11.92) light rainfall occurred at Teknaf, Cox's Bazaar regions and the direction of movement of the cyclone was the same as that of the previous day. On 5th day (21.11.92) the cyclone crossed the Teknaf-Mayanmer coast as DD and moderate rainfall occurred at Teknaf.

Light rainfall is observed in the front and moderate rainfall observed in the left side of the track. As most of our stations are situated on the left of the system, so they have not recorded that much rain. A rainfall amounting 15mm, which is the maximum one for this event, is observed on November 21 at Teknaf.

4.1.5 Rainfall distribution and Movement of Cyclone of 19 November 1998

Fig 4.1.5 (a-b) represents the track of the cyclone that formed in the Bay of Bengal on 19 November 1998 and crossed the Bangladesh coast on 22 November 1998 and the rainfall distribution over Bangladesh during 21 to 22 November 1998.

At 12 BST of 19 November the system was first detected as depression and located in the south east Bay of Bengal with centered at 12^{0}N, 92^{0}E. In the next 12 hours it moved towards north-west and intensified to deep depression. In the next 6 hours it moved towards north north-west with the same intensity and was located at 14.5N, 89^{0}E. In the next twelve hours the system moved towards north-northwest and centered at 16^{0}N, 87.5^{0}E. Within this period further intensification took place and the system became cyclonic storm (CS). From 18 BST of 20 November to 06 BST of 22 November the system moved towards North and its centre reached at 20^{0}N, 87.5^{0}E. Within this period further intensification took place and the system became SCS (H). In the next 9 hours it further moved towards north east and at 15 BST of 22 November it weakened and crossed the Sundarban coast as CS.

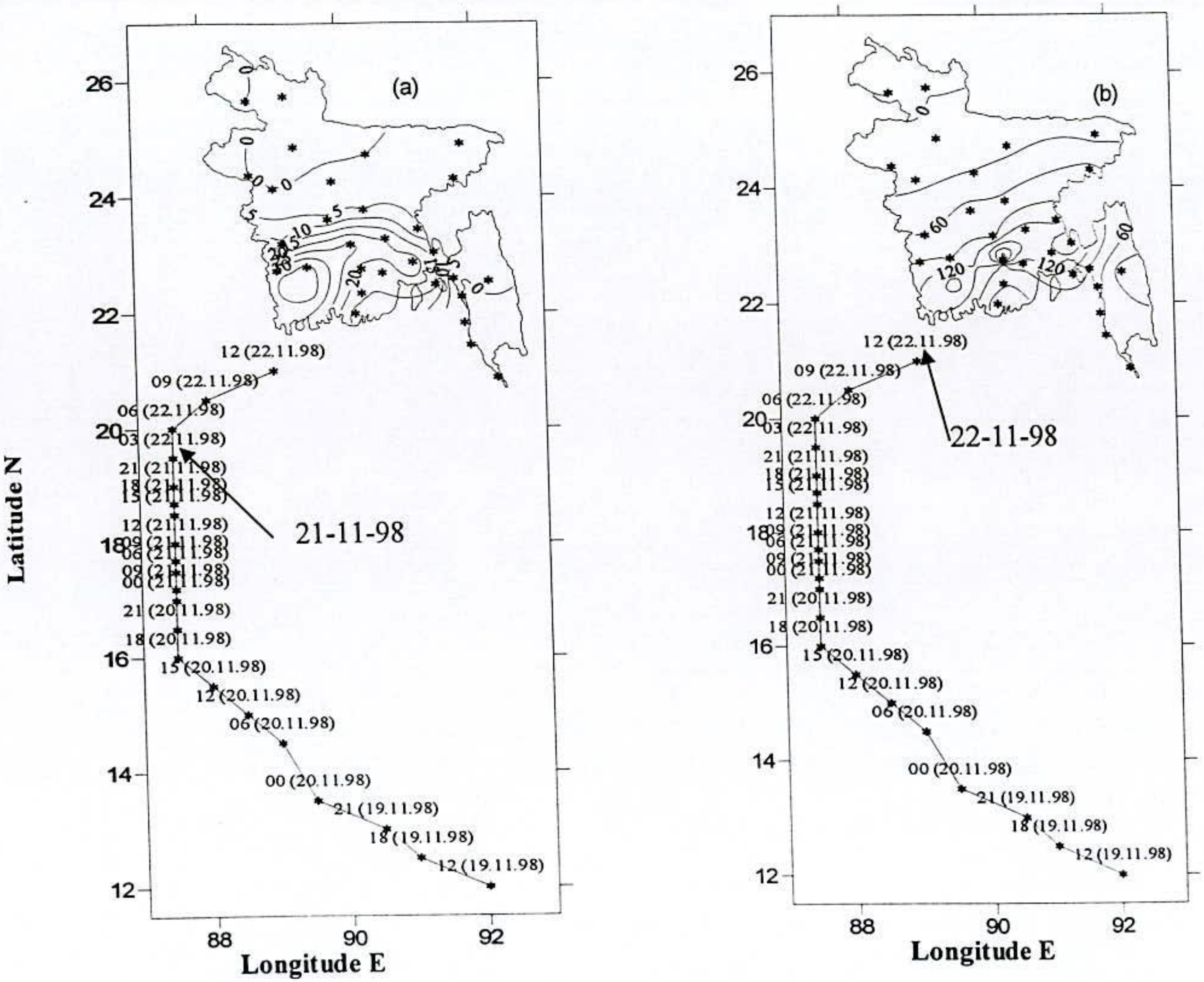

Figure 4.1.5 (a-b) : Rainfall distribution over Bangladesh during November 21-22,1998 due to SCS(H) of 19-22 November 1998, along with its track.

There was no rain in Bangladesh on1st and 2nd day when depression formed and moved towards northwest in the Bay of Bengal and transformed into CS. On 3rd day moderately heavy rainfall occurred at Madaripur, Satkhira, Khulna, Maijdi Court, Mongla and moderate rain occurred at Jessore, Chandpur, Feni, Barisal, Bhola, Patuakhali, Khepupara regions and the direction of movement of the cyclone was towards North. On the 4th day cyclone crossed the Sundarban coast and very heavy rainfall occurred at Comilla, Chandpur, Feni, Satkhira, Barisal, Bhola, Maijdi Court, Mongla, Sandwip and heavy rainfall occurred at Srimongal, Dhaka, Faridpur, Jessore, Madaripur, Khulna, Patuakhali, Sitakundu, Chittagong, Kutubdia, Cox's Bazaar, Teknaf regions and moderately heavy rainfall occurred at Tangail, Chuadanga, Khepupara and moderate rainfall occurred Mymensing and Sylhet regions.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 251mm, which is the maximum one for this event, is observed on November 22 at Barisal.

4.1.6 *Rainfall distribution and Movement of Cyclone 21 November 1995*

Fig 4.1.6 (a-e) represents the track of the cyclone that formed in the Bay of Bengal on 21 November 1995 and crossed the Bangladesh coast on 25th November and the rainfall distribution over Bangladesh during 21 and 23 to 25 November of 1995.

At 21 BST of 21 November the system was first detected as depression and located in the central Bay of Bengal with centered at 7.5^{0}N, 90.5^{0}E. In the next 15 hours it moved towards west-northwest and intensified to deep depression and its centre reached at 8.5^{0}N, 89.5^{0}E. From 12 BST of 22 November to 21 BST of 23 November the system moved the north western direction and its centre arrived at 12^{0}N, 85^{0}E. Within this period further intensification took place and the system became SCS. In the next 15 hours the system again intensified further and became SCS (H) and the direction of movement of the cyclone towards north and its location was 15^{0}N, 85^{0}E. In the next 6 hours it further moved towards north-north east. In the next 6 hours the system moved towards North east with the same intensity and its location was 18.5^{0}N, 87.5^{0}E. In the next 6 hours the system moved towards North- North east and its centre arrived at 20^{0}N, 90^{0}E. There after its intensity dropped drastically and at 08 BST of 25 November it crossed near Cox's Bazaar coast.

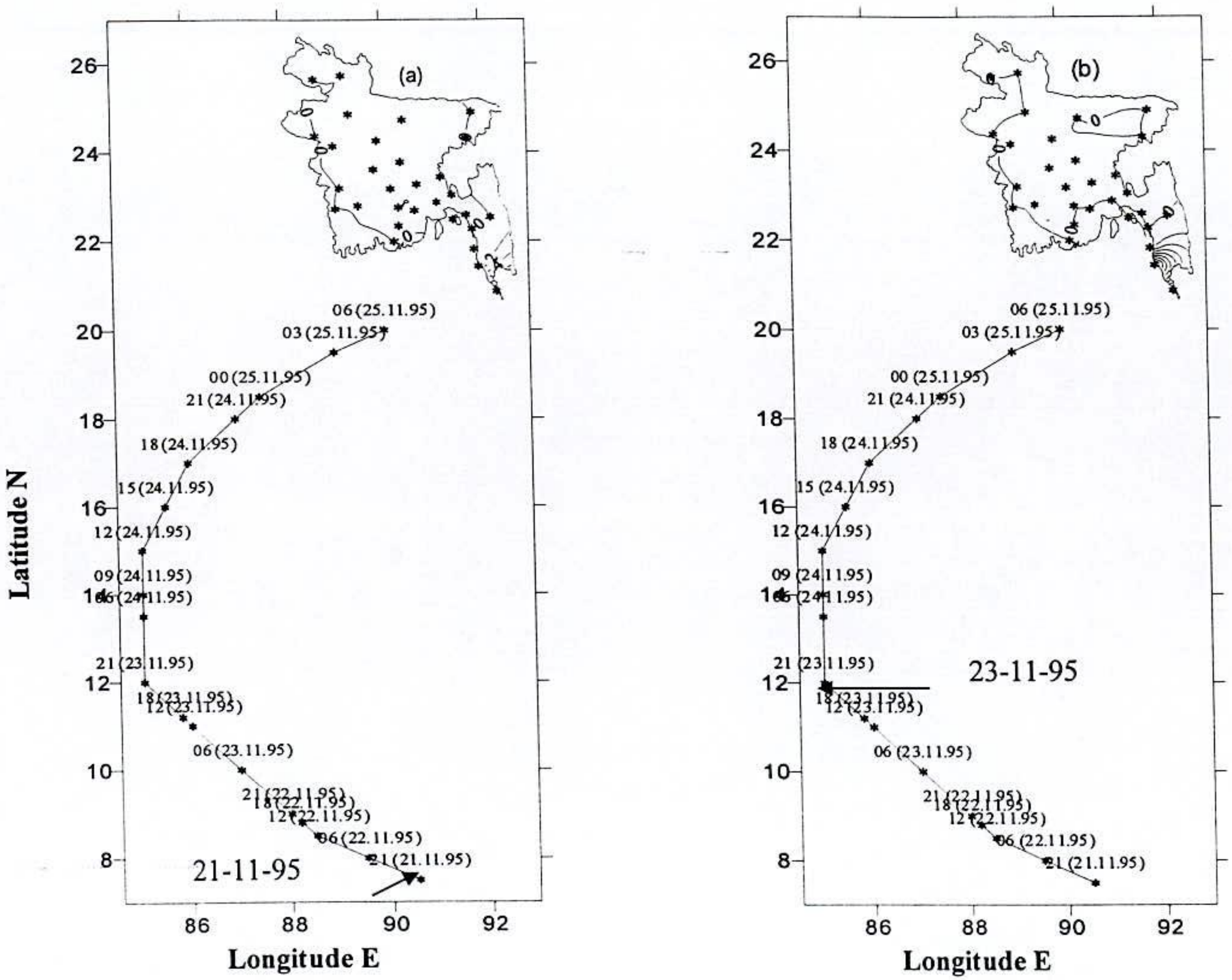

Figure 4.1.6 (a-b) : Rainfall distribution over Bangladesh during November 21,23,1995 due to SCS(H) of 21-25 November 1995, along with its track.

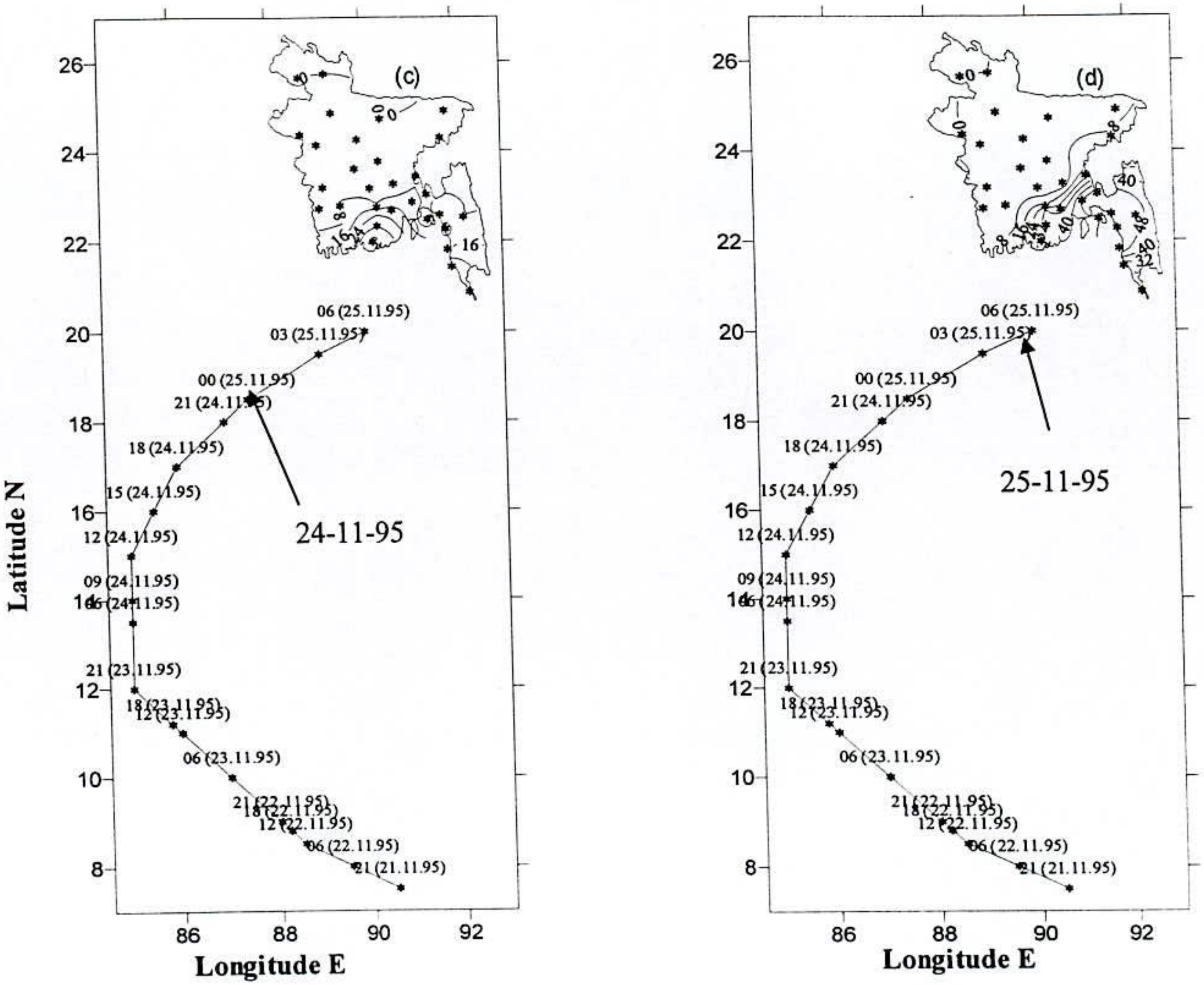

Figure 4.1.6 (c-d) : Rainfall distribution over Bangladesh during November 24-25,1995 due to SCS(H) of 21-25 November 1995, along with its track.

Moderate rainfall occurred on Teknaf at 1st day when depression formed in the Bay of Bengal and the direction of movement was towards west-northwest. On 2nd day there was no rain in Bangladesh though the depression transformed into CS and the direction of movement of the cyclone was towards south west. On 3rd day light rain occurred at Cox's Bazaar region and the system transformed into SCS and its direction is same. On 4th day moderately heavy rainfall occurred at Khepupara, Cox's Bazaar, Teknaf regions and moderate rain occurred at Kutubdia, Chittagong, Sitakundu, Patuakhali, Maijdi Court regions and light rain occurred at Rangamati, Mongla, Barisal, Khulna, Feni, Madaripur, Jessore, Comilla, Tangail regions when the SCS transformed into SCS (H) and the direction of movement of the cyclone was towards northeast. On 5th day SCS(H) weakened and crossed the Cox's Bazaar coast as a depression and heavy rainfall occurred at Feni, Maijdi Court, Sandwip, Sitakundu, Rangamati, Chittagong, Kutubdia regions and moderately heavy rainfall occurred at Bhola, Patuakhali, Khepupara, Cox's Bazaar regions and moderate rain occurred at Comilla, Barisal, Teknaf regions and light rainfall occurred at Mymensing, Srimongal and Dhaka regions.

A rainfall amounting 60mm, which is the maximum one for this event, is observed on November 25 at Sitakundu.

4.1.7 *Rainfall distribution and Movement of Cyclone of 24 November 1988*

Fig 4.1.7 (a-d) represents the track of the cyclone that formed in the Bay of Bengal on 24th November 1988 and crossed the Bangladesh Coast on 29th November and the rainfall distribution over Bangladesh during 27 to 30 November of 1988.

At 09 BST of 24 November the system was first detected as depression and located in the south east Bay of Bengal with centered at 10^0N, 93^0E. In the next 9 hours it moved towards north with the same intensity. From 18 BST of 24 November to 12 BST of 25 November the system moved northwest direction and its centre arrived at 12^0N, 92^0E. Within this period further intensification took place and the system became CS. In the next 15 hours it moved towards northwest and intensified to SCS and its centre arrived at 12.8^0N, 90.5^0E. Form 03 BST of 26 November to 12 BST of 27 November the system moved towards west-northwest direction and its centre arrived at 14^0N, 86.5^0E. Within this period further intensification took place and the system became SCS (H). In the next 9 hours it moved towards north with the same intensity. In the next 12 hours the system

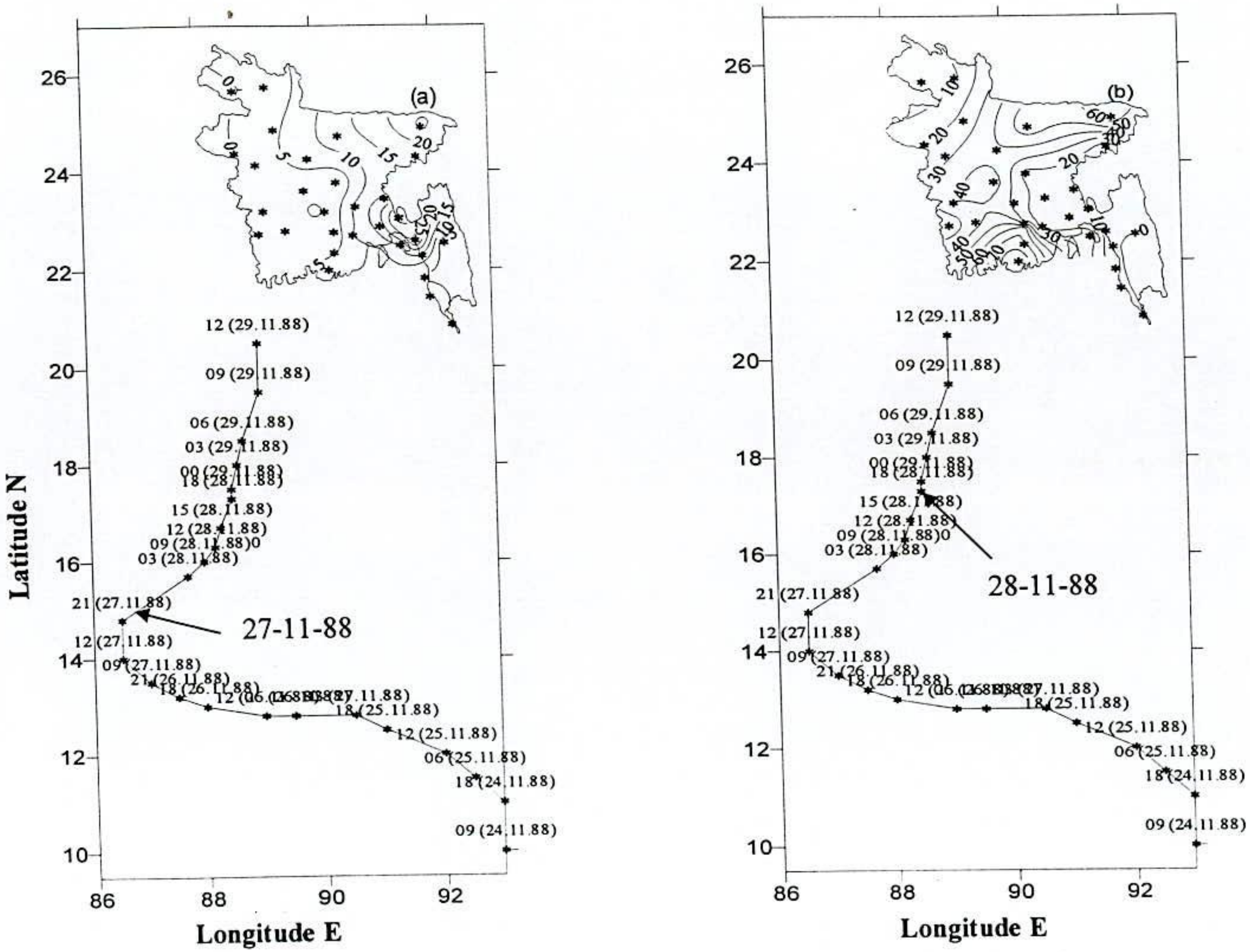

Figure 4.1.7 (a-b) : Rainfall distribution over Bangladesh during November 27-28,1988 due to SCS(H) of 24-30 November 1988, along with its track.

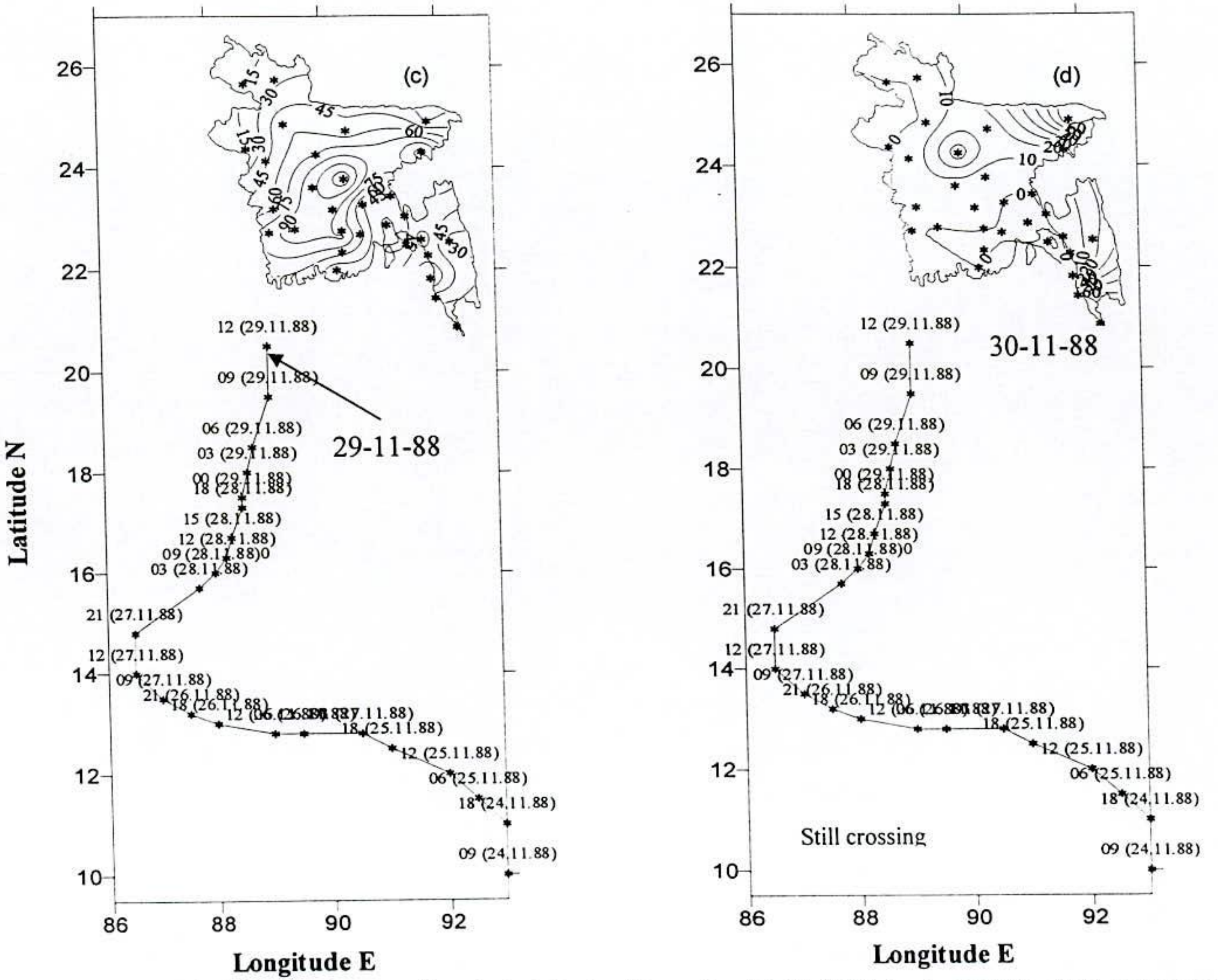

Figure 4.1.7 (c-d) : Rainfall distribution over Bangladesh during November 29-30,1988 due to SCS(H) of 24-30 November 1988, along with its track.

moved towards north easterly direction without any change in its direction and its centre arrived at 16^0N, 88^0E. From 09 BST of 28 November to 09 BST of 29 November, the system moved towards north-north easterly direction without change in its intensity and its centre arrived at 19.5^0N, 89^0E. In the next 3 hours it moved towards north with the same intensity and its centre arrived at 20.5^0N, 89^0E. At 18 BST of 29 November the periphery of the cyclone hit the Khulna coast near Raimongle.

There was no rain in Bangladesh on 1st and 3rd day when depression formed in the south east Bay of Bengal and transformed into SCS(H) and the direction of movement of the cyclone was towards north-north west. On 4th day moderately heavy rainfall occurred at Sylhet, Feni, Sitakundu and moderate rainfall occurred at Chittagong, Sandwip, Hatiya, Maijdi Court, Chandpur, Comilla, Srimongal, Mymensing regions and light rainfall occurred at Cox's Bazaar, Khepupara regions and the direction of movement of the cyclone was towards North. On 5th day very heavy rainfall occurred at Khepupara and heavy rainfall occurred at Patuakhali, Faridpur, Sylhet, Mymensing regions and moderately heavy rainfall occurred at Sandwip, Hatiya, Barisal, Khulna, Madaripur, Jessore, Tangail, Bogra regions and moderate rainfall occurred at Rajshahi, Srimongal, Dhaka, Comilla, Chandpur, Feni, Satkhira, Bhola, Maijdi Court regions and light rainfall occurred at Rangpur, Sitakundu regions and the direction of movement of the cyclone was towards north-north east. On 6th day the system crossed the Khulna coast near Raimongle as SCS (H) and very heavy rainfall occurred at Patuakhali, Khulna, Madaripur, Faridpur, Dhaka, Srimongal regions and heavy rainfall occurred at Bogra, Mymensing, Tangail, Jessore, Chandpur, Satkhira, Barisal, Bhola, Sitakundu, Chittagong, Kutubdia regions and moderately heavy rainfall occurred at Rangpur, Sylhet, Comilla, Feni, Maijdi Court, Hatia, Sandwip, Rangamati, Khepupara, Cox's Bazaar regions and moderate rainfall occurred at Dinajpur, Teknaf regions and light rainfall occurred at Rajshahi. On 7th day the system still crossing and the heavy rainfall occurred at Sylhet, Cox's Bazaar, Teknaf regions and moderately heavy rainfall occurred at Tangail and moderate rainfall occurred at Mymensing, Srimongal, Rangamati regions.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 135mm, which is the maximum one for this event, is observed on November 29 at Dhaka.

4.1.8 Rainfall distribution and Movement of Cyclone of 25 April 1991

Fig 4.1.8(a-d) represents the track of the cyclone that formed in the Bay of Bengal on 25th April 1991 and crossed the Bangladesh coast on 29th April 1991 and the rainfall distribution over Bangladesh during 25 to 29 April of 1991.

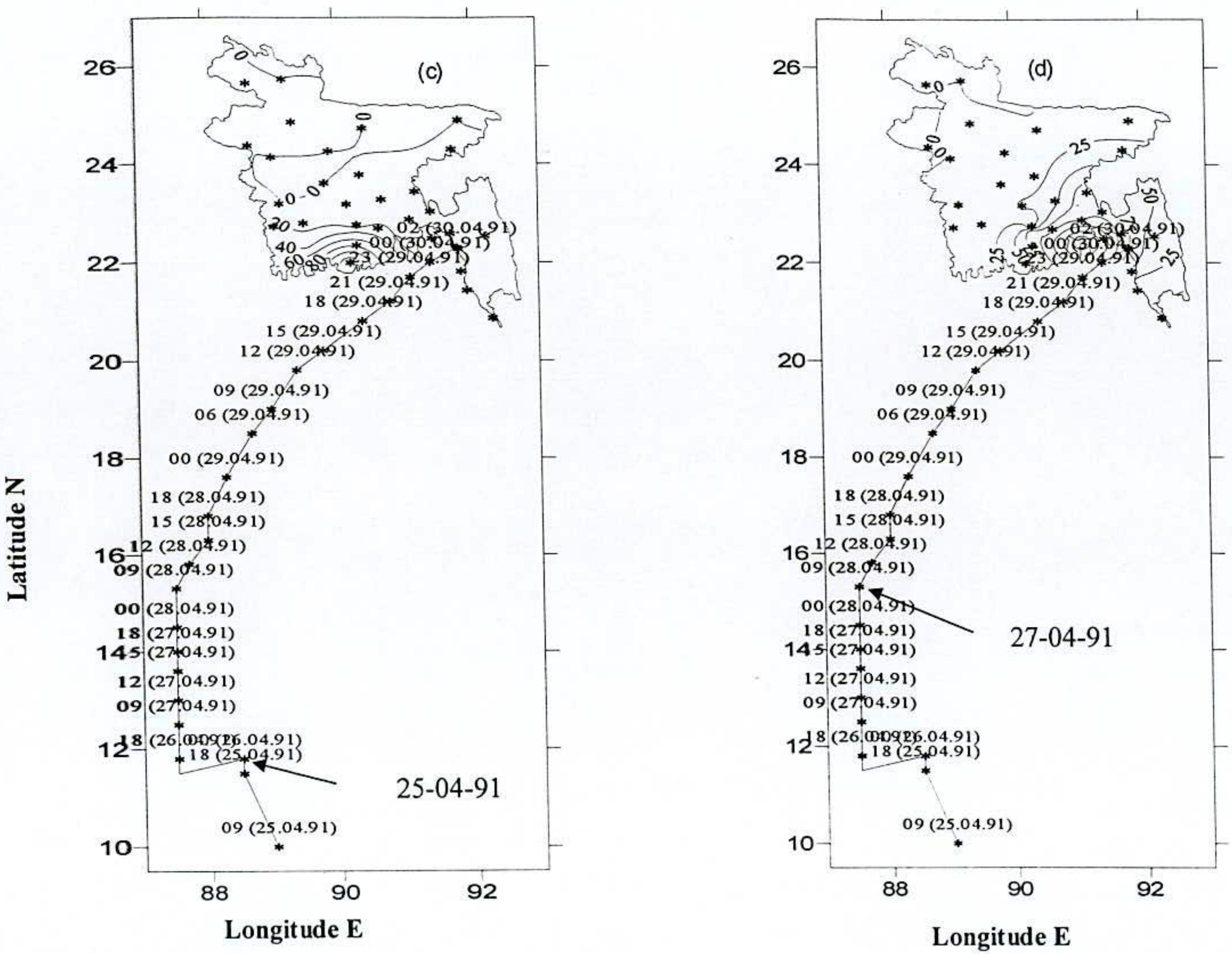

Figure 4.1.8 (c-d) : Rainfall distribution over Bangladesh during April 28-29,1991 due to SCS(H) of 25-29 April 1991, along with its track.

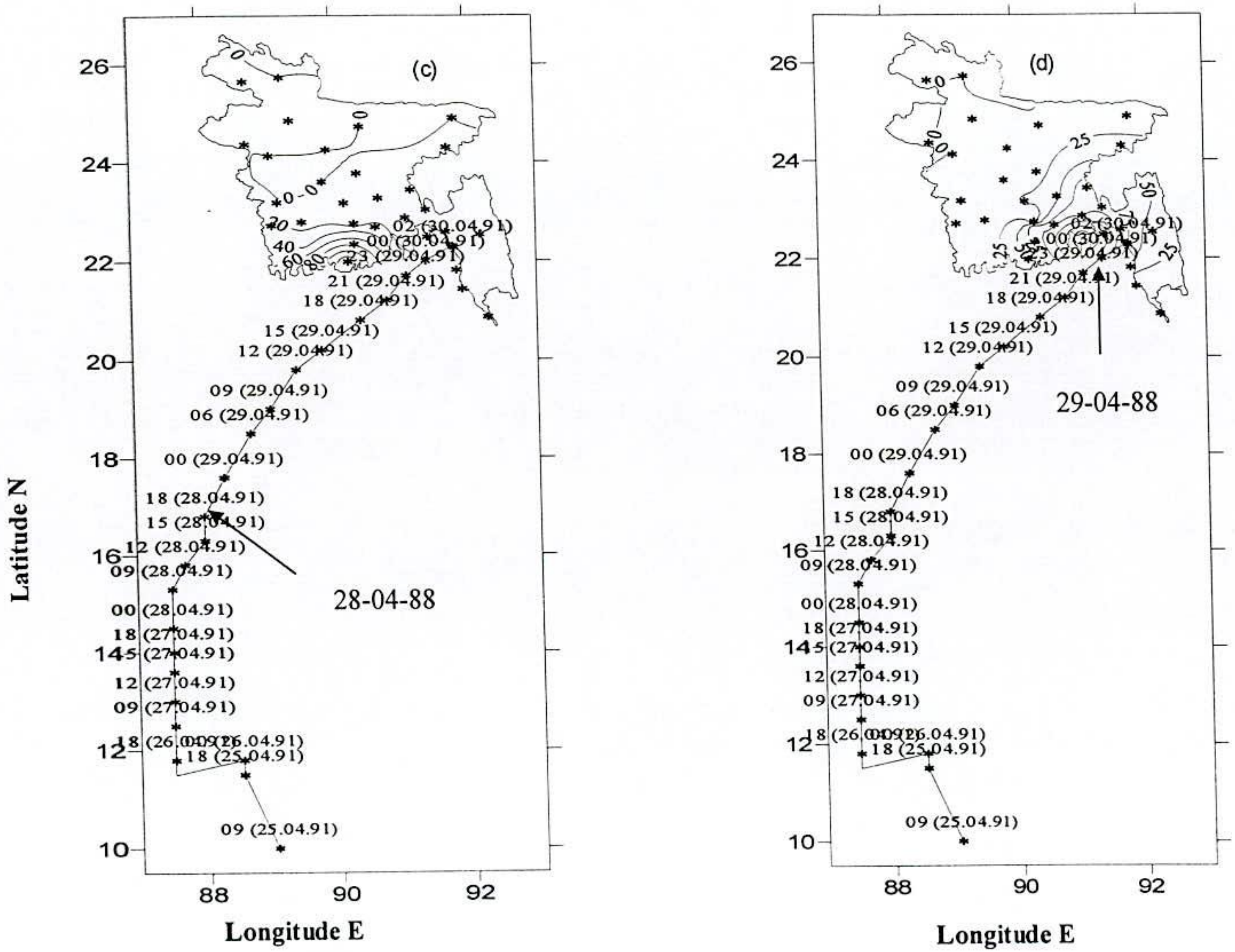

Figure 4.1.8 (c-d) : Rainfall distribution over Bangladesh during April 28-29,1991 due to SCS(H) of 25-29 April 1991, along with its track.

At 18 BST of 25 April the system was at depression and located at 11.5^0N, 88.5^0E though it was traced 9 hours before and was located at 10^0N, 89^0E and it moved towards north-north west. In the next 6 hours the system intensified further and became CS and its direction of movement towards north. From 18 BST of 26 April to 09 BST of 28 April the system moved towards northerly direction and its centre arrived at 15.3^0N, 87.5^0E. Within this period further intensification took place and the system became SCS (H). In the next 3 hours its intensity remained the same and further moved towards north – north easterly direction. In the next 3 hours it moved towards north with the same intensity and centered at 16.3^0N, 87.7^0E. From 18 BST of 28 April to 12 BST of 29 April the system moved in the north-north easterly direction without any change in its intensity and its centre arrived at 19.8^0N, 89.4^0E. In the next 16 hours its intensity remained the same and it further moved towards North east direction and crossed the Chittagong-Cox's Bazaar coast on 04 BST of April 30, 1991.

Moderate rainfall occurred at Faridpur on 1^{st} day when depression formed in the Bay of Bengal at 10^0N, 89^0E and the direction of movement was towards north-northwest. On 2^{nd} day there was no rain in Bangladesh though the depression transformed into CS and the direction of movement of the cyclone was towards north. On 3^{rd} day light rainfall occurred at Rangpur and very light rainfall occurred at Dinajpur, Kutubdia, Cox's Bazaar regions when the CS transformed into SCS in the Bay and the direction of movement the cyclone was towards north–northeast. On 4^{th} day very heavy rainfall occurred at Khepupara and moderately heavy rainfall occurred at Patuakhali, Mongla, Bhola, Satkhira regions and moderate rainfall occurred at Rangamati, Teknaf, Khulna and light rainfall occurred at Maijdi Court, Chandpur, Madaripur, Bogra regions and light rainfall occurred at Dinajpur Dhaka, Comilla, Jessore, Feni, Hatiya, Kutubdia, Cox's Bazaar when the SCS transformed into SCS (H) and direction of movement of the cyclone was towards north-north east. On 5^{th} day i.e. 29 April the system crossed the Chittagong Cox`s Bazaar coast as SCS(H) and very heavy rainfall occurred at Patuakhali, Sitakundu, Hatiya, Maijdi Court, Bhola, Feni, Comilla regions and heavy rainfall occurred at Teknaf and moderately heavy rainfall occurred at Khepupara, Rangamati, Chandpur, Madaripur regions and moderate rainfall occurred at Sylhet, Tangail, Srimongal, Mongla, Dhaka regions and light rainfall occurred at Faridpur, Jessore, Khulna regions and the direction of movement of the cyclone was towards north east and its intensity remained the same.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 205mm, which is the maximum one for this event, is observed on April 29 at Hatiya.

4.2 Track and Rainfall distribution due to SCS

4.2.1 Rainfall distribution and Movement of Cyclone of 9 May 1977

Fig 4.2.1 (a- e) represents the track of the cyclone that formed in the Bay of Bengal on 9th May 1977 and crossed the Bangladesh coast on 13th May and the rainfall distribution over Bangladesh during 09 to 13 May of 1997.

At 09 BST of 9 May the system was depression and located in the south central Bay of Bengal with centered at 11^0N, 83^0E. In the next 39 hours it moved towards north with the same intensity and located at 12^0N, 83^0E. At 09 BST of May 11 it was centered at 14.5^0N, 86.5^0E and its direction of movement towards north-north east. Within this period further intensification took place and the system became CS. In the next 21 hours i.e. by 06 BST of May 12 no further intensification took place. But during the next 6 hours the system again intensified further and became SCS, though its direction of movement remained same. From 12 BST of May 12 to 00 BST of May 13 the system moved northerly direction without any change in its intensity and its centre arrived at 22^0N, 90.5^0E. Thereafter its intensity dropped drastically and at 06 BST of May 13 it crossed near Tetulia River.

Moderately heavy rainfall occurred at Ishwardi and moderate rainfall occurred at Rajshahi on 1st day when depression formed in the south central Bay of Bengal and it remained stationary there till 00 BST of 11 May. On 2nd day light rainfall occurred at Dhaka and Hatiya and the direction of movement of the cyclone was towards north. On 3rd day heavy rainfall occurred at Jessore, Patuakhali, Hatiya, Khepupara and moderately heavy rainfall occurred at Comilla, Feni, Barisal regions when the depression transformed into CS and the direction of movement of the cyclone was north-north easterly. On 4th day CS transformed into SCS and very heavy rainfall occurred at Madaripur, Patuakhali, Hatiya, Sandwip, Khepupara and heavy rainfall occurred at Mymensing, Ishwardi, Comilla, Jessore, Feni, Khulna, Chittagong, Cox's Bazaar regions and moderately heavy rainfall occurred at Dhaka, Faridpur regions and the direction of movement of the cyclone was towards North. On 5th day cyclone crossed near Tetulia River as a depression and very

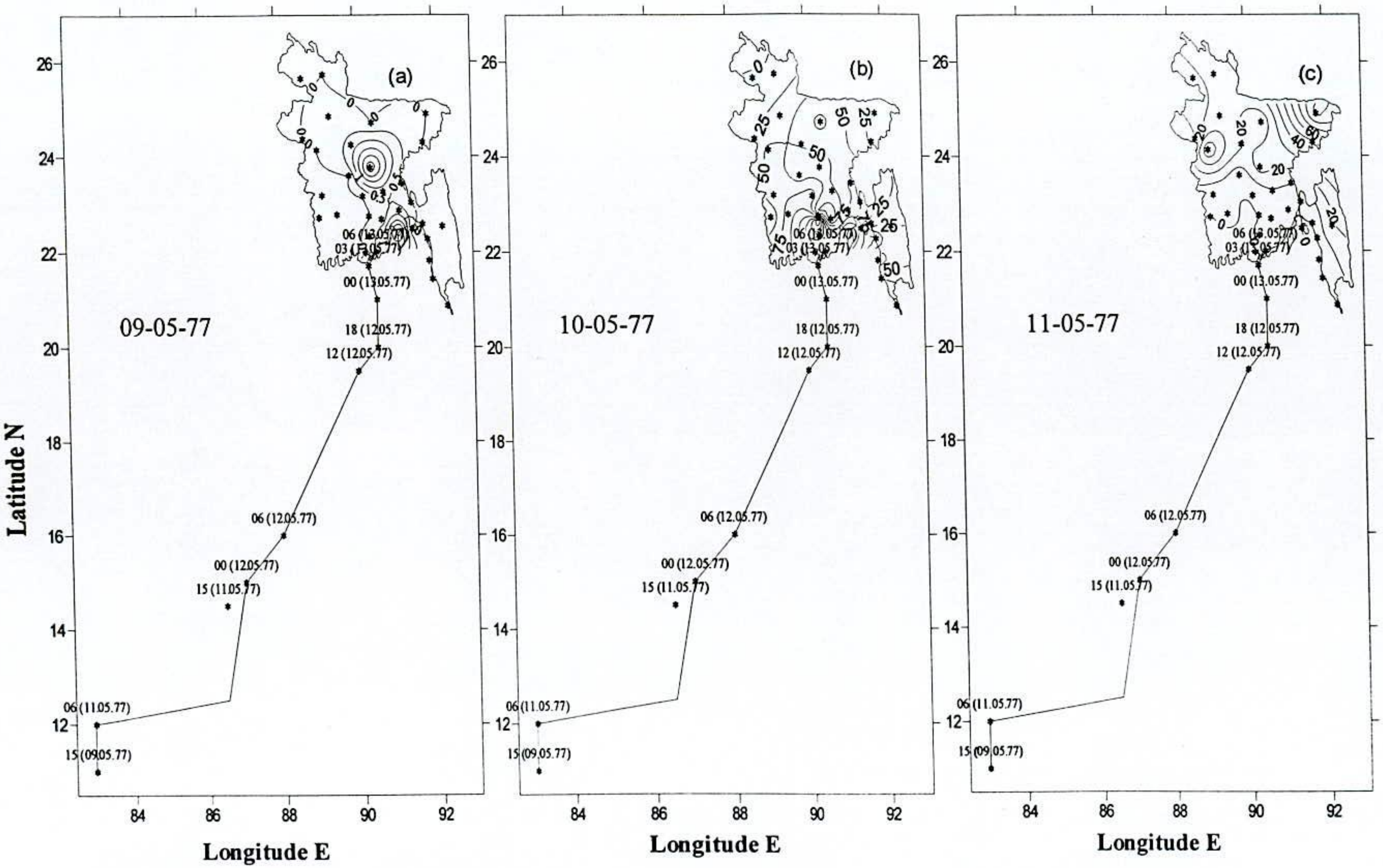

Figure 4.2.1 (a-c) : Rainfall distribution over Bangladesh during May 9-11, 1977 due to SCS of 9-13 May 1977, along with its track.

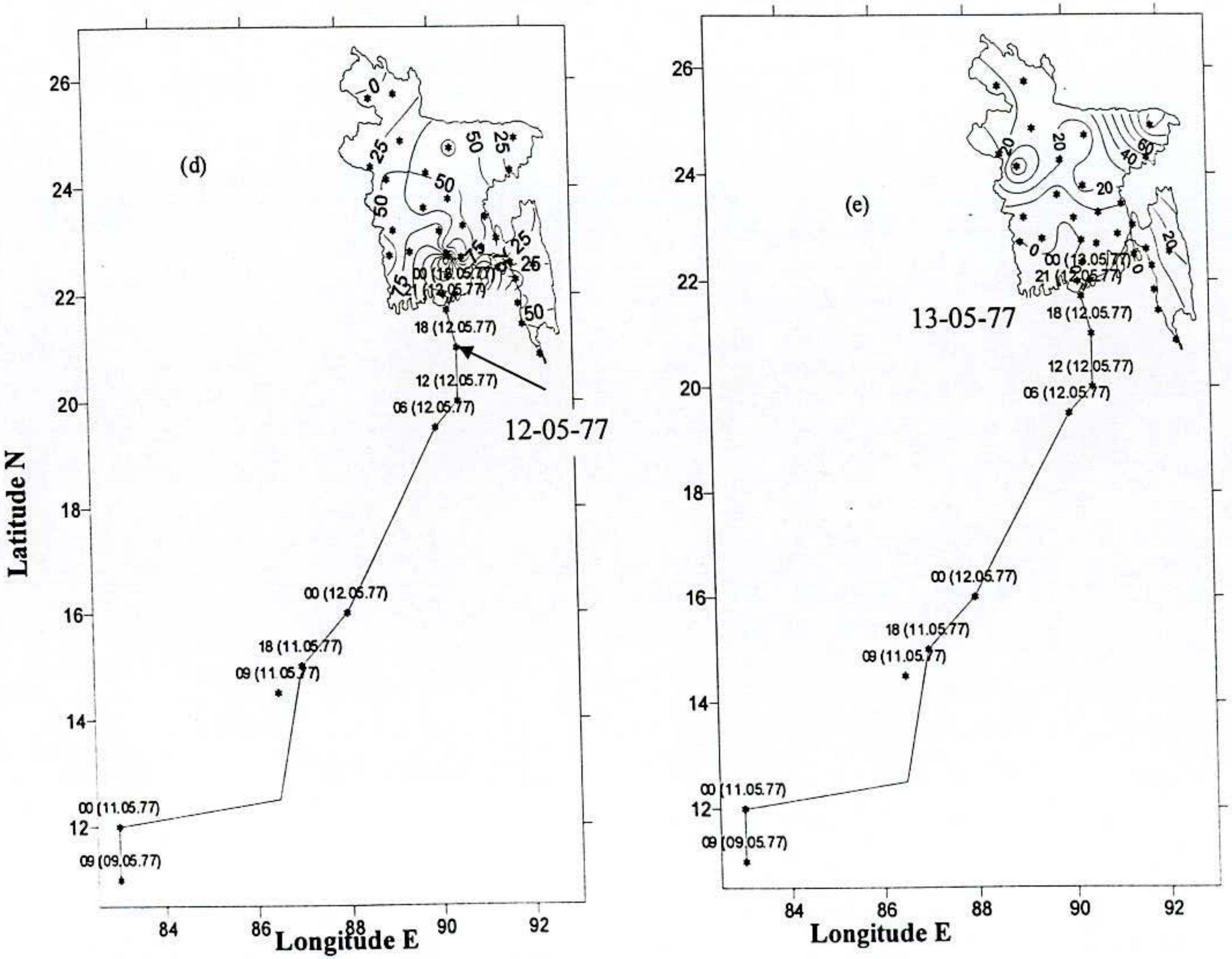

Figure 4.2.1 (d-e) : Rainfall distribution over Bangladesh during May 12-13, 1977 due to SCS of 9-13 May 1977, along with its track.

heavy rainfall occurred at Sylhet and heavy rainfall occurred at Ishwardi, Srimongal and moderately heavy rainfall occurred at Rangpur and Dhaka regions.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 238mm, which is the maximum one for this event, is observed on May 12 at Patuakhali.

4.2.2 Rainfall distribution and Movement of Cyclone of 16 December 1990

Fig 4.2.2 (a-c) represents the track of the cyclone that formed in the Bay of Bengal on 16^{th} December 1990 and crossed the Cox's Bazaar coast on 18^{th} December and the rainfall distribution over Bangladesh during 16 to 18 December of 1990.

At 09 BST of December 16 the system was first detected as depression and was located in the south central Bay of Bengal with centred at 11^0N. 85.5^0E. From 09 BST of December 16 to 06 BST of December 17 the system moved towards north and located at 15.5^0N. 85.5^0E. Within this period further intensification took please and the system became CS. In the next 9 hours the system moved towards north east and intensified to SCS. In the next 3 hours it moved towards north with the same intensity. From 18 BST of December 18 to 09 BST of December 18 the system moved in the north easterly direction without any change in its intensity and its centre was located at 21.5^0N, 91.5^0E. AT 12 BST of December 18 it crossed the near Naikhongchori cost as SCS.

Light rainfall occurred at Teknaf on 1^{st} day when depression formed in the south central Bay of Bengal at 11^0N, 85.5^0E and the direction of movement of the cyclone was towards north. On 2^{nd} day moderate rainfall occurred at Cox's Bazaar, Jessore regions and light rainfall occurred at Teknaf, Kutubdia, Khepupara, Chittagong, Satkhira, Chandpur, Madaripur, Faridpur, Dhaka regions when the depression transformed into SCS with centred at 18^0N, 87.5^0E and the direction of movement of the cyclone was towards north east. On 3^{rd} day cyclone crossed the Naikhongchori coast and heavy rainfall occurred at Rangamati, Sitakundu Sandwip, Hatiya, Maijdi Court, Feni regions and Moderately heavy rainfall occurred at Kutubdia, Khepupara, Chittagong, Patuakhali, Bhola, Barisal, Comilla and moderate rainfall occurred at Chandpur and light rainfall occurred at Teknaf, Cox's Bazaar, Madaripur and Srimongal regions.

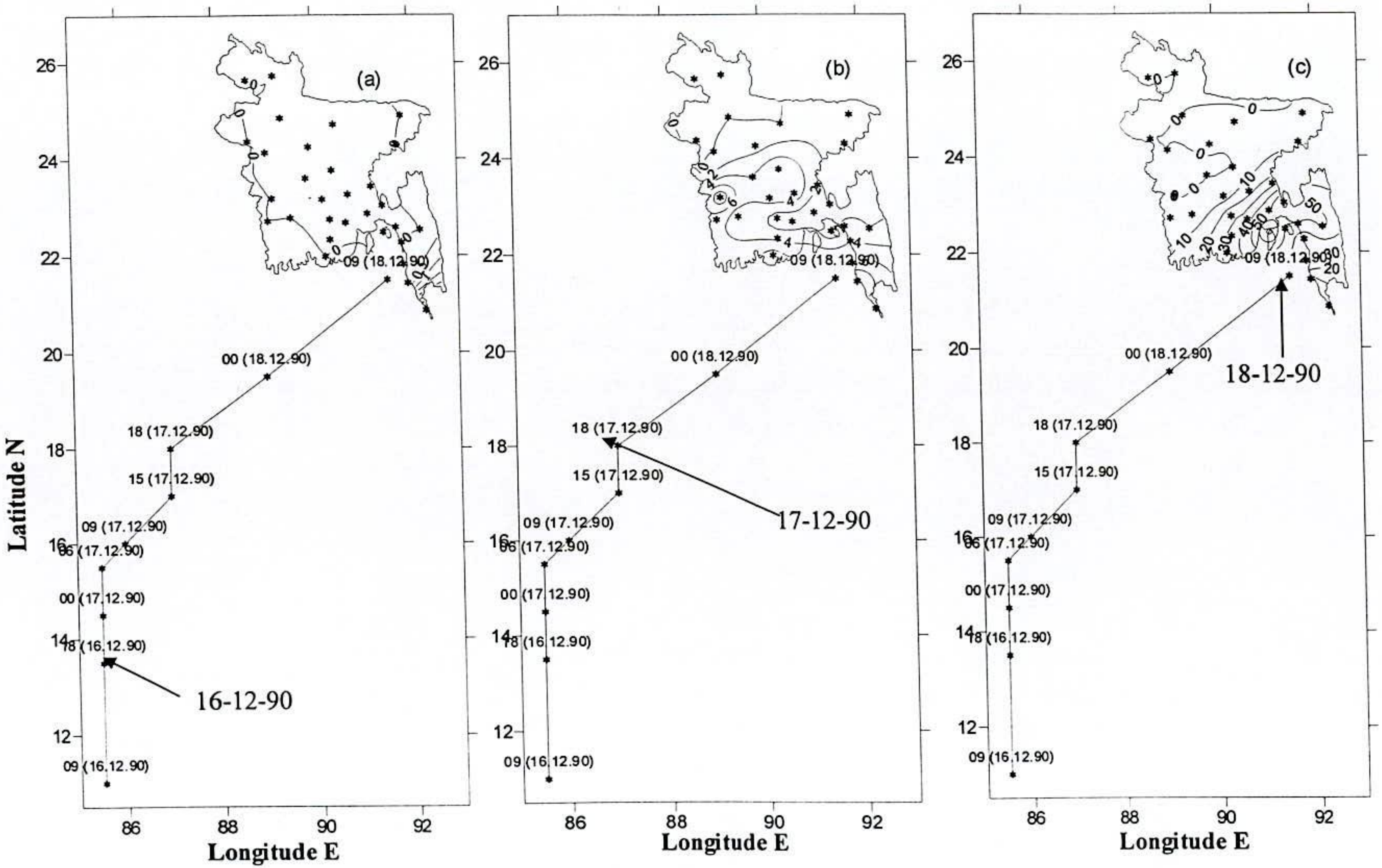

Figure 4.2.2 (a-c) : Rainfall distribution over Bangladesh during December 16-18, 1990 due to SCS of 16-18 December 1990, along with its track.

Heavy and very heavy rainfall is observed in the front and left side of the track. A rainfall amounting 75mm, which is the maximum one for this event, is observed on December 18 at Hatiya.

4.3 Track and Rainfall distribution due to CS

4.3.1 Rainfall distribution and Movement of Cyclone of 5 June 1975

Fig 4.3.1 (a-c) represents the rainfall distribution over Bangladesh along with the tracks due to the depression formed in the Bay of Bengal and was crossing along Chittagong coast during 5-7 June 1975.

At 18 BST of 5 June the system was at deep depression and located at 19^0N, 92^0E, though it was traced 9 hours back as depression and it moved towards north-north east. In the next 6 hours i.e. by 00 BST of June 6 no further intensification took place. The system moved towards south-south west and centered at 19.5^0N, 92.5^0E. But during the next 10 hours the system again intensified further and became CS and the direction of movement of the cyclone towards north and its location was 20^0N, 92^0E. From 10 BST of 6 June to 21 BST of 6 June the system moved towards northerly direction without any change in its intensity and its centre arrived at 20.7^0N, 92^0E. In the next 12 hours the system changes its direction and moved northerly direction and crossed the Chittagong coast on 09 BST of June 7.

Moderate rain occurred at Cox's Bazaar, Rangamati and Dhaka on 1st day when depression formed in the Bay of Bengal and the direction of movement of the cyclone was towards north-northeast. On 2nd day very heavy rainfall occurred at Bhola and heavy rainfall occurred at Barisal, Feni and moderately heavy rainfall occurred at Chittagong, Khepupara and Chandpur when the depression transformed into DD and the direction of movement of the cyclone was towards north. On 3rd day i.e. 7th June 1975 the cyclone crossed in the Chittagong coast and very heavy rainfall occurred at Chittagong, Cox's Bazaar, Hatiya, Srimongal and heavy rainfall occurred at Rangamati, Barisal, Feni and Comilla regions.

Heavy and very heavy rainfall is observed in the front and right side of the track.

A rainfall amounting 147mm, which is the maximum one for this event, is observed on June 7 at Cox`s Bazaar.

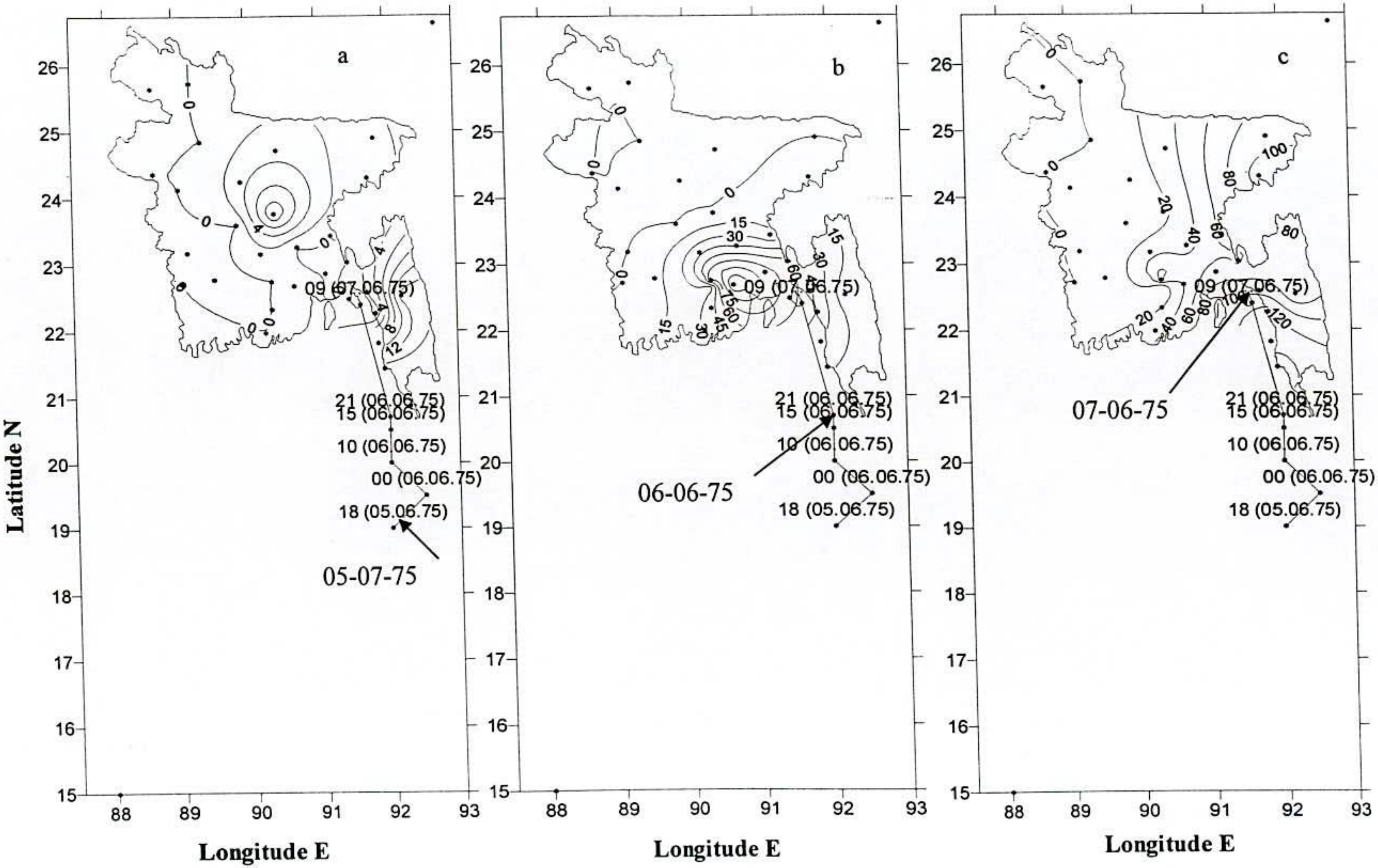

Figure 4.3.1(a-c) : Rainfall distribution over Bangladesh during June 5-7,1975 due to CS of 5-7 June 1975, along with its track.

4.3.2 *Rainfall distribution and Movement of Cyclone of 26 October 1996*

Fig 4.3.2 (a–c) represents the track of the cyclone that formed in the Bay of Bengal and crossed the Bangladesh coast and the rainfall distribution over Bangladesh during 26 to 28 October of 1996.

At 09 BST of 26 October the system was first detected as depression and was located in the central Bay of Bengal with centered at 13.5^0N, 86^0E. In the next 9 hours it moved towards northwesterly direction without any change in its intensity and its centre was located at 14^0N, 85.5^0E. In the next 15 hours again it moved towards west-northwesterly with the same intensity. From 09 BST of 27 October to 00 BST of 28 October the system moved the northerly direction and its centre was located at 16^0N, 84.5^0E. Within this period further intensification took place and the system became DD. In the next 6 hours the system moved towards north-northeast with the same intensity and its centre arrived at 17^0N, 85^0E. In the next 6 hours in the system again intensified further and became CS and the direction of movement towards north east. In the next 09 hours its intensity and direction remained the same. At 00 BST of 29 October it crossed the Sundarban coast.

Heavy rainfall occurred at Rangamati, Khepupara and moderately heavy rainfall occurred at Dhaka, Maijdi Court, Kutubdia regions and moderate rain occurred at Feni, Barisal, Sandwip, Teknaf regions on 1st day when depression formed in the Bay of Bengal at 13.5^0N, 86^0E and the direction of movement of the cyclone was towards northwest. On 2nd day very heavy rainfall occurred at Satkhira, Khulna, Barisal, Bhola, Mongla, Patuakhali, Khepupara regions and heavy rainfall occurred at Jessore, Madaripur, Chandpur, Maijdi Court, Sandwip, Kutubdia, Teknaf regions and moderately heavy rainfall occurred at Rajshahi, Dhaka, Chuadanga, Faridpur, Comilla, Feni, Sitakundu, Chittagong, Cox's Bazaar regions and moderate rainfall occurred at Bogra, Sylhet Ishwardi, Srimongal regions when the depression transformed into DD and the direction of movement was towards north. On 3rd day very heavy rainfall occurred at Bogra, Mymensing, Ishwardi, Tangail, Dhaka, Chuadanga, Faridpur, Jessore, Madaripur, Chandpur, Satkhira, Khulna, Barisal, Maijdi Court, Mongla, Sandwip, Khepupara, Teknaf regions and heavy rainfall occurred at Sylhet, Rajshahi, Srimongal, Comilla, Feni, Patuakhali, Sitakundu, Chittagong, Kutubdia regions and moderately heavy rainfall occurred at Rangpur, Dinajpur, Rangamati, Cox's Bazaar regions when the deep depression transformed in the CS and the

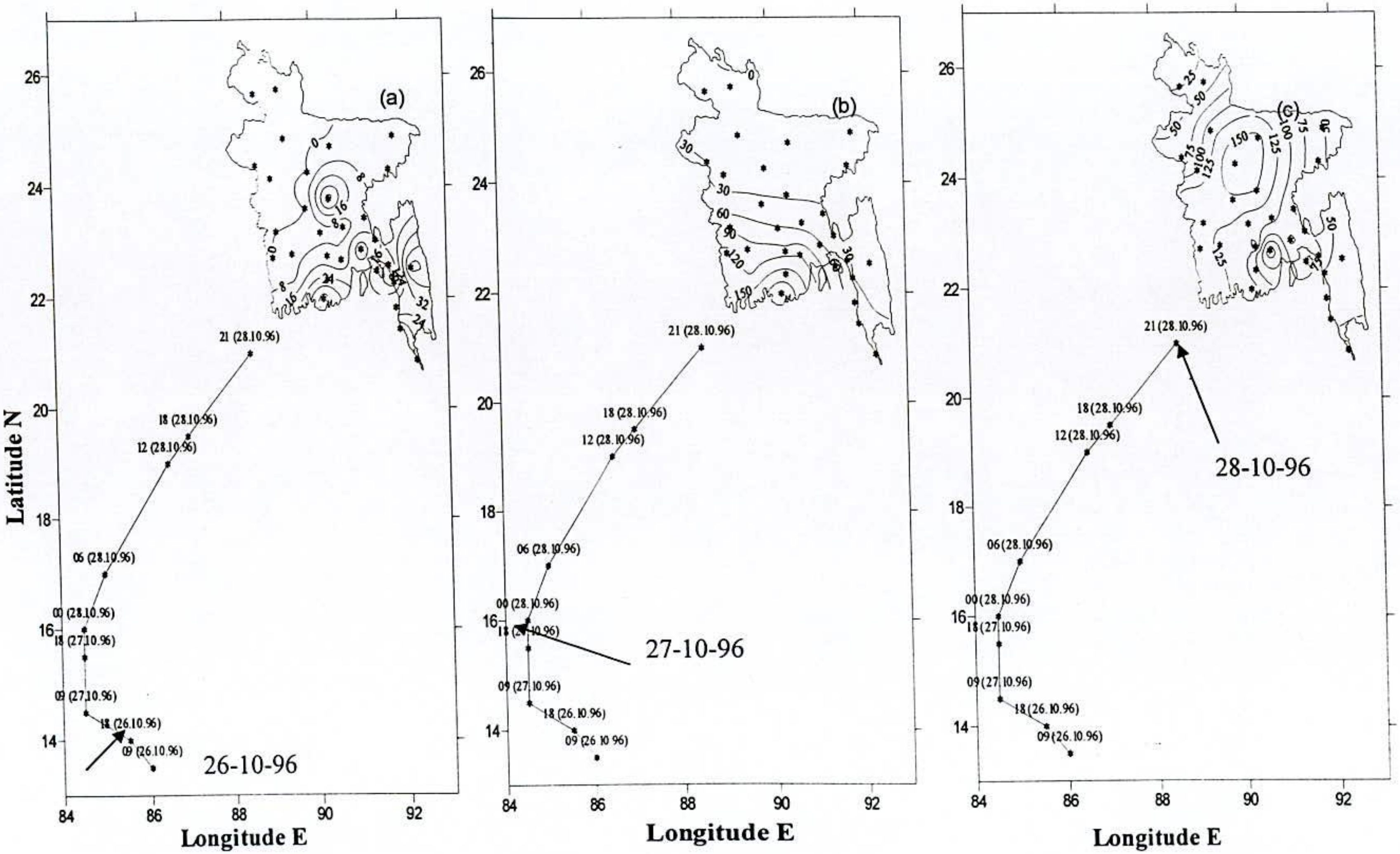

Figure 4.3.2 (a-c) : Rainfall distribution over Bangladesh during October 26-28, 1996 due to CS of 26-28 October 1996, along with its track.

direction of movement of the cyclone was north easterly. On 29th October the system crossed the Sundarban coast.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 211mm, which is the maximum one for this event, is observed on October 27 at Khepupara.

4.3.3 *Rainfall distribution and Movement of Cyclone 31 May 1991*

Fig 4.3.3 (a-c) represents the track of the cyclone that formed in the Bay of Bengal on 31st May 1991 and crossed the Bangladesh coast and the rainfall distribution over Bangladesh during 31 May to 2 June of 1991.

At 15 BST of May 31 the system was first detected as depression and was located in the Central Bay of Bengal with centered at 15.5^0N, 89.5^0E. In the next 3 hours it moved towards north with the same intensity. In the next 6 hours the system moved towards northwest and intensified to DD. From 00 BST of 1 June to 18 BST of 1 June it moved towards north and was located at 19.5^0N, 89.2^0E. Within this period further intensification took place and the system became CS. From 18 BST of 1 June to 02 BST of 2 June it moved towards north northeast direction without any change in its intensity. At 06 BST of June 2 it crossed Bhola coast as CS.

Heavy rainfall occurred at Dinajpur, moderate rainfall occurred at Rangamati, Srimongal, Mongla, Sandwip, Khepupara, Kutubdia regions and light rainfall occurred at Dhaka, Hatiya, Sitakundu regions on 1st day (31.05.91) when depression formed in the Bay of Bengal at 15.5^0N, 89.5^0E and the direction of movement of the depression was towards north. On 2nd day very heavy rainfall occurred at Khepupara, Sandwip, Hatiya, Patuakhali, Maijdi Court, Bhola, Madaripur regions, heavy rainfall occurred at Teknaf, Cox's Bazaar, Chittagong, Sitakundu, Mongla, Khulna, Feni, Chandpur, Faridpur, Dhaka regions, moderately heavy rainfall occurred at Kutubdia, Rangamati, Comilla, Dinajpur regions, moderate rainfall occurred at Satkhira, Sylhet regions and light rainfall occurred at Jessore, Tangail, Mymensing regions when the depression transformed into CS in the Bay and the direction of movement of the system was north-north easterly. On 3rd day the system crossed in the Bhola coast and very heavy rainfall occurred at Sylhet, heavy rainfall occurred at Sandwip, Barisal, Feni, Comilla, Srimongal regions, moderately heavy rainfall occurred at Teknaf, Rangamati, Chandpur, Dhaka regions, moderate rainfall

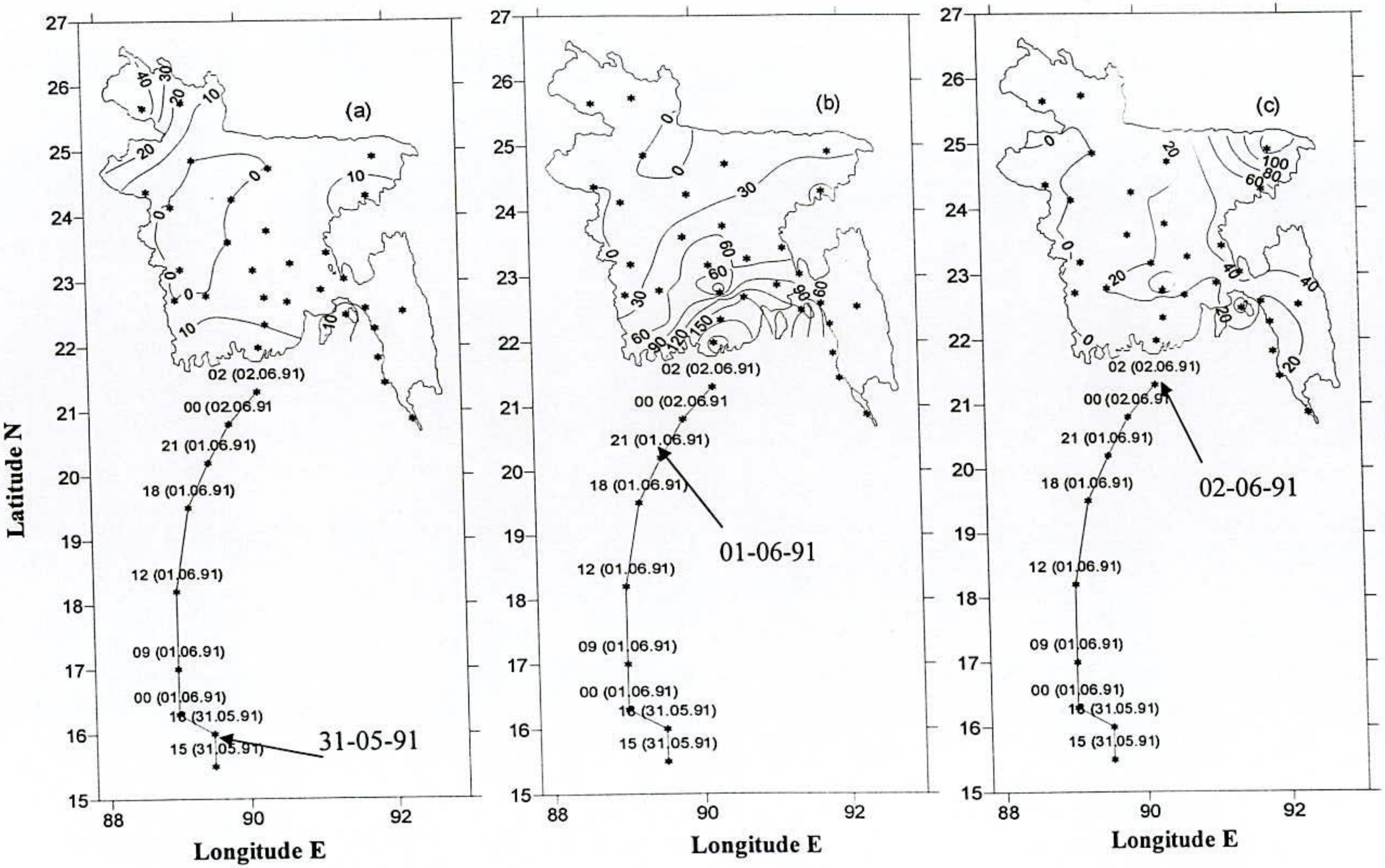

Figure 4.3.3 (a-c): Rainfall distribution over Bangladesh during May 31- June 2, 1991 due to CS of 31 May-2 June 1991, along with its track.

occurred at Cox's Bazaar, Sitakundu, Hatiya, Patuakhali, Maijdi Court, Bhola, Khulna, Madaripur, Tangail regions and light rainfall occurred at Kutubdia, Chittagong, Mongla, Satkhira regions.

Heavy and very heavy rainfall is observed in the right side of the track.

A rainfall amounting 129mm, which is the maximum one for this event, is observed on June 2 at Sylhet.

4.4 *Track and Rainfall distribution due to DD*

4.4.1 Rainfall distribution and Movement of Cyclone of 1 June 1987

Fig 4.4.1 (a-e) represents the track of the disturbances that formed in the Bay of Bengal on 1^{st} June 1987 and crossed the Bangladesh coast and the rainfall distribution over Bangladesh during 1 to 5 June of 1987.

The system was first detected as depression at 06 BST of June 1 and was located in the south central Bay of Bengal with centered at 15.5^0N, 90.5^0E. In the next 15 hours it moved towards north and its centre was located at 160N, 90.5^0E. At 09 BST of June 02 it was centered at 16^0N, 88.5^0E and its direction of movement towards west. In the next 9 hours i.e. by 18 BST of June 02 no further intensification took place. In the next 18 hours i.e. 06 BST of June 3 it moved towards north–north easterly direction and its centre was located at 16^0N, 88.5^0E. Within the period further intensification took place and the system became deep depression. From 06 BST of 3 June to 12 BST of 4 June the system moved in the north-north easterly direction without any change in its intensity and its centre arrived at 21.8^0N, 90.8^0E. In the next 6 hours the system moved towards north-northwest and at 12 BST of June 4 it was located at 21.8^0N, 90.8^0E. At 00 BST of June 5 it crossed the Barisal region as deep depression.

Very heavy rainfall occurred at Rangpur on 1st day when depression formed in the Bay of Bengal and the direction of movement of the disturbances was towards north. on 2nd day heavy rainfall occurred at Sitakundu, moderately heavy rainfall occurred at Mymensing, Madaripur, Feni, Khulna, Teknaf and the direction of movement of the cyclone was towards west. On 3rd day heavy rainfall occurred at Khepupara and moderate rainfall occurred at Sandwip, Patuakhali and Teknaf when the depression transformed into DD and the direction of movement was north easterly. On 4th day very heavy rainfall occurred at Dhaka, Comilla, Madaripur, Feni, Khulna, Barisal, Bhola, Maijdi Court, Sandwip,

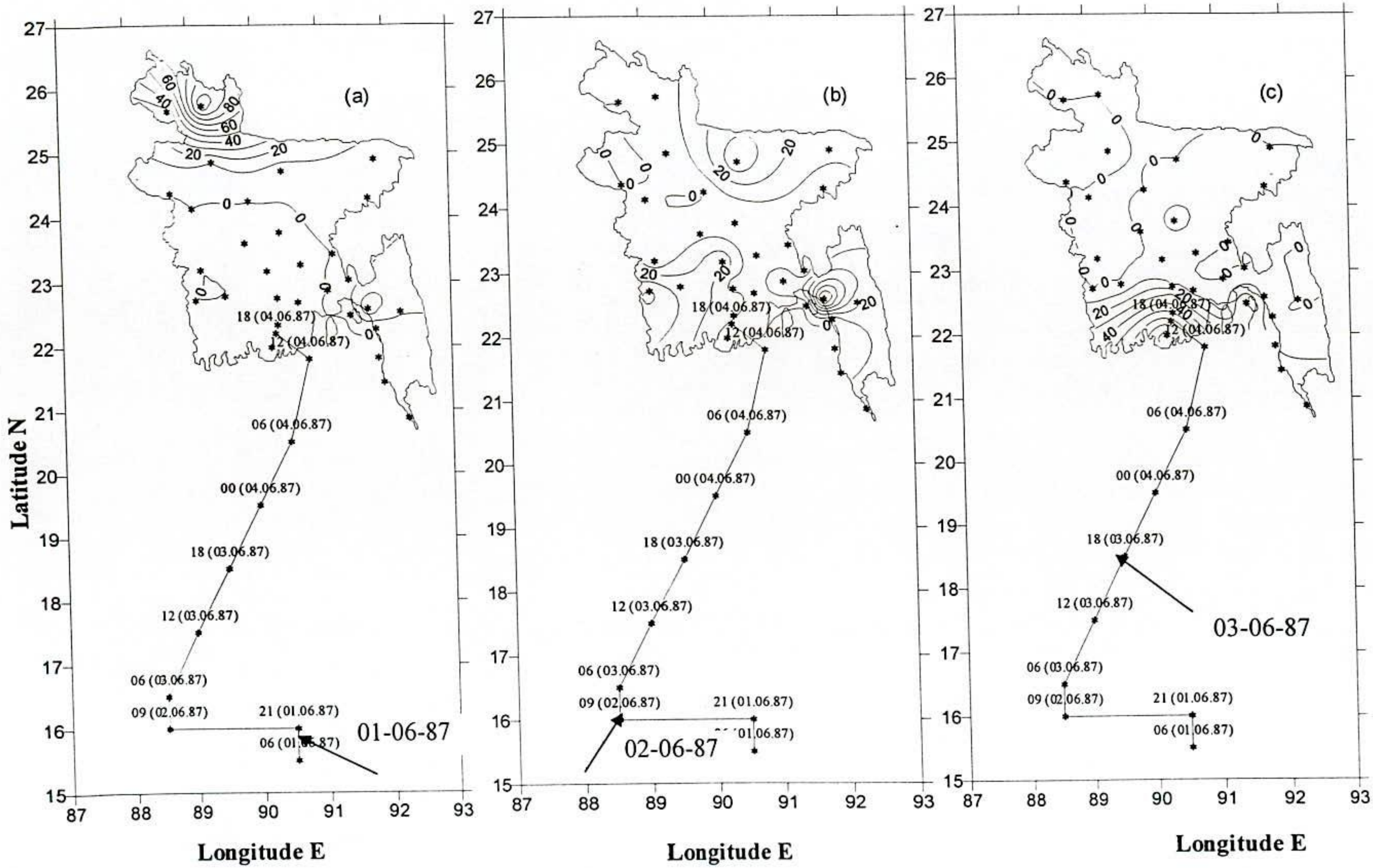

Figure 4.4.1 (a-c): Rainfall distribution over Bangladesh during June 1-3, 1987 due to DD of 1-5 June 1987, along with its track.

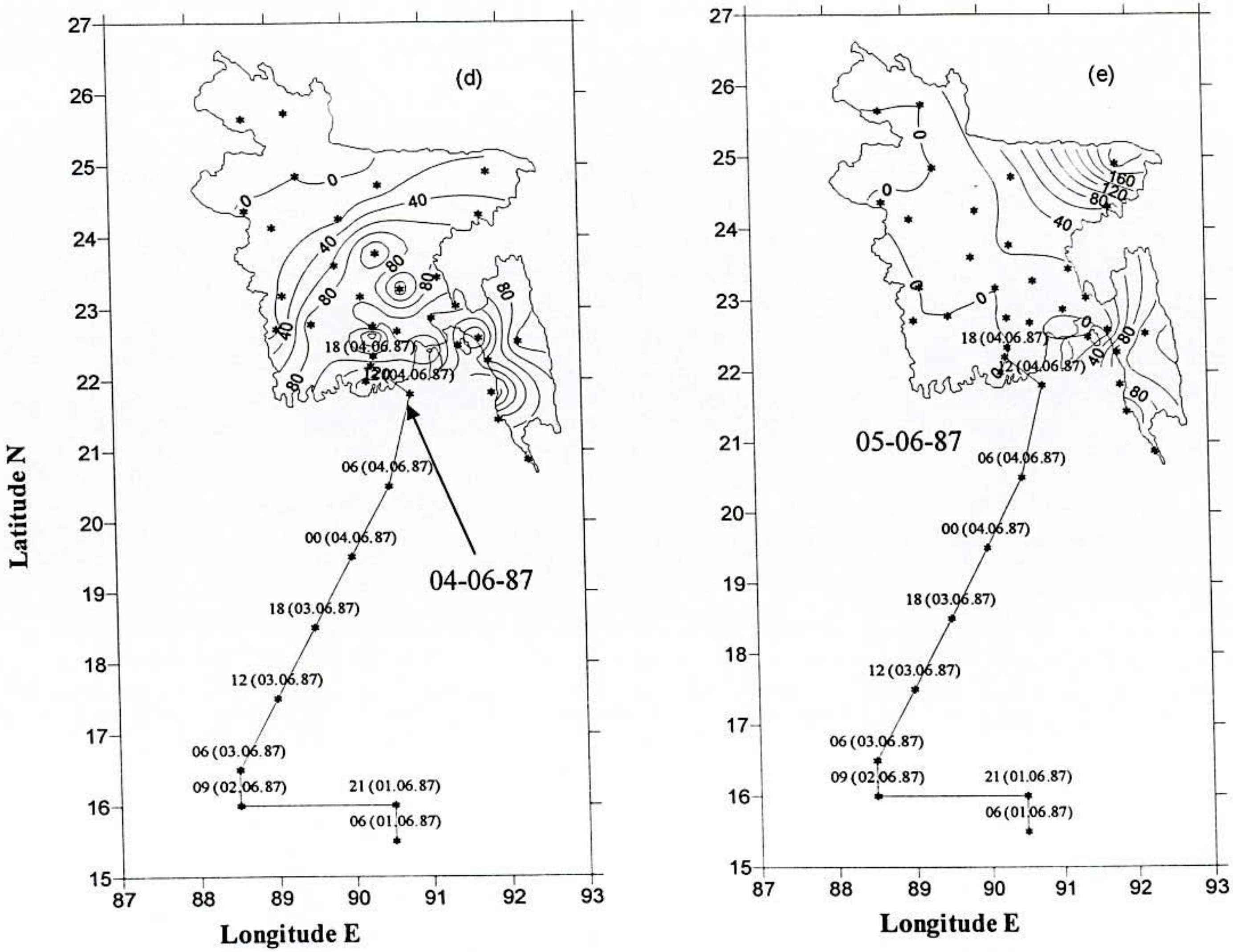

Figure 4.4.1 (d-e): Rainfall distribution over Bangladesh during June 4-5, 1987 due to DD of 1-5 June 1987, along with its track.

Chittagong, Khepupara, Kutubdia, Cox's Bazaar and heavy rainfall occurred at Srimongal, Faridpur, Hatiya, Rangamati, Teknaf and the direction of movement of the disturbances towards north- north east. On 5th day cyclone crossed the Barisal region and very heavy rainfall occurred at Sylhet, Chittagong, Rangamati and heavy rainfall occurred at Srimongal, Kutubdia, Teknaf and moderately heavy rainfall occurred at Mymensing and Cox's Bazaar regions.

Heavy and very heavy rainfall is observed in the front and right side of the track. A rainfall amounting 221mm, which is the maximum one for this event, is observed on June 4 at Kutubdia.

4.4.2 *Rainfall distribution and Movement of Cyclone of 2 October 1980*

Fig 4.4.2 (a-c) represents the track of the disturbance that formed in the Bay of Bengal on 2nd October 1980 and crossed the Bangladesh coast and the rainfall distribution over Bangladesh during 2 to 4 October of 1980.

At 09 BST of October 2, 1980 the system was first detected as deep depression and was located in the south central Bay of Bengal with centered at 16^0N, 87^0E. In the next 9 hours it moved towards north and its centre was located at 17^0N, 87^0E with the same intensity. In the next 9 hours i.e. 09 BST of October 3 it was located at 19^0N, 88.5^0E as depression and the system moved towards north-north east. At 15 BST it was located at 20.5^0N, 89.5^0E with the same intensity, and it further moved towards east. At 18 BST of October 3 it was at 20.6^0N, 90.6^0E. In the next 12 hours i.e. 06 BST of October 4 it crossed near Chittagong coast.

Heavy rainfall occurred at Barisal, Teknaf, Maijdi Court and moderately heavy rainfall occurred at Madaripur, Bhola and Rangamati on 1st day when deep depression located in the Bay of Bengal at 16^0N, 87^0E and the direction of movement of the disturbance was towards north. On 2nd day deep depression weakened and transformed into depression and very heavy rainfall occurred at Rangamati and heavy rainfall occurred at Chittagong, Teknaf, Sandwip, Hatiya and the direction of movement of the disturbance was towards north-north east. In 3rd day the system crossed the Chittagong coast and moderately heavy rainfall occurred at Sylhet region.

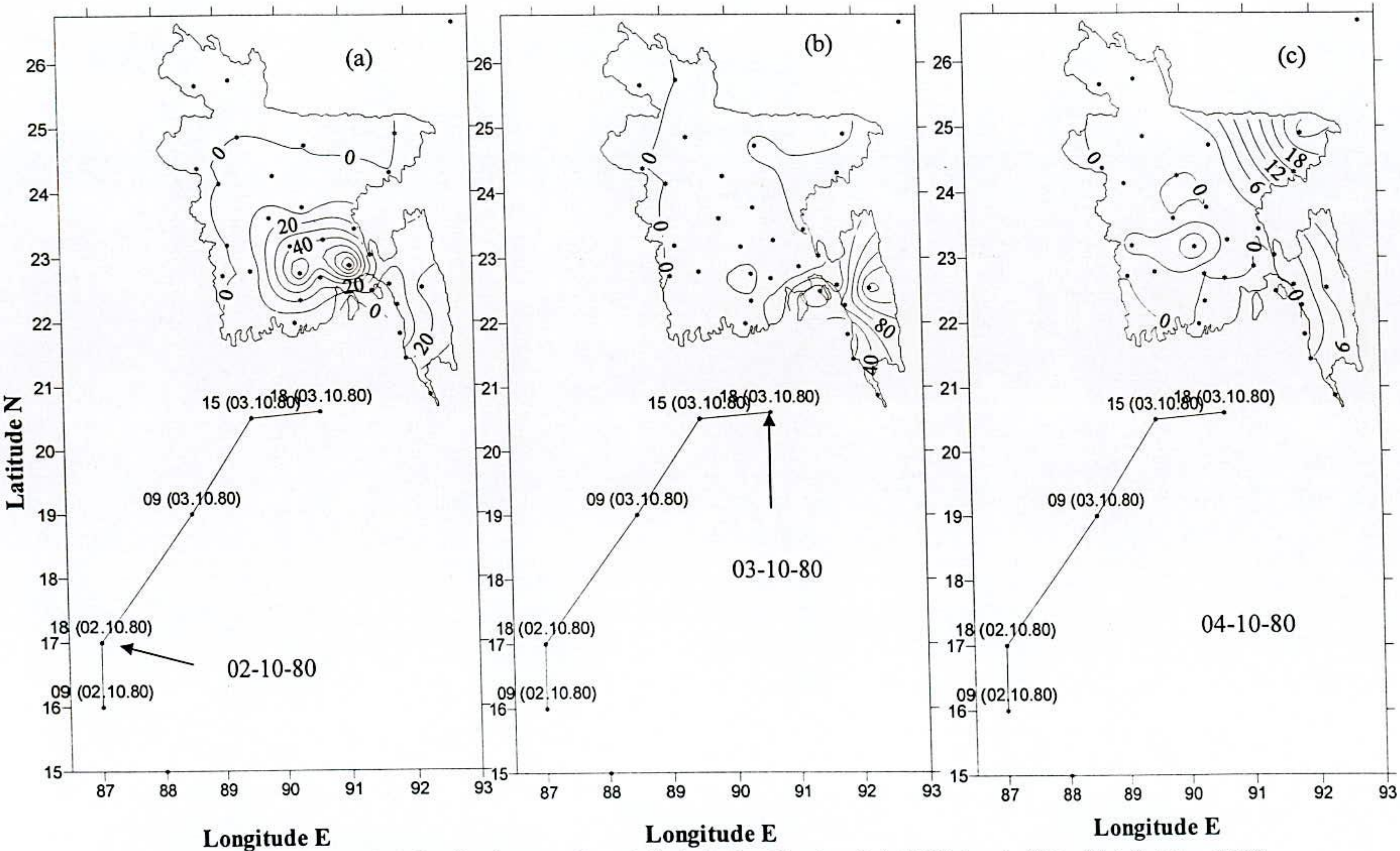

Figure 4.4.2 (a-c) : Rainfall distribution over Bangladesh during October 2-4, 1980 due to DD of 2-4 October 1980, along with its track.

Heavy and very heavy rainfall is observed in the front and left side of the track. A rainfall amounting 150mm, which is the maximum one for this event, is observed on October 3 at Rangamati.

4.4.3 Rainfall distribution and Movement of Cyclone of 16 November 1985

Fig 4.4.3 (a – d) represents the track of the disturbance that formed in the Bay of Bengal on 16th November 1985 and crossed the Bangladesh coast and the rainfall distribution over Bangladesh during 16 to 19 November of 1985.

At 09 BST of 16 November the system was at deep depression and detected in the south west Bay of Bengal with centred at 13^0N, 85^0E. In the next 15 hours it moved towards west and intensified to CS. From 00 BST of 17 November to 00 BST of 18 November the system moved towards north-north westerly direction without any change in its intensity and its centred arrived at 15^0N, 81^0E. In the next 30 hours the system moved towards north east and its intensity dropped drastically and 06 BST of November 19 it was located at 20^0N, 89^0E as a depression. But during the next 9 hours the system again intensified further and became DD and the direction of movement of the system towards east. In the next 3 hours its intensity remained the same and it further moved towards north. At 21 BST of November 19 it crossed the Noakhali - Chittagong coast as deep depression.

Moderately heavy rainfall occurred at Kutubdia and moderate rainfall occurred at Hatiya, Teknaf regions on 1st day when depression formed in the Bay of Bengal at 13^0N, 85^0E and the direction of movement of the system was towards west. On 2nd day very heavy rainfall occurred at Cox's Bazaar and heavy rainfall occurred at Kutubdia, Sitakundu and moderately heavy rainfall occurred at Teknaf, Hatiya regions and moderate rainfall occurred at Chittagong, Rangamati, Patuakhali, Bhola, Khepupara and light rainfall occurred at Barisal, Sandwip regions when the deep depression transformed into CS and the direction of movement of the cyclone was north west. On 3rd day CS transformed into depression and very heavy rainfall occurred at Teknaf, Cox's Bazaar, Chittagong, heavy rainfall occurred at Kutubdia, moderately heavy rainfall occurred at Rangamati, moderate rainfall occurred at Sandwip and light rainfall occurred at Hatiya and the direction of movement of the cyclone was towards north east. On 4th day depression crossed in the Noakhali-Chittagong coast as a deep depression and very heavy rainfall occurred at

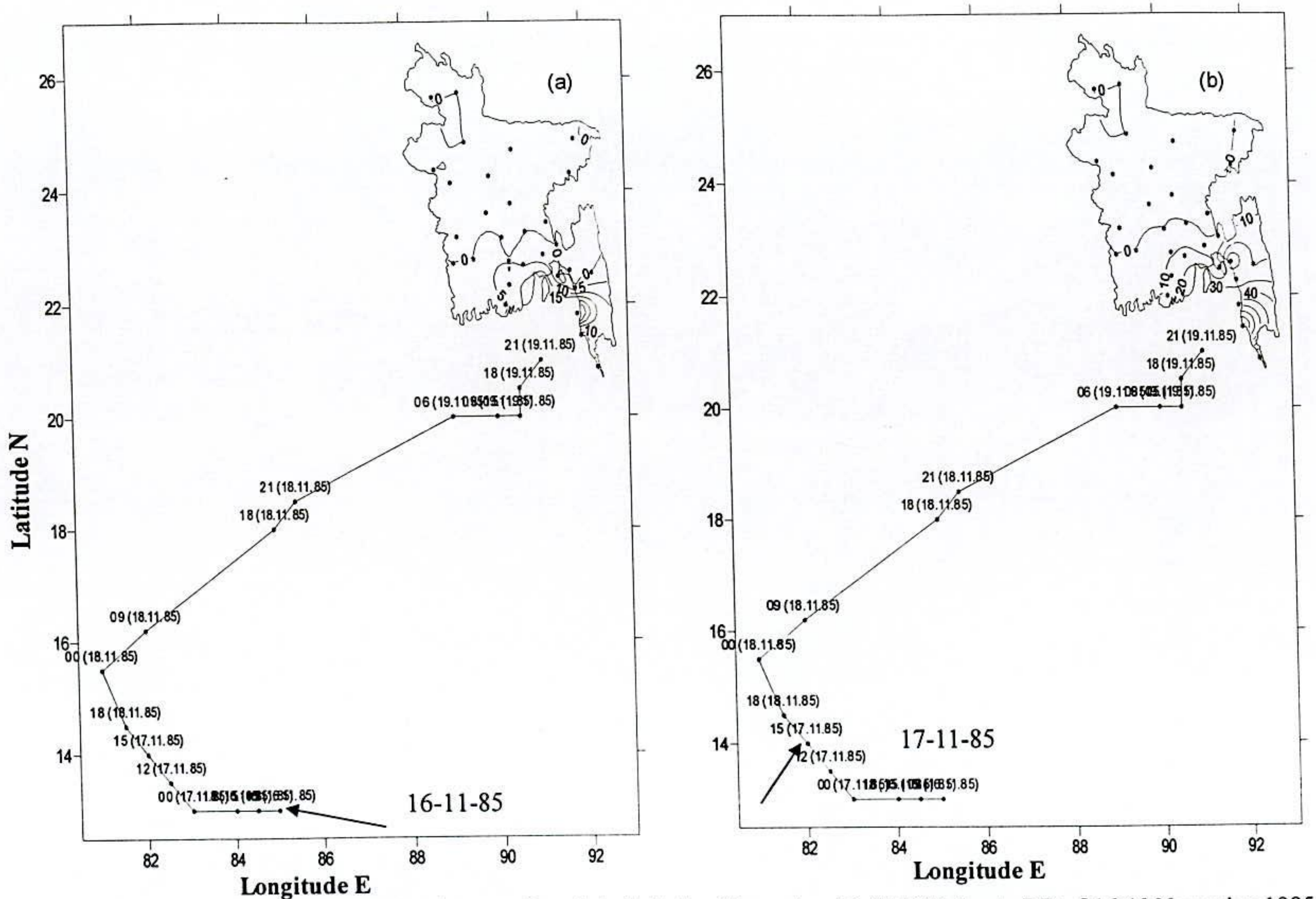

Figure 4.4.3 (a-b) : Rainfall distribution over Bangladesh during November 16-17,1985 due to DD of 16-19 November 1985, along with its track.

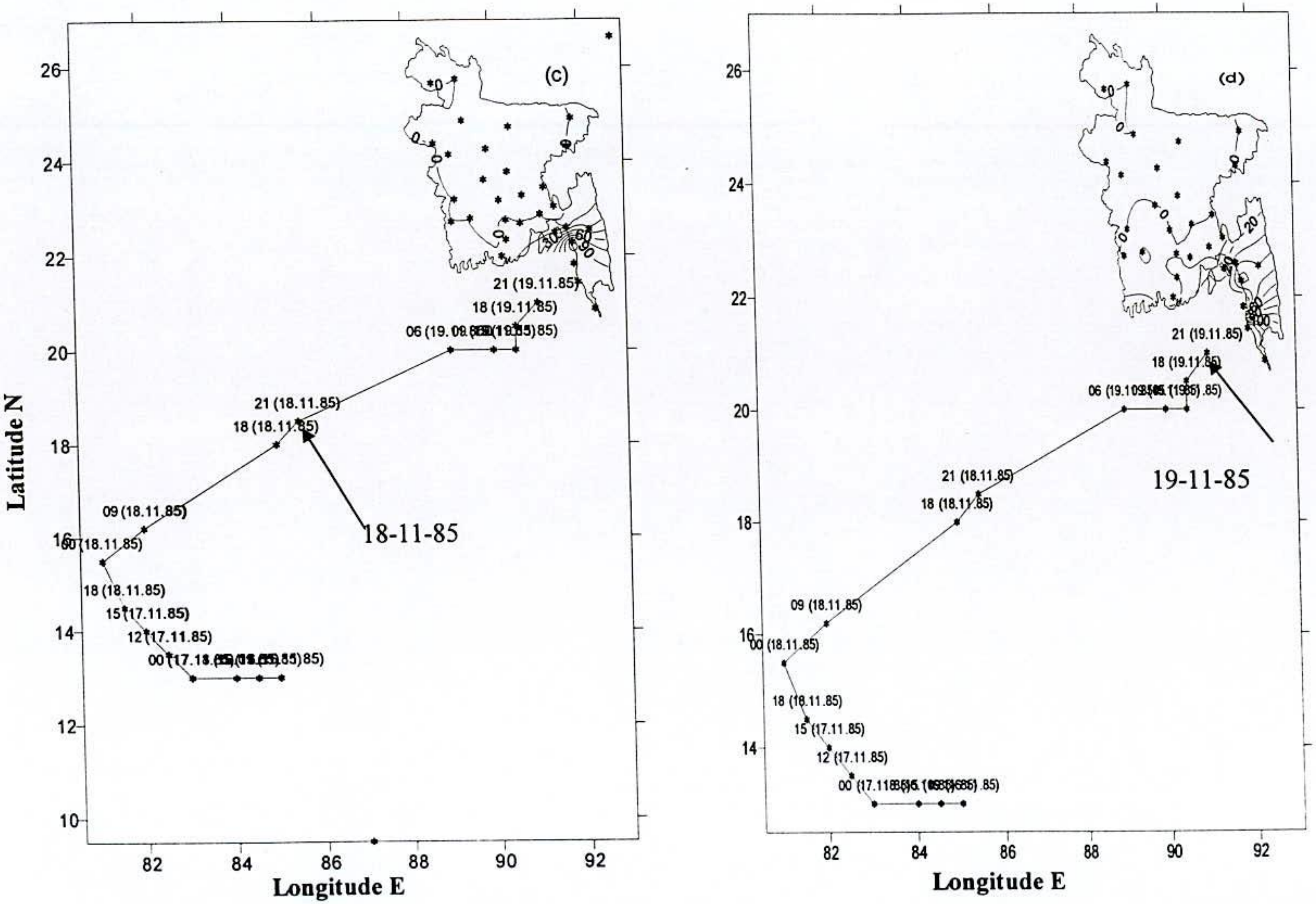

Figure 4.4.3 (c-d) : Rainfall distribution over Bangladesh during November 18-19, 1985 due to DD of 16-19 November 1985, along with its track.

Teknaf, Cox's Bazaar regions, heavy rainfall occurred at Chittagong, moderately heavy rainfall occurred at Rangamati, Sitakundu, moderate rainfall occurred at Hatiya, Patuakhali, Khulna regions and light rainfall occurred at Sandwip, Maijdi Court and Bhola regions.

Heavy and very heavy rainfall is observed in the front and left side of the track. A rainfall amounting 156mm, which is the maximum one for this event, is observed on November 19 at Cox`s Bazaar.

4.5 Track and Rainfall distribution due to Depression

4.5.1 Rainfall distribution and Movement of Cyclone of 4 June 1980

Fig 4.5.1 (a-b) represents the rainfall distribution over Bangladesh along with the tracks due to the depression formed in the Bay Bengal and crossed along the Meghna estuary during 4-5 June 1980.

The system was first detected as depression at 12 BST of June 4 and was located in the south central Bay of Bengal with centered at 19.5^0N, 88.5^0E. In the next 6 hours it moved towards north- north easterly direction and its centre was located at 20^0N, 89^0E with the same intensity. The system remained there for the next 15 hours again it moved towards North East and at 09 BST of June 5 it was located at 21^0N, 90.5^0E as a depression. There after the system crossed the Meghna estuary.

On 1st day heavy rainfall occurred at Teknaf and moderately heavy rainfall occurred at Cox's Bazaar, Hatiya when depression moved towards the coast. The direction of movement of the cyclone was north east. On 2nd day i.e. on June 5 the system crossed the Meghna estuary and very heavy rainfall occurred at Chittagong, heavy rainfall occurred at Rangamati and moderately heavy rainfall occurred at Kutubdia, Cox's Bazaar, Teknaf, Feni, Bhola, Srimongal and direction of movement of the cyclone was the same as that of previous day.

Heavy and very heavy rainfall is observed in the front and right side of the track.

A rainfall amounting 325mm, which is the maximum one for this event, is observed on June 5 at Chittagong.

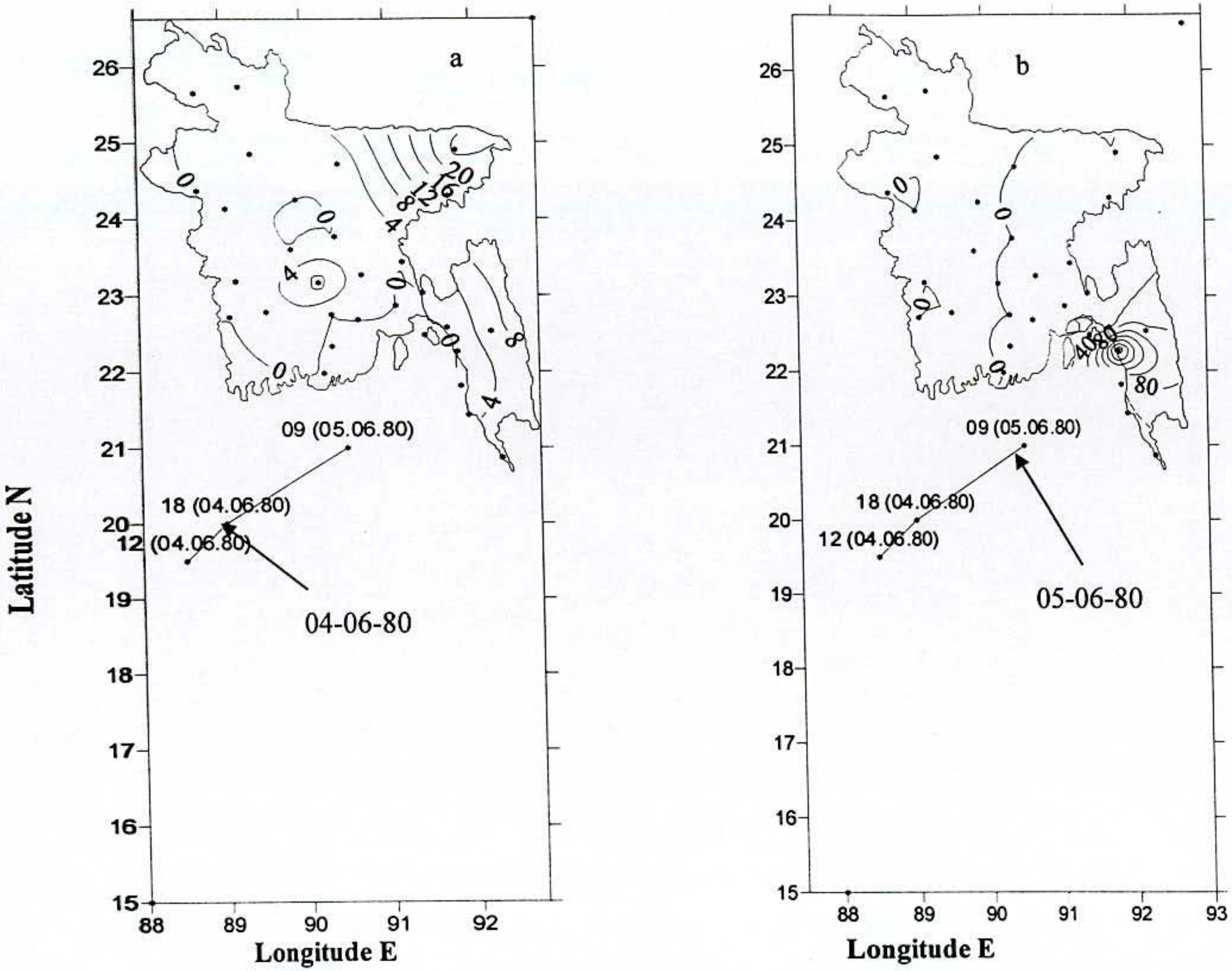

Figure 4.5.1 (a-b): Rainfall distribution over Bangladesh during June 4-5, 1980 due to D of 4-5 June 1980, along with its track.

The following table shows the amount of highest rainfall and where it occurred on each day of every event along with the status of the system.

Event of	Date	Intensity	Station name	Maximum amount of Rainfall(mm)
05-11.12.81	07-12-81	CS	Comilla	10
	08-12-81	SCS	Cox`s Bazaar	2
	09-12-81	SCS(H)	Maijdi Court	24
	10-12-81	SCS(H)	Jessore	133
	11-12-81	SCS(H)	Teknaf	27
15-19.05.97	15-05-97	D	Sylhet	14
	16-05-97	CS	Chuadanga	24
	18-05-97	SCS(H)	Teknaf	26
	19-05-97	SCS(H)	Sitakundu	149
17-20.05.98	17-05-98	DD	Srimongal	12
	18-05-98	DD	Teknaf	17
	19-05-98	SCS(H)	Cox`s Bazaar	154
	20-05-98	SCS(H)	Rangamati	204
17-21.11.92	19-11-92	SCS(H)	Kutubdia	4
	20-11-92	SCS(H)	Teknaf	8
	21-11-92	SCS(H)	Teknaf	15
19-22.11.98	21-11-98	SCS(H)	Khulna, Mongla	37
	22-11-98	SCS(H)	Barisal	251
21-25.11.95	21-11-95	D	Teknaf	12
	23-11-95	SCS	Cox`s Bazaar	1
	24-11-95	SCS(H)	Khepupara	44
	25-11-95	SCS(H)	Sitakundu	60
24-30.11.88	27-11-88	SCS(H)	Sitakundu, Feni	32
	28-11-88	SCS(H)	Khepupara	92
	29-11-88	SCS(H)	Dhaka	135
	30-11-88	SCS(H)	Sylhet	80
25-29.04.91	25-04-91	D	Faridpur	21
	27-04-91	SCS	Rangpur	6
	28-04-91	SCS(H)	Khepupara	140
	29-04-91	SCS(H)	Hatiya	205
09-13.05.77	09-05-77	D	Ishwardi	31
	10-05-77	D	Hatiya	3
	11-05-77	CS	Jessore	72
	12-05-77	SCS	Patuakhali	238
	13-05-77	SCS	Sylhet	94
16-18.12.90	16-12-90	DD	Teknaf	4
	17-12-90	SCS	Cox`s Bazaar	11
	18-12-90	SCS	Hatiya	75

Event of	Date	Intensity	Station name	Maximum amount of Rainfall(mm)
05-07.06.75	05-06-75	DD	Cox`s Bazaar	15
	06-06-75	CS	Bhola	122
	07-06-75	CS	Cox`s Bazaar	147
26-28.10.96	26-10-96	D	Rangamati	52
	27-10-96	DD	Khepupara	211
	28-10-96	CS	Tangail	175
31 May-2 June.91	31-05-91	DD	Dinajpur	51
	01-06-91	CS	Khepupara	226
	02-06-91	CS	Sylhet	122
01-05.06.87	01-06-87	D	Rangpur	109
	02-06-87	DD	Sitakundu	80
	03-06-87	DD	Khepupara	87
	04-06-87	DD	Kutubdia	221
	05-06-87	DD	Rajshahi	211
02-04.0.0	02-10-80	DD	Maijdi Court	87
	03-10-80	D	Rangamati	150
	04-10-80	D	Sylhet	25
16-19.11.85	16-11-85	DD	Kutubdia	41
	17-11-85	CS	Cox`s Bazaar	97
	18-11-85	D	Chittagong	121
	19-11-85	DD	Cox`s Bazaar	156
04-05.06.80	04-06-80	D	Teknaf	50
	05-06-80	D	Chittagong	325

CHAPTER FIVE

Conclusions and Recommendations

CHAPTER 5

CONCLUSIONS

The study of rainfall distribution for cyclonic disturbances of the Bay of Bengal that has the landfall to Bangladesh was made. All together 17 cyclonic disturbances from 1974-2001 of which 8 were Severe Cyclonic Strom with core of Hurricane wind, 2 Severe Cyclonic Strom, 3 Cyclonic Strom, 3 Deep Depression, 1 Depression were taken. The station wise rainfalls for 30 stations of Bangladesh during the life cycle of the disturbances were used. Based on the results and discussions made in chapter 4, the following conclusions are made.

i) The rainfall distributions for the individual dates of the disturbances show that the maximum rainfall had been occurred on 5 June 1980 due to the depression at Chittagong.

ii) The study shows that heavy and very heavy rainfall is obtained in the front right quadrant of the disturbances.

It may be note worthy that we have used data only in the Bangladesh region but no rain data in the Bay of Bengal, India and Myanmar regions are used. For the better prediction of cyclone tracks the rainfall data at least in the Bay of Bengal regions are required.

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