# TRACK PREDICTION OF TROPICAL CYCLONES FORMED IN THE BAY OF BENGAL USING NUMERICAL METHOD

BY



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Declaration

This is to certify that this work has been done by me and has not been submitted elsewhere for the award of any other degree or diploma.

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ABSTRACT

Track predictions of cyclonesformed in the Bay of Bengal have been simulated with the help of numerical model. The governing equation of the model is the Barotropic Vorticity Equation in x-y-t space. It is a third order differential equation. The equation is solved for the time rate of change of stream function by using finite difference method. To forecast the future circulation, streamfunction is extrapolated ahead for small time increaments. For simplicity it is assumed that the stream function is zero at all boundary points.

The model area covers 0 to 30N latitude and 70 to 100E longitude. The horizontal X,Y space is equally divided into 25x25 grid points. Values of the grid points are evaluated by Taylor series taking upto first two terms. Grid point values are used as the initial data. Computed extrapolated values of stream-functions are converted into geo-potential and contours are drawn and then compared with the corresponding actual one.

Track of cyclone is predicted by following the path of the centre which determines the location of the cyclone at different times. The agreement between the predicted and the actual path of the cyclones are quite encouraging.

## CONTENTS

# CHAPTER 1

# INTRODUCTION

## 1.1 Review

Bangladesh is frequently exposed to severe cyclones which generally originate in the form of depression at the Bay of Bengal. The damage wrought by a single cyclone is colossal. Science today has not yet been able to invent techniques for preventing or controlling the fury of such storms. All that can be done is to predict their arrival and take precautionary measures. Several works on tropical cyclones have already been done.

In "SPARRSO" a computer test model termed as "TYAN" [1] is being used for prediction of paths of Bay of Bengal cyclone by a combination of persistance and climatology of cyclones from 1877-1970. The climatology of cyclone tracks show that in a particular month, a cyclone formed in a particular region of the Bay of Bengal has a preferred direction of movement, speed of movement, recurvature etc. All these information have been used in the 'TYAN' model. The equation of trajectory of a tropical cyclone has been derived by Choudhury [2] when the boundaries are two orthogonal planes and the landfall is at the origin. This has been found to be a rose petal with four loops when the boundaries are perpendicular. The tangent of the curve at the origin serves as the x-axis. This shows reasonable agreement with the observed tracks of cyclones in the Bay of Bengal.

A barotropic model known as "SANBAR" was originally designed by Sanders [3] and Burpee [4] and later modified by Pike [5]. This model predicts tropical cyclone motion by the tracking of minimum stream function and maximum vorticity centres. Computations are made on a grid of mesh length 1.5 degrees of longitude and extending from the equator to latitude 55°N and from longitude 36.5°W to 123.5°W. A time step of 30 minutes has been used and the forecasts have generally been made out of 72 hours. In the original version of SANBAR the initial storm motion computed by the model did not agree with the actual storm motion. Modification made by Pike resulted in much improved forecasts of direction, especially in the first 24 hours, but the slow bias largely remained.

The Electronic computation centre of the Japan Meteorological Agency [6] performs numerical predictions of typhoon movement. A northern hemispheric balanced barotropic model [7] adapted to 500 mb and is employed for the forecast. Steep pressure gradients associated with typhoons are artificially modified in the computational procedure of the model. The results of the numerical typhoon track forecasts show some systematic errors.

The European centre for Medium range weather Forecasts (ECMWF) [8] is devoted to the task of predicting the weather in the medium range (4-10 days). The forecasting system consists of two components; a general circulation type model and a comprehensive data assimilation system and the same model has been used to predict intense small scale weather phenomena (such as cyclones) as well as to simulate climate for periods of upto ten years.

D Vorak [9] model describes tropical cyclone development in terms of day by day changes in the cloud pattern of the storm and its environment as observed in satellite pictures. The rate is defined as one "T-number" per day. T stands for tropical and is related to the cyclone's intensity.

In Bangladesh only a beginning has been made towards the understanding of cyclones. A lot remains to be known. The research work so far done in this field is inadequate, fewer in number and meager in magnitude. This dissertation has been undertaken keeping the above points in view.

## 1.2 What is a cyclone?

A cyclone is a natural phenomenon and is an intense vortex in atmosphere. At all latitudes the word cyclone means any large rotating bad weather phenomena with low pressure in the centre around which the air circulates in an anti clockwise direction in the northern hemisphere and in a clockwise direction in the southern hemisphere.

Mathematically a tropical cyclone can be assumed to be a cylindrical vortex such that the vorticity $\zeta = \vec{\nabla} \times \vec{V}$ [10] where $\vec{V}$ is the velocity and has a finite value.

Cyclones are usually defined by the following elements

(a) Diameter of a rotating mass of warm humid air, normally between 300 and 1500 kilometers

(b) Movement velocity and course.

(c) Rotation velocity of winds. The strongest winds may approach 200km/hr.

(d) Duration

(e) Amount of rain

(f) Storm surge

Tropical cyclones, the most destructive of Nature's phenomena, are known to form over all tropical oceans, with the exception of the South Atlantic.

The term cyclone is derived from the greek word "Kyklos" meaning a circle or a coil of snakes.

Tropical cyclones in matured conditions are known as hurricanes in the Atlantic and Eastern Pacific Oceans, typhoons in the Western North Pacific Ocean, willy-willy in Australia and baguio in the Philippine islands; elsewhere they are called tropical cyclones. In the west, cyclones used to be given girls' names such as Anna, Carol, Dorothy, Eve Jane etc. A list of four sets of names in alphabetical order was introduced, one set being used each year. After every four years the sets were repeated. Recently, the naming of cyclones after male names has been introduced, such as Gilbert. While these names are related to the locality of occurrence. All tropical cyclones are essentially similar in origin, structure and behaviour.

### 1.3 Unique nature of the cyclone

(a) The cyclone is a macroscale event with a meso-scale impact (hundreds of kilometers versus tens of kilometers).

(b) It is basically an oceanic storm conceived in a barotropic environment.

(c) Having achieved maturity, the cyclone may outrun its barotropic environment and draw upon baroclinic sources to circulate moisture plenty air through its heat engine rapidly enough to supply the latent heat required to sustain its structure and fury even while moving over cold water and sometimes great distances inland.

(d) In the areas struck by tropical cyclones the resultant damages are often extensive. The principal damaging forces associated with tropical cyclones are the storm surge, floods caused by the high winds and torrential rains.

## 1.4 Classification:

Cyclones in the South Asian Subcontinent are classified according to their intensity [11]. The following nomenclature is in use:

(1) Depression: Winds upto 30 mph (48.3 km/h)

(2) Deep depression: Winds of 30-38 mph(49-61 km/h)

(3) Cyclonic storm: Winds of 39-54 mph (62-86 km/h)

(4) Severe cyclonic storm: Winds of 55-73 mph(87-117 km/h)

(5) Severe Severe Cyclonic storm: winds above 74 mph or 118 km/hr

## 1.5 Causes of formation of a cyclone

The origin of tropical cyclones is still not well understood. It is not clear under what conditions a weak tropical disturbance can be transformed into a severe cyclone. To explain, the process involved in the formation and development of tropical cyclones, many theories have been advanced by meteorologists. Riehl [12] considered Atlantic cyclone development as a progressive process of intensification of a migrating disturbance. Sadler [13] has analysed cyclone development resulting from downward intensification of a pre-existing upper-tropospheric trough.

On the seasonal scale, Ramage [14] suggests that Ocean temperature lowered by strong evaporation in the monsoon season in the seas around India prevents cyclones from forming in the months with strongest monsoon.

The earth receives all of its energies from the sun but different areas are heated unequally and this variability gives rise to areas of low and high atmoshperic pressure. As soon as a low pressure area is formed, air from all directions converges on it. This is called "Low Level Convergence". The Coriolis effect turns the incoming air so that it spirals inwards and upwards at an increasing rate, causing heavy rain and thunder storms. The air is also made very moist by rapid evaporation from the warm ocean. In the low pressure region itself, air rapidly moves upwards and diverges. This is called "high level divergence". The latent heat released by the condensation of water vapour warms the air and keeps it unstable. This latent heat is also thought to supply the necessary energy of the cyclone.

The co-operative interaction between the cumulus convection and a large scale perturbation leads to unstable growth of the large scale system, the process is referred to as conditional instability of the second kind (CISK) [15]. This meahanism has been quite successful in explaining the development of intense tropical storms and cyclones. Under favourable conditions of moisture supply, the CISK mechanism can lead to rapid development of a cyclonic scale disturbance. In this amplification process friction must be thought of as playing an energy producing role. Charney and Eliassen's [16] study concludes that the co-operative interaction of cumulus convection and the large-scale fields can produce an amplifying disturbance on the cyclonic scale provided that the mean atmosphere is unsaturated but conditionally unstable.

Though solar energy ultimately controls terrestrial weather, certain other conditions have been found to be pre-requisites for the development of cyclones. They are:

(i) Cyclones are found only in certain seasons in certain regions and they form over oceans having a surface termperature of at least 26-27°C. It is now recognized that such high surface temperature is necessary to produce a steep lapse rate through a major part of the troposphere and a steep lapse rate is necessary to maintain the vertical circulation in a cyclone.

(ii) They exist only over the oceans and die out rapidly after making a land fall. Over land, the rain cools the surface and produces a stable lapse rate in the lowest layer. At sea, such cooling is insignificant because the rain is churned into the sea water, which because of its very high conductive capacity, supplies heat in generous amounts to the air.

(iii) They derive their energy from the latent heat of condensation.

(iv) Cyclones are seldom observed within five degrees of the equator, thus indicating some dependence on the Coriolis effect for their development and maintenance.

Although these conditions are necessary, they are by no means sufficient to produce a cyclone.

1.6 Life cycle of cyclones

The life span of tropical cyclones with full cyclonic intensity averages out at about six days from the time they form until the time they enter land or recurve into the middle latitudes. The evolution of the average storm from birth to death has been divided into four stages:

(1) Formative stage:

In this stage, the pattern center is poorly defined and cloud bands are poorly organized. No eye is visible and the wind speed range is 30-50 mph. Unusual fall of pressure over 24 hours by 2-3 mb or more takes place in the center of the vorticity concentration.

(2) Immature stage:

Winds of cyclonic force form a tight band around the center. the cloud and rain pattern changes from disorganized squalls to narrow organized bands spiralling inward. Only a small area is as yet involved, though there may be a large outer envelope. The eye is usually visible but ragged and irregular in shape.

(3) Mature stage:

On the average the mature stage occupies the longest part of the cycle and most often lasts several days. Central speed and pressure need not exceed those of the immature stage. But the circulation widens out, and in moving storms, cyclone winds may extend several hundreds of kilometers from the center to the right of the direction of motion. The eye is prominent and circular, the cloud pattern is almost circular and smooth. At this stage, heating from convective clouds furnishes the largest amount of energy for cyclone maintenance. Pressure gradients are largest at the surface. Wind speed range is between 80-200 mph.

(4) Decaying or Transformation 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 mountaineous. Some cyclones do 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 air mass behind a cold front or by a cold center at high levels moving over their top.

## 1.7 The Mature Cyclone

A clear 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.

### a) Pressure

Within 200 km of the cyclone center, 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. Ordinarily, 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.

### b) Cloud pattern

Cloud photographs obtained from weather satellite have revealed that a cyclone seedling initially appears as a cluster of rain clouds. A mature cyclone has a well organized cloud pattern. It is possible to deduce the wind speeds 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

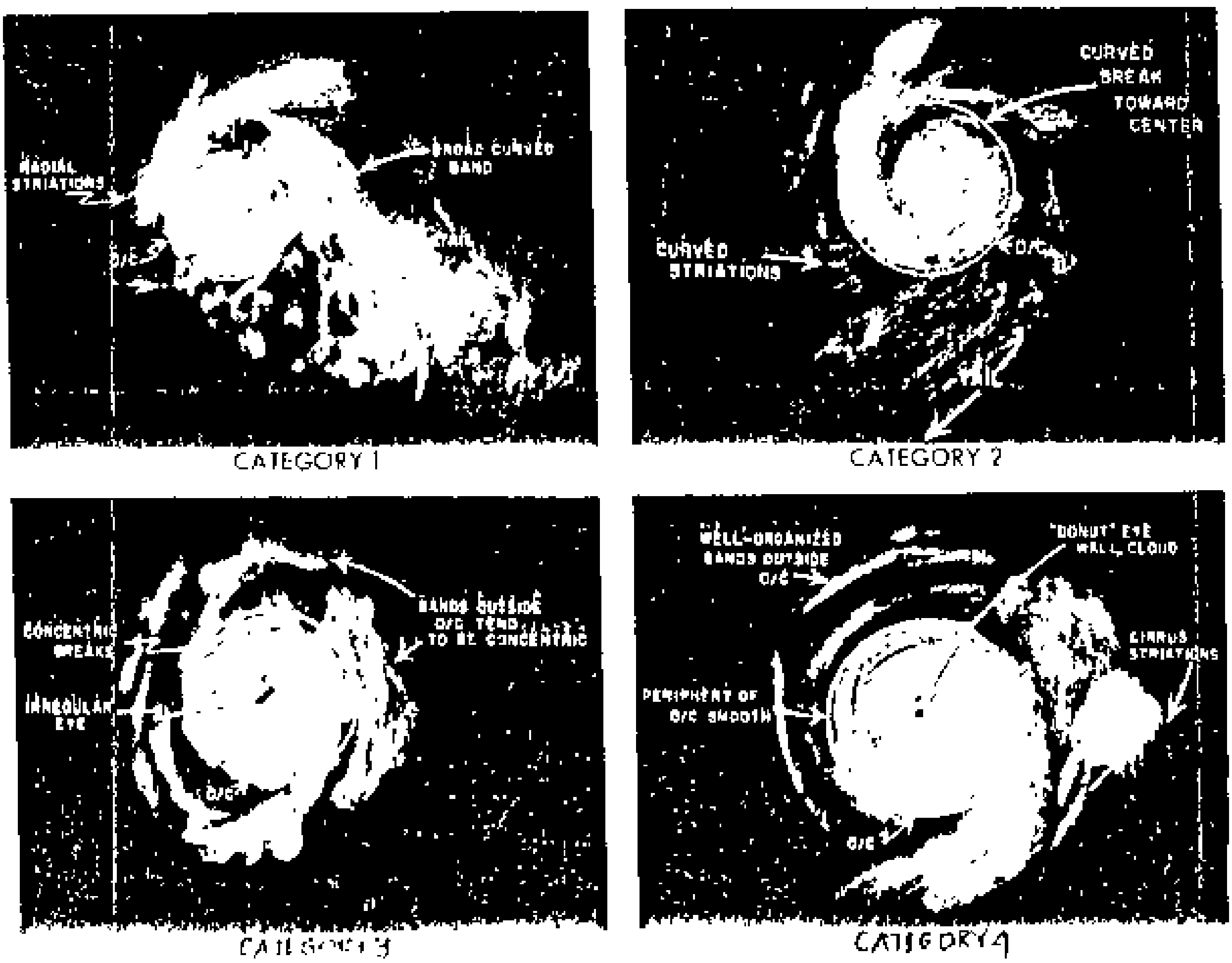



Fig 1.2. Organization of the cloud patterns during the development of a cyclone. (after Timchalk, Hubert and Fritz [17])

direction of motion, which is toward north-northwest. Usually a central dot denoting the eye is visible.

c) Wind fields

When a cyclone lies embedded in what we may term a steering current of large scale, the speeds of the steering current and of the vortex are largely additive. To the right of the direction of motion of the center, the direction of vortex motion and steering current coincide. On the left side they 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 cyclones. Streamlines spiral inward to the ring of strongest wind. The spiral is observed in all cyclones.

d) Precipitation

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

e) The eye of the cyclone

The center of the cyclone is revealed as a 'singular point':

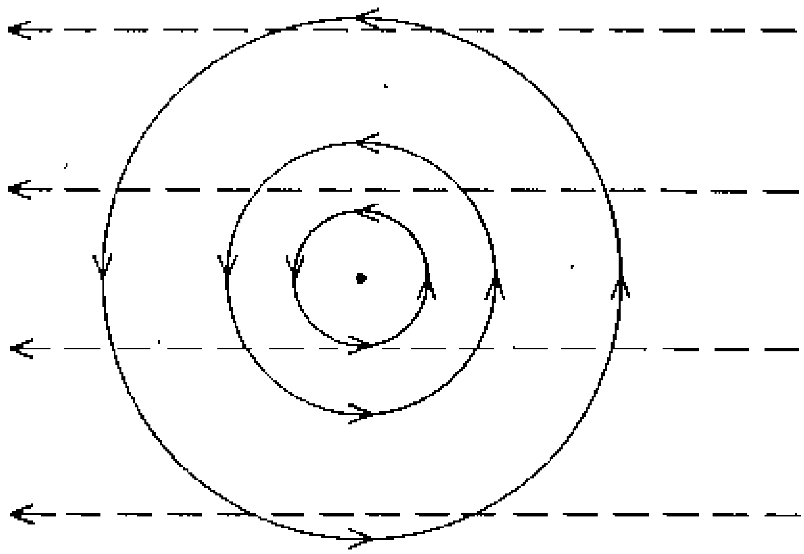


Fig 1.3. Linear superposition of vortex circulation and straight steering current.

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 waves are confused. Eye diameter vary from 5 to over 60 km, depending on rate of storm propagation. The eye is usually pictured as circular, it sometimes becomes elongated. Sometimes it is diffused with a double structured appearance. Modern observations especially radar, have proved that an eye does not remain in steady state but is constantly undergoing transformation.

## 1.8 Favoured areas and seasons of cyclone development

Cyclone development is rare between 5°N and 5°S latitude, where the vertical component of the earth rotation $\omega \sin\phi$ is very weak or zero, where

$\omega$ = rotation of the earth about its axis in angular measure.

$\phi$ = latitude.

$\sin\phi$ ranges from zero at the equator to 1 at the pole (90°). At latitudes 5° to 6° $\sin\phi \simeq 0.1$ and this is the lower limit for development of most, though not all cyclones. Cyclones are known in all tropical oceans except the South Atlantic. In general they tend to be most frequent in the late summer and early fall. In Bangladesh the most favoured seasons for cyclones are pre-monsoon (April-May) and post monsoon (September-December).

CHAPTER 2

# NUMERICAL METHODS OF CYCLONE TRACK PREDICTION

## 2.1 Introduction

Because of the forces responsible for the motion of tropical cyclones are not understood clearly, the problem of forecasting the movement of tropical cyclones is one of the most difficult tasks in the meteorology. A pioneering attempt to predict the weather by numerical integration was made by an English man, L.F. Richardson [19] in 1922. Although his procedure was basically sound, there was some flaws that resulted in large errors with respect to the observed fields.

After Richardson's failure, numerical prediction was not attempted for many years. After World War II the electronic computer was installed and Charney, Fjortoft and von Neumann [20] made the first successful numerical forecast at 500mb with a simple barotropic vorticity model.

With the development of vastly more powerful computers and more sophisticated modelling techniques, more emphasis is now in numerical forecasting. With its ability to handle large volumes of data and make formidable calculations quickly, the computers can give the meteorologist a guidance on preparing forecasts for public informations.

## 2.2 Fundamental Equations

The atmosphere is an open system that responds to solar radiation and interacts in a variety of ways with the earth's surface. The forces acting on each parcel are gravity, friction, internal pressure force and the effect of earth's rotation. Atmospheric motions are governed by three fundamental physical principals: conservation of mass, conservation of momentum and conservation of energy.

The momentum equation which is basic to most work in dynamic meteorology is given below

$$\frac{d\bar{U}}{dt} = -2\,\bar{\Omega}\times\bar{U} - \frac{1}{\rho}\bar{\nabla}P + \bar{g} + \bar{F}_r \quad \ldots\ldots\ldots(2.1)$$

$\bar{U}$ = velocity vector

$\bar{\Omega}$ = angular velocity vector of earth

$\bar{\nabla}P$ = gradient of pressure

$\bar{g}$ = gravitational force

$\bar{F}_r$ = frictional force

For the purpose of theoretical analysis and numerical prediction, it is convenient to expand equation (2.1) in sherical co-ordinates so that the surace of the earth corresponds to a co-ordinate surface. The co-ordinate axes are then $(\lambda, \phi, Z)$, where

$\lambda$ = longitude

$\phi$ = latitude

Z = vertical distance above the surface of the earth

The equations are simplified for synoptic scale motions by defining characteristic scale of the field variables based on observed values for mid-latitudes.

From Table (2.1) it is clear that for mid-latitude synoptic scale disturbances the Coriolis force and the pressure gradient force are in approximate balance. To obtain prediction equations it is necessary to retain the acceleration term. Approximate horizontal prognostic equations are

$$\frac{du}{dt} - fv = -\frac{1}{\rho}\frac{\partial P}{\partial x} \quad \text{.........(2.2)}$$

$$\frac{dv}{dt} + fu = -\frac{1}{\rho}\frac{\partial P}{\partial y} \quad \text{.........(2.3)}$$

Meteorological measurements are generally referred to constant pressure surfaces. To simplify system of equations, it is convenient to replace the horizontal equations of motion by the vorticity equation in the isobaric co-ordinate system and can be written as follows :

$$\frac{\partial \zeta}{\partial t} = -\vec{V}\cdot\vec{\nabla}(\zeta+f) - \omega\frac{\partial \zeta}{\partial P} - (\zeta+f)\vec{\nabla}\cdot\vec{V} + \left\{\frac{\partial u}{\partial P}\frac{\partial \omega}{\partial y} - \frac{\partial v}{\partial P}\frac{\partial \omega}{\partial x}\right\} \quad \text{.........(2.4)}$$

The term on the left hand side of eqn.(2.4) is the local rate of change of relative vorticity. The terms on the right hand side of the equation beginning from the left are

i) horizontal advection of absolute vorticity

ii) the vertical advection of relative vorticity

iii) the divergence term

iv) the twisting or tilting term.

# TABLE 2.1.

*Scale Analysis of the Horizontal Momentum Equations*

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| x-component momentum equation | $\frac{du}{dt}$ | $-2\Omega v \sin\phi$ | $+2\Omega w \cos\phi$ | $+\frac{uw}{a}$ | $-\frac{uv \tan\phi}{a}$ | $=-\frac{1}{\rho}\frac{\partial p}{\partial x}$ |
| y-component momentum equation | $\frac{dv}{dt}$ | $+2\Omega u \sin\phi$ | | $+\frac{vw}{a}$ | $+\frac{u^2 \tan\phi}{a}$ | $=-\frac{1}{\rho}\frac{\partial p}{\partial y}$ |
| Scales of individual terms | $\frac{U^2}{L}$ | $f_0 U$ | $f_0 W$ | $\frac{UW}{a}$ | $\frac{U^2}{a}$ | $\frac{\Delta P}{\rho L}$ |
| Magnitudes of the terms ($m\,s^{-2}$) | $10^{-4}$ | $10^{-3}$ | $10^{-6}$ | $10^{-8}$ | $10^{-5}$ | $10^{-3}$ |

boundary and decay away from the boundary with the pressure and the density fields remaining in hydrostatic balance every where. These waves have maximum pressure oscillations at the ground they may be filtered simply by requiring that

$$\omega = \frac{dP}{dt} = 0 \qquad \ldots\ldots(2.5)$$

at the lower boundary.

where $\omega$ = vertical motion

$P$ = pressure

To filter out the time dependent gravity waves, the local rate of change of the horizontal diverence is neglected in computing the relationship between the mass and the velocity fields. The horizontal equations of motion replaced by the vorticity and divergence equations and this is the minimum simplification required to filter gravity waves.

## 2.4 Filtered Forecast Equation

To exhibit the relationship between the scaling and filtering more clearly it is convenient to divide the horizontal velocity field into nondivergent and irrotational components. Helmholtz [21] states that any velocity field can be written as the vector sum of a nondivergent part and an irrotational part, such that

$$\vec{V} = \vec{V}_\psi + \vec{V}_e \qquad \ldots\ldots(2.6)$$

where $V_\psi$ is the non divergent part with

$$\vec{\nabla} \cdot \vec{V}_\psi = 0 \qquad \ldots(2.7)$$

and $\bar{V}_\chi$ is the irrotational part with

$$\bar{\nabla} \times \bar{V}_\chi = 0 \qquad \ldots\ldots(2.8)$$

For mid latitude synoptic scale motion, the vorticity equation when scaled gives a relationship between $\bar{V}_\psi$ and $\Phi$ which is known as the balanced equation. Here $|\bar{V}_\psi| >> |\bar{V}_\chi|$

Balanced equation may be written as

$$\nabla^2\left[\Phi + \tfrac{1}{2}(\nabla\psi)^2\right] = \bar{\nabla}\cdot\left[(f + \nabla^2\psi)\bar{\nabla}\psi\right] \qquad \ldots\ldots(2.9)$$

where $\Phi$ is the geo-potential.

Eqn.(2.9) may be used as a basis for a forecast model which filters out the gravity wave solutions. It gives a complicated nonlinear relationship between $\Phi$ and $\psi$ and that is why it is not widely used in numerical forecasting.

It is observed for synoptic scale motions the nonlinear terms are small compared to linear terms in the equation. Therefore, small terms can be neglected and stream function is given approximately by the relation

$$\psi = \frac{\Phi}{f_0} \qquad \ldots\ldots\ldots(2.10)$$

The approximate vorticity equation for a level of non-divergence becomes

$$\frac{\partial}{\partial t}\nabla^2\psi = -\bar{V}_\psi\cdot\bar{\nabla}(\nabla^2\psi + f) \qquad \ldots\ldots(2.11)$$

## 2.5 Numerical Technique

The objective of numerical prediction is to predict the future state of the atmospheric circulation from knowledge of its present state by use of the dynamical equations. To fulfill this objective we need

(1) The intial state of the field variables.

(2) A closed set of prediction equations relating the field variables.

(3) A method of integrating the equations in time to obtain the future distribution of the field variables.

The most common numerical integration procedure for weather prediction has been the finite difference method in which the derivatives in the differential equations of motion are replaced by finite difference approximations at a discrete set of points in space and time.

There are a number of problems associated with deriving finite difference analogs to partial differential equations.

(i) Computational stability:

A solution of the difference equations approximate a solution of the original system. It turns out that the ratio of the time and space increments must satisfy certain conditions. Courant-Friedrichs-Levy (CFL) [22]. Condition for computation stability is

$$C \frac{\Delta t}{\Delta x} \leq 1.$$

C = wave speed

$\Delta t$ = time step

$\Delta x$ = grid length.

(ii) Truncation error:

Difference equation is only an approximation to the differential equation, the accuracy of the former may be measured by taking the difference between the two, which is called the Truncation error $T_r$.

$T_r$ = difference equation - differential equation.

## 2.6 Numerical solution of the Barotropic Vorticity equation

The barotropic model is the simplest dynamic tropical cyclone track prediction model. To produce a forecast, we require the numerical solution of some type of vorticity equation. The governing equation is given by

$$\nabla^2 \chi + F(x, y, t) = 0 \qquad \text{......(2.12)}$$

Where

$$F(x,y,t) = \bar{V}_\psi \cdot \bar{\nabla}(\nabla^2\psi + f) = \frac{\partial\psi}{\partial x}\frac{\partial}{\partial y}\nabla^2\psi - \frac{\partial\psi}{\partial y}\frac{\partial}{\partial x}\nabla^2\psi + \beta\frac{\partial\psi}{\partial x} \quad \ldots (2.13)$$

and

$$\chi = \frac{\partial\psi}{\partial t} \quad \ldots\ldots (2.14)$$

The advection of absolute vorticity F(x,y,t) may be calculated at any point in space provided that we know the field of $\psi(x,y,t)$. Equation (2.12) is a poisson equation in the variable $\chi$ with F(x,y,t) a known source function. It may be solved for $\chi$ by several standard methods. The most common method is to write equation (2.12) in finite difference form and solve for $\chi$ approximately using the iterative method called relaxation. Let the horizontal x,y, space is divided into a grid of (M+1) x (N+1) points separated by distance increment h. Then we can write the co-ordinate distances as x=mh and y=nh, where m=0,1,2...... M and n = 0,1,2, ......N. Thus any point on the grid is uniquely identified by the indices (m.n).

Using centered difference formulas, derivatives of $\psi$ at the point (m,n) may be expressed in terms of the values of $\psi$ at surrounding points,

$$\left(\frac{\partial\psi}{\partial x}\right)_{m,n} \simeq \frac{\psi_{m+1,n} - \psi_{m-1,n}}{2h} \quad \ldots\ldots (2.15)$$

$$\left(\frac{\partial\psi}{\partial y}\right)_{m,n} \simeq \frac{\psi_{m,n+1} - \psi_{m,n-1}}{2h} \quad \ldots\ldots (2.16)$$

In a similar fashion second derivatives can be written as

$$\left(\frac{\partial^2\psi}{\partial x^2}\right)_{m,n} \simeq \left[\psi_{m+1,n} - 2\psi_{m,n} + \psi_{m-1,n}\right]/h^2 \quad \ldots \quad (2.17)$$

$$\left(\frac{\partial^2\psi}{\partial y^2}\right)_{m,n} \simeq \left[\psi_{m,n+1} - 2\psi_{m,n} + \psi_{m,n-1}\right]/h^2 \quad \ldots \quad (2.18)$$

Thus, we may write as the finite difference approximation to the horizontal laplacian:

$$\nabla^2\psi \simeq \left[\psi_{m+1,n} + \psi_{m,n+1} + \psi_{m-1,n} + \psi_{m,n-1} - 4\psi_{m,n}\right]/h^2 \quad \ldots \quad (2.19)$$

It is possible to obtain finite difference analog in which both the energy and average vorticity are conserved on the grid mesh. So, as a finite difference form for F(x,y), we take centered differences to get

$$\begin{aligned} F_{m,n} \simeq \frac{1}{4h^2}\Big[ & (\psi_{m+1,n+1} - \psi_{m-1,n+1})\nabla^2\psi_{m,n+1} \\ & - (\psi_{m+1,n-1} - \psi_{m-1,n-1})\nabla^2\psi_{m,n-1} \\ & - (\psi_{m+1,n+1} - \psi_{m+1,n-1})\nabla^2\psi_{m+1,n} \\ & + (\psi_{m-1,n+1} - \psi_{m-1,n-1})\nabla^2\psi_{m-1,n}\Big] \\ & + \beta/2h\,(\psi_{m+1,n} - \psi_{m-1,n}) \quad \ldots \quad (2.20) \end{aligned}$$

It is verified that

$$\sum_{m=1}^{M-1} \sum_{n=1}^{N-1} F_{m,n} = 0 \qquad \text{. . . . .} \qquad (2.21)$$

Provided that $\psi$ is constant on the boundaries, otherwise, the average vorticity will not be conserved in the finite difference form of the vorticity equation. In addition to conservation of average vorticity, kinetic energy and mean square vorticity are also conserved.

Finite difference form of equation (2.20) may be written as

$$\nabla^2 \chi_{m,n} + F_{m,n} = 0 \qquad \text{...........} (2.22)$$

Relaxation:

To solve the equation (2.21) for (m,n) a simple scheme on a large grid mesh an iterative technique known as relaxation is used. Relaxation is an iterative procedure. Relaxation schemes may be dividied into two classes: (1) Simultaneous relaxation and (2) Successive relxation. First an initial guess of the solution is made and then progressively improved until an acceptable level of accuracy is reached. We thus label $\chi$ with the superscript $\nu$ to indicate the $\nu$th guess $\chi^{\nu}$ .If the method is convergent, $\chi^{\nu}$ should approach the true solution $\chi$ at all points as $\nu \rightarrow \infty$ . We write the initial guess for the $\chi$ field as $\chi^{0}_{m,n}$. Equation (2.21) can be written as

$$\chi^{0}_{m+1,n} + \chi^{0}_{m-1,n} + \chi^{0}_{m,n+1} + \chi^{0}_{m,n-1} - 4\chi^{0}_{m,n} = -d^{2}F_{m,n} + R^{0}_{m,n} \qquad \ldots \quad (2.23)$$

where $R^{0}_{m,n}$ is the residual which is a measure of the difference between the initial guess and the true solution. The residual at any point (m,n) may be reduced to zero by altering the guess $\chi^{0}_{m,n}$ at that point to $\chi^{1}_{m,n}$ defined by

$$\chi^{1}_{m,n} = \chi^{0}_{m,n} + \frac{1}{4} R^{0}_{m,n} \quad \ldots \quad (2.24)$$

while leaving the guesses at all surrounding points unchanged.

It is clear that once a new guess has been made at a given point, the new values can be used to modify the residuals at the surrounding points. Thus, the residuals can be computed sequentially starting from grid point (1,1) and working to the right along the grid to point (M-1,1), then skipping to the second interior row of points and working from point (1,2) to (M-1,2) etc.

<u>Time integration</u>

To forecast the future circulation, the calculated $\chi_{m,n}$ field is extrapolated ahead in time using a finite difference approximation. Choosing a centered differencing scheme $\psi$ can be written as

$$\psi(t_0 + \delta t) = \psi(t_0 - \delta t) + 2\,\delta t\,\chi(t_0) \quad \ldots \quad (2.25)$$

This scheme requires the values of $\psi$ at two time levels, $\psi(t_0 - \delta t)$ and $\psi(t_0)$ in order to compute $\psi(t_0 + \delta t)$. Since at the first time step of the forecast ($t_0 = 0$) only $\psi(t_0)$ is known, to initiate the forecast a forward time step is used. Thus

$$\psi(\delta t) = \psi(0) + \delta t\,\chi(0) \quad \ldots \quad (2.26)$$

A larger value of $\delta t$ will tend to give a poor approximation due to truncation errors. Such errors can be controlled by making $\delta t$ sufficiently small.

# CHAPTER 3

# TRACK PREDICTION OF BAY OF BENGAL CYCLONES

## 3.1 Bay of Bengal Cyclones

Bangladesh is a part of the humid tropics with the Himalayas in the North and a funnel shaped coast line touching the Bay of Bengal in the South. This peculiar geography causes Bangladesh very often the landing ground of cyclones causing a lot of damage. Because of the low flat terrain, high density of population and poorly built houses, most of the damage occurs in the coastal districts and in the off-shore islands.

Of all the terrible cyclones that have hit Bangladesh perhaps the most deadly was that of 12 November 1970. The damage to property and crops was colossal. The estimated maximum wind speed was about 224 Km. p.h. (140 m/hours) and the maximum storm surge height about 9m (30 ft). The cyclone occured during a high tide period and hence the great surge height. There is a record in Ain-E-Akbari of a great storm in 1584 which affected the coastal diatricts of Barisal, Noakhali and Chittagong. The storm surge due to this cyclone was thought to be about 12m (40 ft). About 200,000 people died.

In our country tropical cyclones occur mostly during pre (April-May) and post (Sept-Dec) monsoon period.

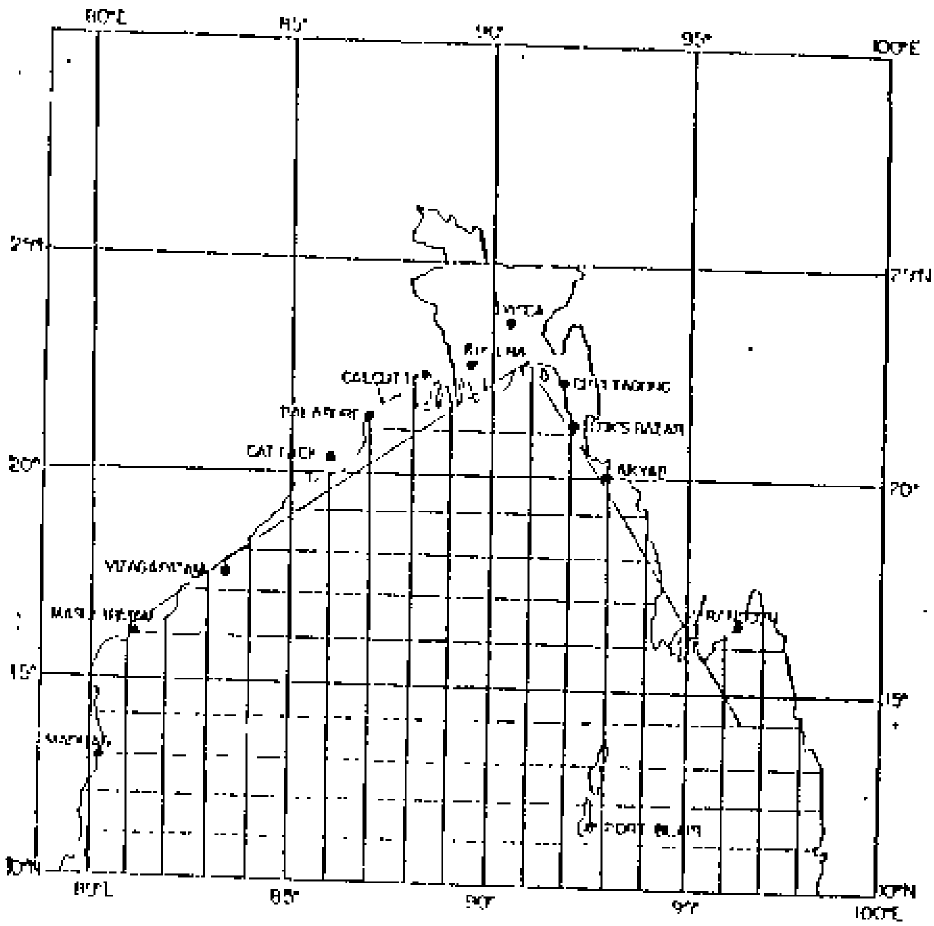



Fig 3.1. Funnel shaped coast line touching the Bay of Bengal in the south.

## 3.2 Area of analysis and grid representation

Area of analysis in this work covers from 0° to 30°N latitude and 70° to 100°E longitude, which includes most part of the Bay of Bengal, Bangladesh, Souterhn part of India and Burma.

It is normal practice that the contours are drawn for different layers of the atmosphere. Here one 500 mb height contour and one 850mb height contour was chosen for analysis.

The whole contour area is divided in 25 x 25 equidistant that is 625 grid points.

An example of the contour within the area under study is shown in fig. (3.2). As the contour lines do not pass through the grid points, the values of the geo-potential height are needed to be calculated from the given contour values. Taylor series expansion can be applied very effectively in this regard. Let $\Phi(x,y)$ represent the value of geopotential height at any point, then

$$\Phi(x+h_x,y) = \Phi(x,y) + h_x \frac{\partial \Phi}{\partial x} + \quad \ldots\ldots\ldots\ldots (3.1)$$

where $h_x$ is the finite increment along +x direction.

and

$$\Phi(x-h'_x,y) = \Phi(x,y) - h'_x \frac{\partial \Phi}{\partial x} + \ldots\ldots\ldots\ldots (3.2)$$

Date - 7 - 11 - 83 Time - 0000 GMT

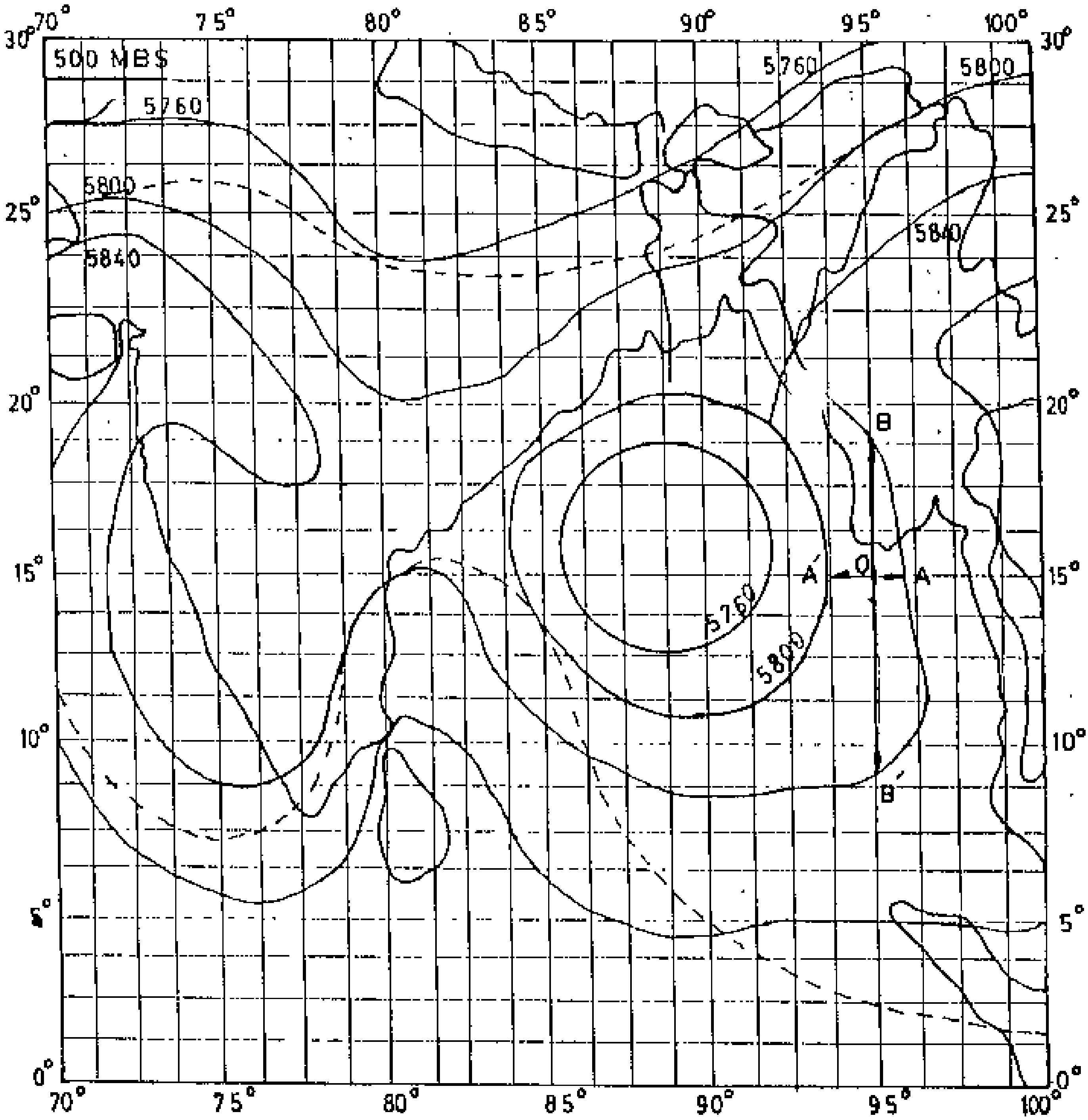



Fig 3.2. Contour diagram and determination of the grid point at position O.

OA → $h_x$ For point O between contours 5800 and 5840

OA′ → $h'_x$ $\frac{\partial \phi}{\partial x} = \frac{40}{2} = 20$

OB → $h_y$ $\frac{\partial \phi}{\partial y} = 0$

OB′ → $h'_y$

$\phi'_x (h'_x - h_x) = 20(-1.1 - .9)$

$= -40$

$\phi'_y (h'_y - h_y) = 0$

Value of point: O

$\phi_{i,j} = [5840 + 5800 + 5840 + 5840 - 40 [illegible] / 4 = 58[illegible]$

$h'_x$ is the finite increment along -x direction.

adding 3.1 and 3.2

$$\Phi(x+h_x,y) + \Phi(x-h'_x,y) = 2\,\Phi(x,y) + \frac{\partial\Phi(x,y)}{\partial x}[h_x - h'_x]$$

$$\Phi(x,y) = \frac{1}{2}\,[\Phi_1 + \Phi_2 + \Phi'_x\,(h'_x - h_x)] \quad \ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

where
$\Phi_1 = \Phi(x+h_x, y)$
$\Phi_2 = \Phi(x-h'_x, y)$
$\Phi'_x = \frac{\partial\Phi}{\partial x}$

Similarly, we can write for y direction

$$\Phi(x,y) = \frac{1}{2}\,[\Phi_3 + \Phi_4 + \Phi'_y\,(h'_y - h_y)] \quad \ldots\ldots\ldots (3.4)$$

where
$\Phi_3 = \Phi(x, y+h_y)$
$\Phi_4 = \Phi(x, y-h'_y)$
$\Phi'_y = \frac{\partial\Phi}{\partial y}$

$h'_y$ finite increment along - y direction

$h_y$ finite increment along + y direction.

Therefore,

$$\Phi(x,y) = \frac{1}{4}\left[ ( \Phi_1 + \Phi_2 + \Phi_3 + \Phi_4 + \Phi'_x ( h'_x - h_x ) + \Phi'_y ( h'_y - h_y ) \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.5)}$$

Equation (3.5) is used for evaluation. All these works are done manually. For this reason it is very tedious and time consuming one and the computer which is used has not any contour evaluating facility. However, there are contour evaluating programmes in other computers.

On the boundaries only one known point is available and rest three points are not known. In such cases the boundary grid values are assumed to be the same as that of the nearest contours.

It is preferable to replace geo-potential $\Phi(Z)$ by a quantity called geopotential height which is defined as $Z = \Phi(Z)/g_0$ where $g_0$ = 9.80665 m/sec² is the global average of gravity at sea level. In troposphere and lower stratosphere Z is numerically very close to the geometric height.

After evaluating each grid point, computer programme is developed by using the finite difference form of the barotropic vorticity equation.

$\chi$ , time rate of change of stream function is evaluated by relaxation method. Time step for integration for forecasting is taken 30 minutes.

The results obtained for 30 minutes time-step integration is used as input for next 30 minutes forecast. In this manner the programme runs for 56 hours ahead for 7-11-83 cyclone and 48 hours for 12-11-84 cyclone.

Next task was to draw the geopotential height contours using the data obtained after integration. Contours are drawn by the computer. Then the location of the cyclone centre is compared with the actual cyclone centre that is supplied by the meteorological department.

3.3 Result

In the present work two cyclones have been studied. They are -

i) The cyclone of 7-11-83. For this cyclone 500mb height data were used.

ii) The cyclone of 12-11-84. For this cyclone 850mb height data were used.

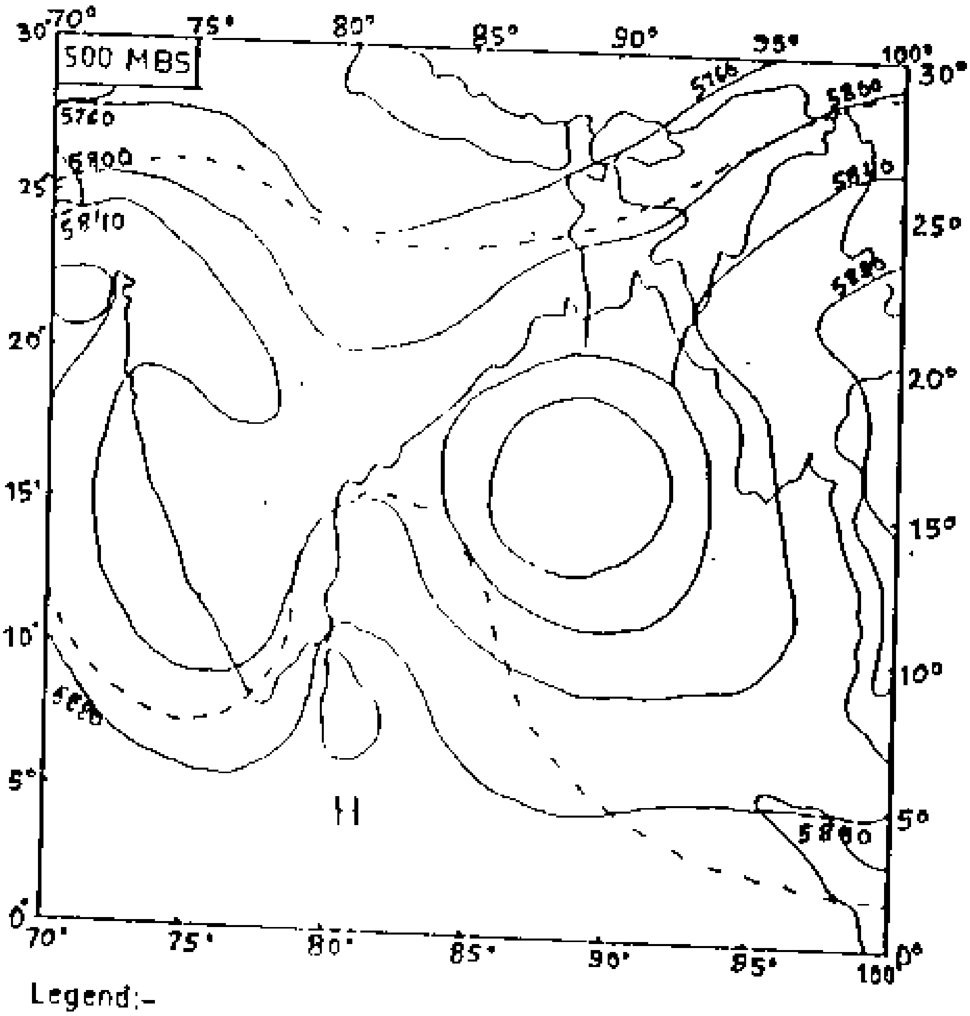
Cyclone of 7-11-83

The centre of the cyclone that occured on 7-11-83 was at the position 16.25° N latitude and 88.75°E longitude at 00:00 GMT. After 24 hours the centre shifted to 17.1° N latitude and 89.5° E longitude. After a lapse of further 24 hours ( i.e., 48 hours from 00:00 GMT on 7-11-83) the centre was found to occupy a position 90.0°E longitude and 18° N latitude and 91.8°E longitude and 18.8° N latitude after 56 hours.

Bangladesh Meteorological Department
Constant Pressure Chart

Date - 7 - 11 - 83

Time - 0000 GMT




Legend:-

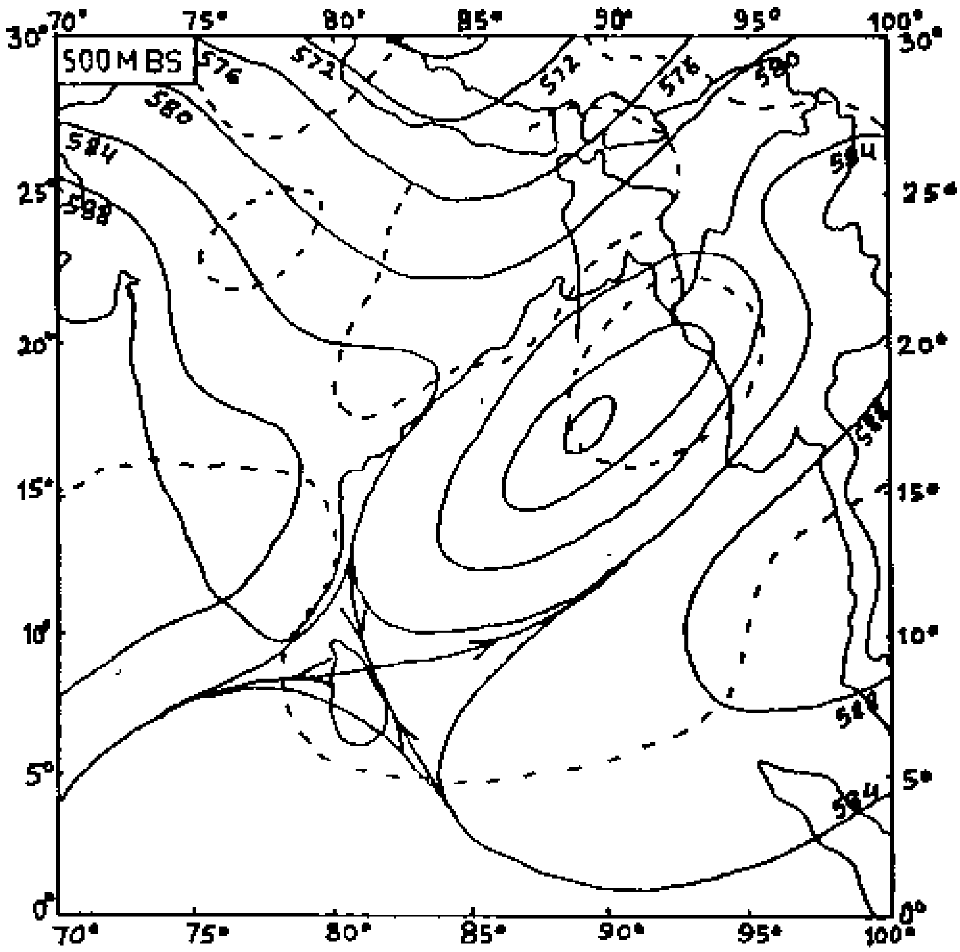
——— Contour line

- - - - Isotherm line

Bangladesh Meteorological Department

Constant Pressure Chart

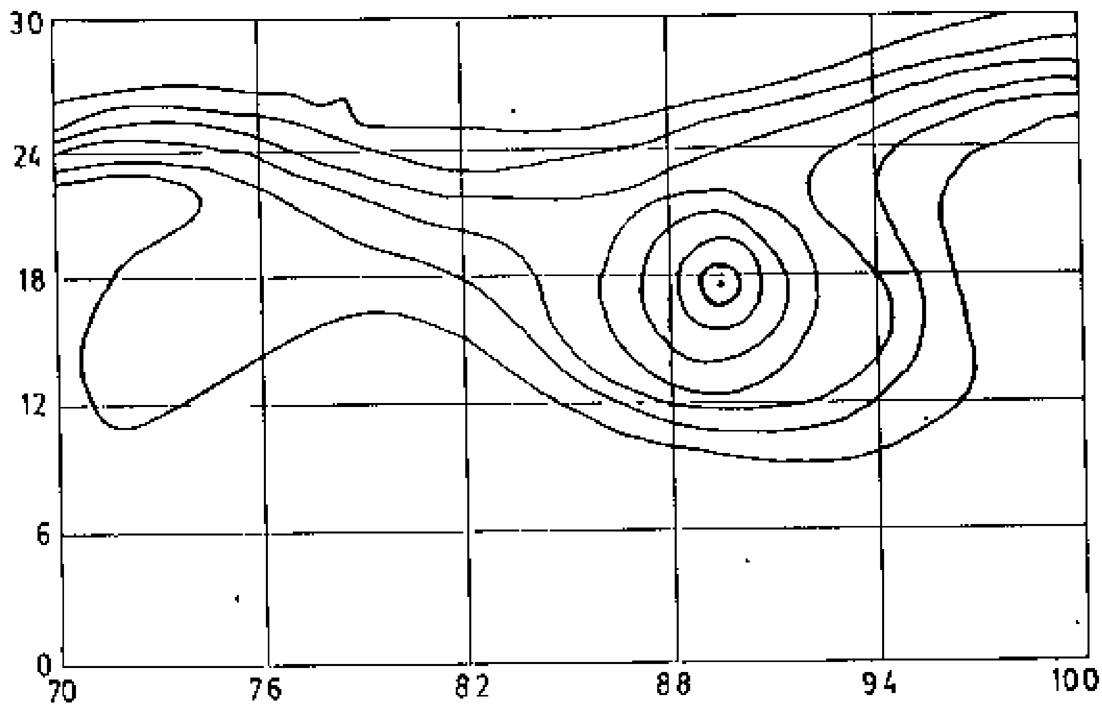
Date -8 - 11-83 Time -0000GMT



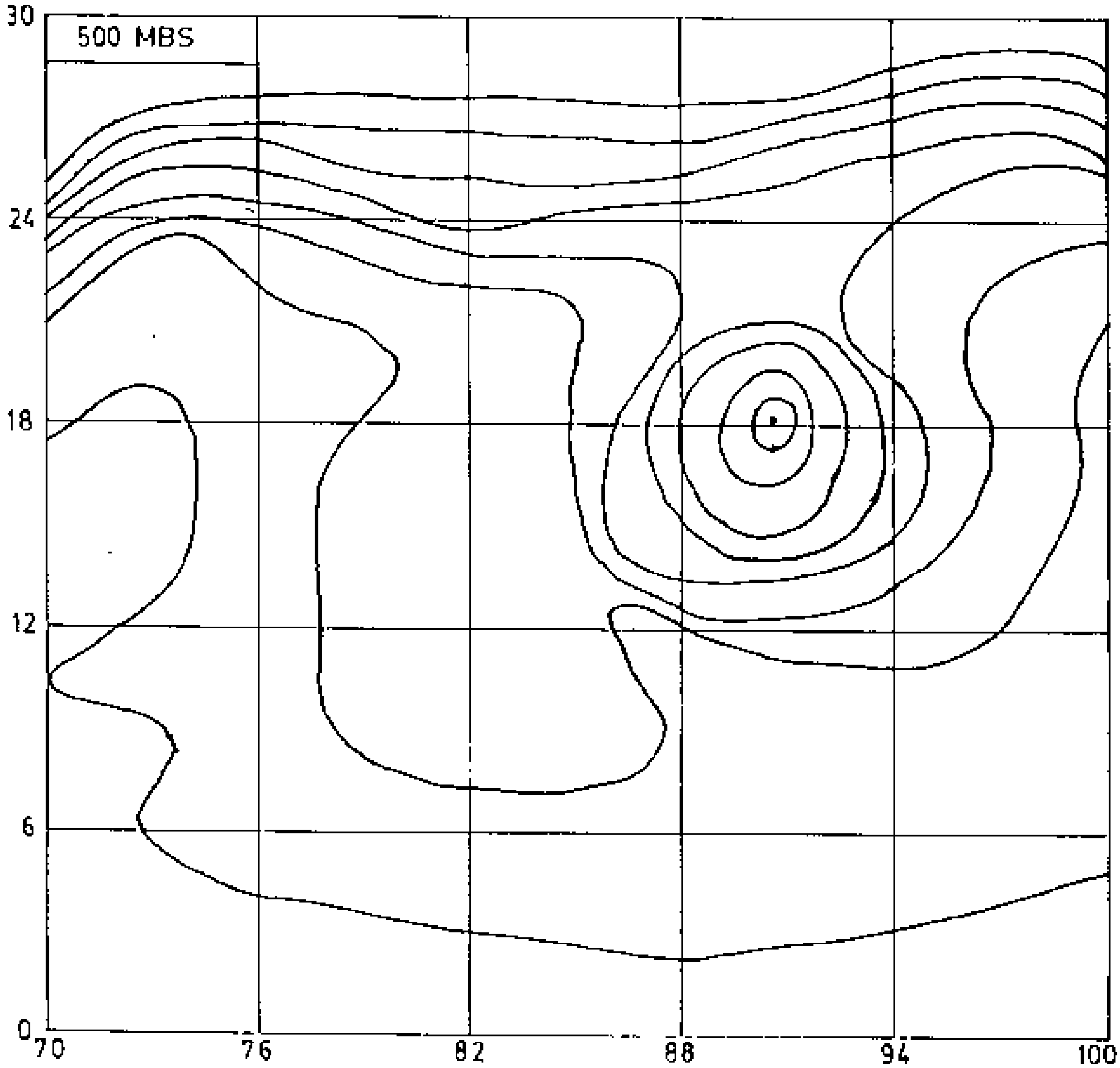

Legend -

——— Contour line

- - - - - Isotherm line




Date - 8 -11- 83
Time -0000 GMT




Date : 9.11.83
Time -0[illegible]00 GMT

TABLE 3:1

| Date | Height | Time | Centre of Cyclone | | | |
|---|---|---|---|---|---|---|
| | mb | GMT | Actual | | Predicted | |
| | | | Latitude | Longitude | Latitude | Longitude |
| 7.11.83 | 500 | 00.00 | $16.25^{\circ}N$ | $88.75^{\circ}E$ | $16.25^{\circ}N$ | $88.75^{\circ}E$ |
| 8.11.83 | 500 | 00.00 | $17.10^{\circ}N$ | $89.50^{\circ}E$ | $17.50^{\circ}N$ | $89.50^{\circ}E$ |
| 9.11.83 | 500 | 00.00 | $18.00^{\circ}N$ | $90.00^{\circ}E$ | $18.00^{\circ}N$ | $90.50^{\circ}E$ |
| 9.11.83 | 500 | 08.00 | $18.80^{\circ}N$ | $91.80^{\circ}E$ | $18.20^{\circ}N$ | $90.80^{\circ}E$ |

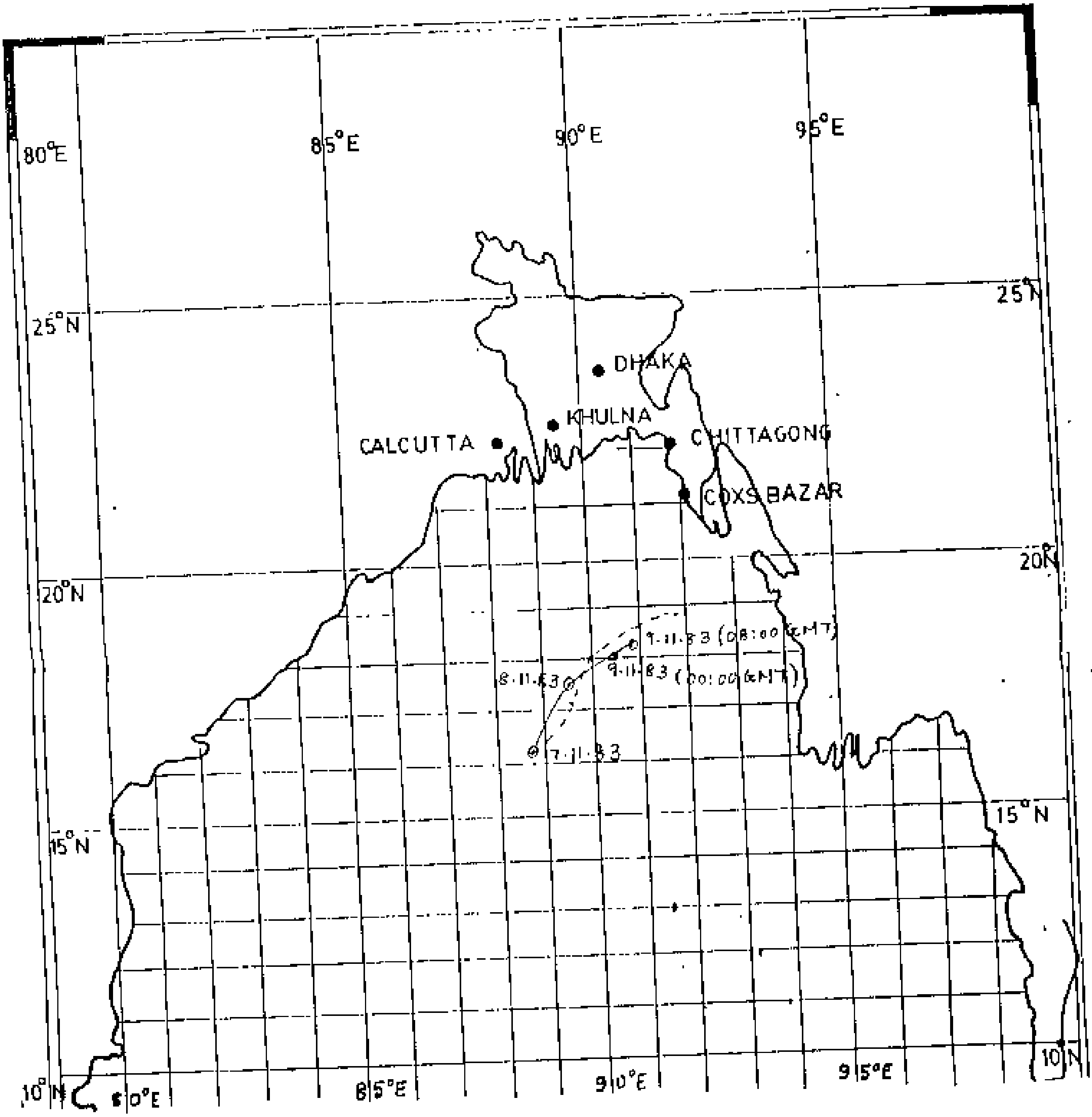



Fig 3.3. Predicted track of Bay of Bengal cyclone from 7.11.83 to 9.11.83.

PREDICTED TRACK.

ACTUAL TRACK.

Prediction on the basis of relevant data analysis applying BVE indicates a location 89.5°E longitude and 17.5° N latitude after 24 hours, a position of 90.5°E longitude and 18°N latitude after 48 hours and 90.8°E longitude and 18.2° latitude after 56 hours.

Cyclone of 12-11-84

The centre of the cyclone that occured on 12-11-84 was at the position 81.87°E and 13.2°N at 12:00 GMT. After 24 hours the centre shifted to 80° E and 14°N, After a lapse of further 24 hours ( 48 hours from 00:00 GMT on 12-11-84) the centre was found to occupy a position 79°E and 14.5°N. Prediction on the basis of relevant data analysis by applying BVE indicates a location 81.5° E and 13.5°N after 24 hours and 81.0°E and 15°N after 48 hours.

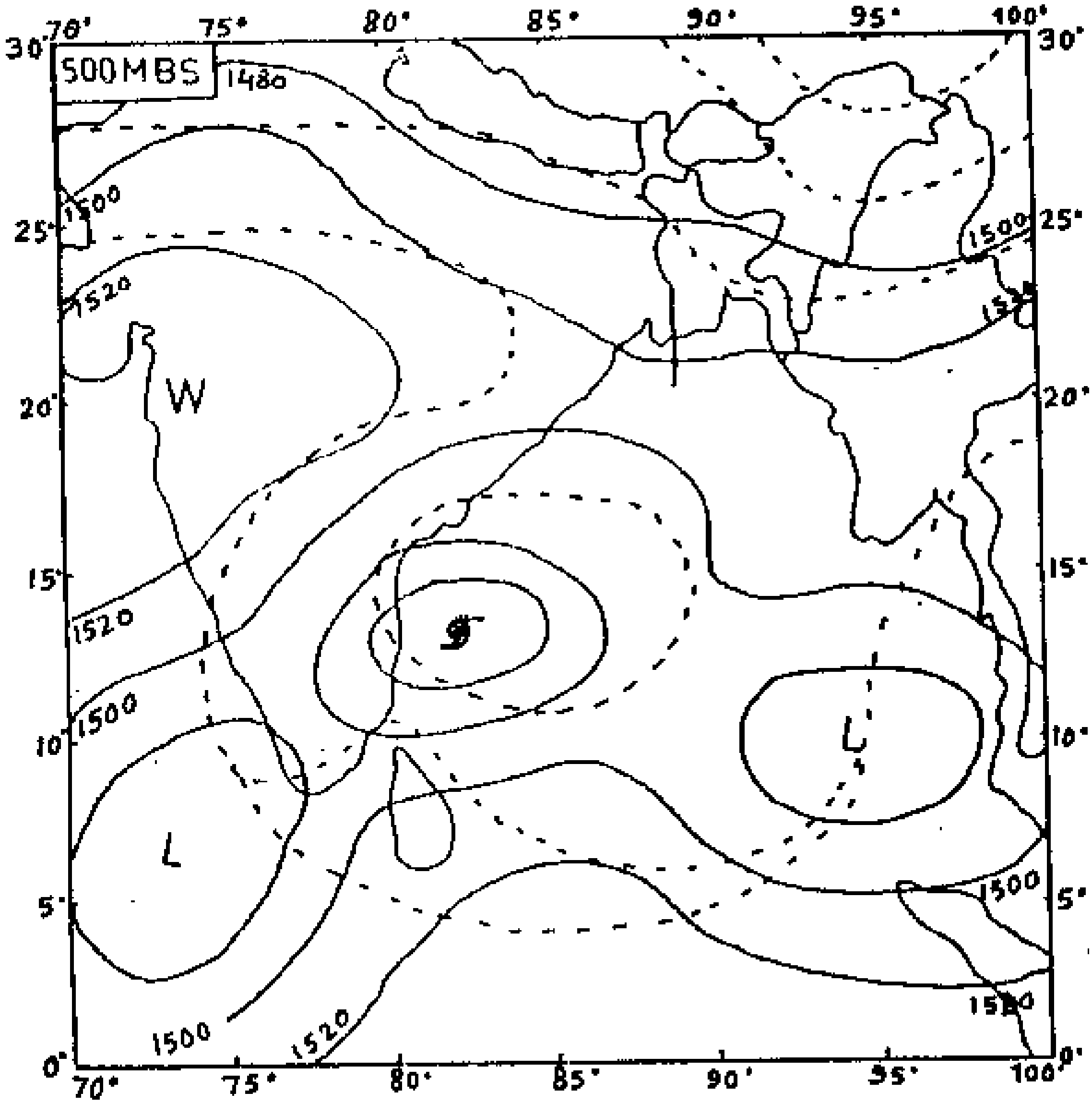
### 3.4 Discussion

The study of cyclone of 12-11-84 was undertaken with a different purpose; we wanted to apply the equation that has been developed for a pressure height of 500mb to a pressure height of 850 mb of another cyclone and to have some idea about the extent of divergence between the observed and the prescribed track. The results show that the divergnce both in respect of movement and location are quite different. This indicates that the equation has to be modified to suit a different pressure height.

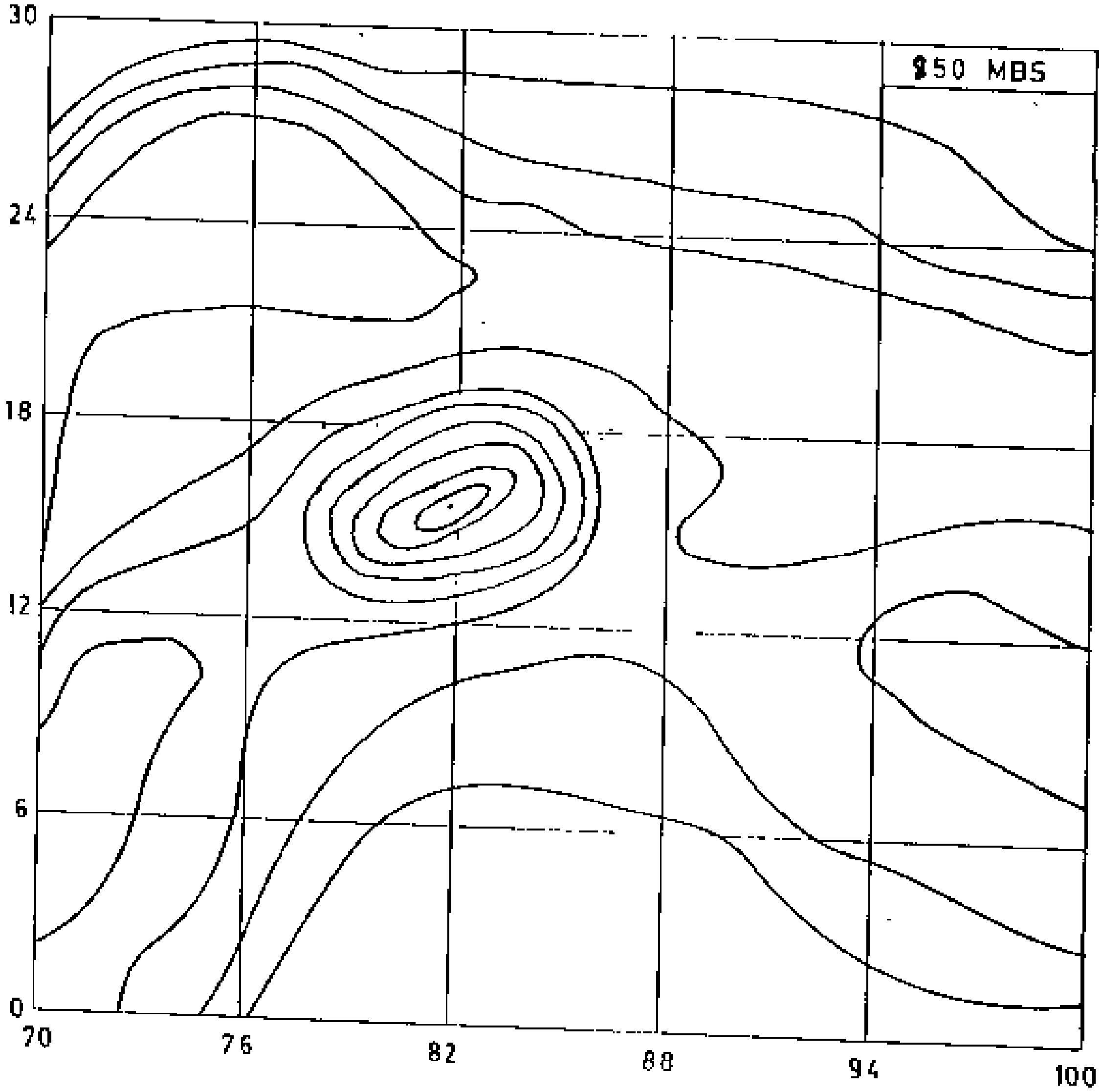
It is obvious from the study that the result is quite encouraging for the 7-11-83 cyclone inspite of the simplicity of the model. The deviation is more in the case of 12-11-84 cyclone.

Bangladesh Meteorological Deparment
Constant Pressure Chart

Date-12-11-84 Time-1200GMT




Legend -
——— Contour line
– – – – Isotherm line




Date : 14.11.84
Time - 12:00 GMT

TABLE 3.2

| Date | Height | Time | Centre of Cyclone | | | |
|---|---|---|---|---|---|---|
| | mb | GMT | Actual | | Predicted | |
| | | | Latitude | Longitude | Latitude | Longitude |
| 12.11.84 | 850 | 12.00 | 13.20°N | 81.87°E | 13.20°N | 81.87°E |
| 13.11.84 | 850 | 12.00 | 14.00°N | 80.00°E | 13.50°N | 81.50°E |
| 14.11.84 | 850 | 12.00 | 14.50°N | 79.00°E | 15.00°N | 81.00°E |

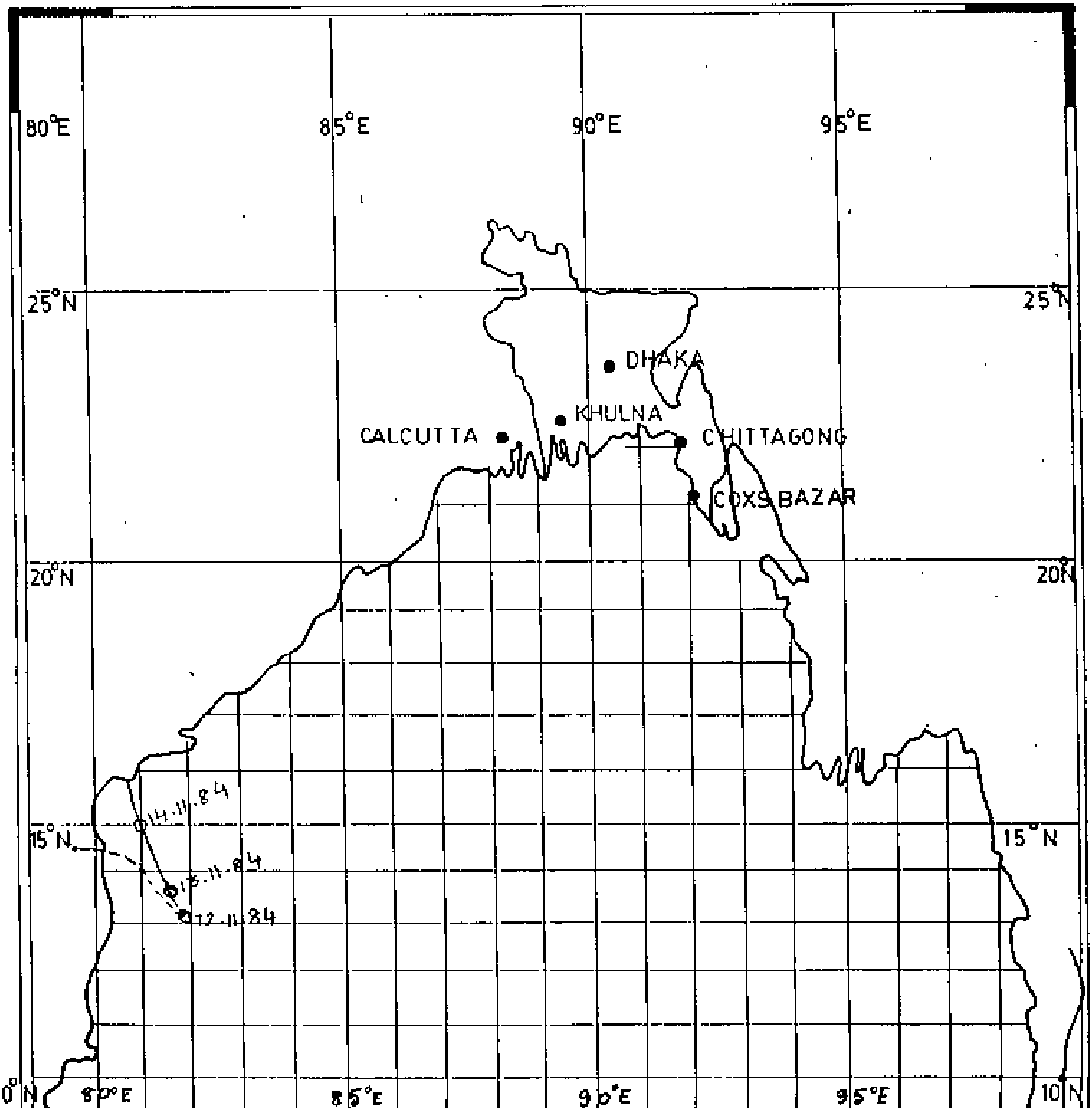



Fig 3.4. Predicted track of Bay of Bengal cyclone from 12.11.84 to 14.11.84

—o—o—o— PREDICTED TRACK

- - - - - - ACTUAL TRACK

This could be due to the fact that in the former case the data was used for 500mb where as in the case of latter data for 850 mb was used. Better results could be achieved by developing more complicated model.

CHAPTER 4

# MINIMIZING CYCLONE LOSSES

## 4.1 Introduction

Tropical cyclones are a major source of natural disaster and it is a meteorological event. It is important to know just where a cyclone will strike, how intense it will be and how long it will last. Because enormous loss of life and an untold variety and amount of damage can result from a cyclone passage. Although cyclones are small in number, the frequency of opportunity for their development per season, is always high.

For effective reduction of the impact of a cyclone and the risks of living in a cyclone-prone area, co-ordinated action at several levels of government is needed; beginning with some form of land use planning and regulation. Equally important in defending against a cyclone disaster are public awareness programmes to promote an understanding of the cyclone and its potential impact and of the measures that coastal residents must take to face the threat of a cyclone with minimal risk to their lives and property. Perhaps the most important single element in the defence against cyclone disaster is the cyclone prediction and warning service and its associated systems for communicating and interpreting warning advices to those who must take emergency actions on short notice to protect life and property.

### 4.2 Forecast Problems

The cyclones approaching the coast must contain at least five elements: (1) The current position, strength and movement, (2) The predicted time and position at landfall, (3) The strength at landfall, (4) Peak cyclonic tides and areas of inundation and (5) Specific warnings for the coastal areas at risk. Of these, the most critical are the predictions of position and strength at landfall. If these two are known, the remainder can usually be observed or derived from data supplied by the customary cyclone monitoring facilities - aircraft, weather satellites and radar. A rapid increase in cyclone strength during its last 12 hours at sea can sometimes double the peak-surge heights and escalate the urgency for evacuation.

### 4.3 Predicting Cyclone Movement

Cyclone prediction is not an exact science. Success in predicting cyclone movement depends upon the intial direction of movement, the stage of development and the strength of the steering current.

Three classes of models for predicting cyclone movement were in use in 1980:

(i) kinematic analog models
(ii) dynamic analog models
(iii) pure dynamical models

(i) The first draws upon the climatology of cyclone tracks and of persistence of movement to produce a most probable displacement of the center. The output is a function of initial position, past movement and time of occurance.

(ii) The second extracts from historical cases the dynamical properties of the near or the large-scale environment that correlate with some aspect of cyclone movement. These are combined in a multiple regression statement as analogs to the migration of the vortex.

(iii) The third model combines basic principles of fluid motion, the thermodynamics of an ideal gas, and the application of conservation relationships to predict the behaviour and displacement of the cyclone vortex.

## 4.4 Background of Prediction Methods

Movement: Before the advent of dynamic prediction models, cyclone movement was regarded conceptually as the response of a vortex to a steering current. Most forecast decision making was centered around the identification of the steering level and the reasoning about changes that could modify the steering and future track of the system.

In 1956 H. Riehl [23] proposed a model to provide objective predictions of movement. He considered that the best available index to steering the cyclone is the geostrophic flow of the environment at the level of non-divergence (4-6km). He computed zonal and meridional components of geostrophic wind from 500-mb analyses using a rectangular grid superimposed on the vortex. These data were used as inputs to a regression based upon historic storm cases to obtain the westward and northward components of displacement for the ensuing 24-hour period. The method worked quite well in a research environment, but operationally it suffered from subjectivity of hurried hand analyses for the 500-mb surface.

## 4.5 Development

The simulation of development is complex because of the need to incorporate explicity or by parameterization, the smaller-scale motions that distribute heat generated by the cumuli throughout the warm core. The explosive development of disturbances and rapid growth of cyclones into extreme events are currently beyond the reach of operational models and remain unresolved problems. These unresolved problems are the more important because significant changes in strength or size of the cyclone strongly influence the height of peak storm surges, the extent of coastal inundation and the requirement for evacuation.

Chapter 5

# GENERAL DISCUSSION

With the present scientific knowledge and technology available to man it is not possible to stop the formation of a cyclone. The accurate prediction of cyclone intensity and movement is pre-requisite for taking preparedness measures towards minimizing the loss of life and property due to this calamity.

In this dissertation attempts have been made to ascertain how far the application of the Barotopic vorticity equation to cyclones of this region will help us predict the cyclone tracks. The results show some discrepencies between the actual value and the predicted value. The discrepency may be partially due to the following reasons.

(i) The Barotropic model is idealistic. In such simplified models some terms are neglected or approximated in the governing equation and this gives rise to errors.

(ii) Incompltete uderstanding of various physical processes of tropical meteorology.

(iii) Bay of Bengal is situated between $0^{\circ}$ to $25^{\circ}$ North latitude. But the model equation is set up for middle latitude ($45^{\circ}$ latitude) synoptic scale for convenience and hence is in need of corrections.

(iv) Coriolis parameter varies with latitude. But in this dissertation an average value of this parameter has been taken.

(v) Values of the grid points are determined by Taylor series expansion. This method cannot give the correct input data; because at least four known points are required to evaluate a point. Any mistake in any one of the points will lead to large errors to other points and vitiate the result.

(vi) The laws governing the variations of various parameters are only approximate.

(vii) Because of the instabilities in the atmosphere (barotropic, baroclinic etc), there is a maximum time limit upto which predictions will be valid.

(viii) The governing Barotropic Vorticity equation is an exact model only for a homogeneous incompressible fluid confined between rigid, frictionless horizontal boundaries. It is obvious that the atmosphere does not meet these basic requirements.

(ix) One of the possible sources of error could be in the observations.

For more accurate predictions, the governing equation should be modified. Some parameters with proper weightage may be introduced in the equation.

It is proposed to study the above aspect further with a view to

(i) examine closely such deviations in respect of selected cyclones.

(ii) Modify the equation to suit the changed pressure heights.

(iii) Ascertain which equation yields the most satisfactory results of cyclones occuring in this region.

Cyclone is a synoptic scale phenomena and it frequently hits Bangladesh every year. Inspite of this, comprehensive and intensive research work has not so far been seriously undertaken on this catastrophic phenomenon. In this regard some research work have been done but they are inadequate and fewer in number. Hence the study of cyclone of Bay of Bengal should, therefore, receive the highest priority.

## Glossary

### Definition of Technical Terms

1. Coriolis force : Coriolis force is a deflecting force. It arises due to the rotation of the earth. It acts perpendicular to the velocity vector, can change only the direction of travel and the deflection is to the right direction of motion.

2. Vorticity : It is an important parameter widely used in the study of meteorology. It is a vector measure of the local rate of rotation of a fluid. It is a microscopic quantity.

3. Track : The path taken by the centre of a tropical Cyclone.

4. Barotropic Environment : An atmosphere in which temperature variations in the horizontal directions are small or absent, with density a function of pressure alone. The surface of equal density do not intersect in the isobaric surfaces.

5. Baroclinic environment : An atmosphere characterized by significant variations in temperature, horizontally with density a function of both pressure and temperature. Constant pressure surfaces (isobaric) intersect constant density surfaces.

6. Geo-potential : At any height Z it is defined as the work required to raise a unit mass to height Z from sea level.

7. Conditinal instability : The state of a column of air when its

vertical distribution of temperature is such that the layer is stable for dry air but unstable for saturated air.

8. Hydrostatic equilibrium : The state of a fluid in which complete balance exists between the force of gravity and the pressure force.

9. Synoptic chart : In meteorology, any chart or map on which data and analyses are presented that describe the atmosphere over a large area at a given moment.

10. Beta-plane approximation : The Coriolis parameter can be expanded in a Taylor series about the latitude as follows

$$f = f_0 + \beta y + \text{higher terms}$$

Where $\beta = df/dy$ . If let L designate the latitudinal scale of the motions, then the ratio of the first two terms in the expansion of f has order of magnitude

$$\beta L/f_0 \sim [\cos\phi_0 . L]/[\sin\phi_0 . a]$$

When $L/a \ll 1$ , then it is assumed that $\beta = df/dy$ is constant. This approximation is usually termed as the beta- plane approximation.

DATE - 7-11-83

500 OBS

| | | | | |
|---|---|---|---|---|
| 5700 | 5760 | 5760 | 5760 | 5760 |
| 5760 | 5760 | 5760 | 5760 | 5760 |
| 5760 | 5760 | 5760 | 5700 | 5700 |
| 5760 | 5760 | 5700 | 5700 | 5760 |
| 5760 | 5760 | 5777,72 | 5705,6 | 5790,8 |
| 5760 | 5760 | 5760,925 | 5760 | 5760,925 |
| 5761,592 | 5760,112 | 5762,427 | 5760,326 | 5761,12 |
| 5760,353 | 5760,504 | 5760,244 | 5760,504 | 5761,19 |
| 5760,204 | 5761,089 | 5760 | 5766,201 | 5772,676 |
| 5776,403 | 5785,149 | 5790,047 | 5800 | 5800,4 |
| 5760 | 5700 | 5760 | 5760,7 | 5760 |
| 5760 | 5766,269 | 5760,443 | 5760,34 | 5760,855 |
| 5761,198 | 5760,556 | 5761,139 | 5760,419 | 5760,815 |
| 5764,347 | 5700 | 5760 | 5777,405 | 5785,125 |
| 5793,3 | 5800,487 | 5800,317 | 5814,1 | 5822,6 |
| 5791,33 | 5781,53 | 5784,6 | 5781,4 | 5778,2 |
| 5773,33 | 5760 | 5769,123 | 5761,358 | 5761,691 |
| 5761,224 | 5761,156 | 5760,244 | 5762,554 | 5760 |
| 5760 | 5775,021 | 5770,594 | 5788,272 | 5795,56 |
| 5800,544 | 5812,919 | 5825,955 | 5840 | 5840 |
| 5800 | 5805,10 | 5808,57 | 5800,2 | 5794,15 |
| 5781,806 | 5782,793 | 5760 | 5760 | 5764,127 |
| 5762,207 | 5760 | 5760 | 5760 | 5768,2 |
| 5790,620 | 5783,432 | 5795,330 | 5800,7 | 5812,564 |
| 5813,278 | 5840 | 5845,501 | 5849,23 | 5861,5 |
| 5840 | 5848,16 | 5878,442 | 5840 | 5804,855 |
| 5805,9 | 5784,531 | 5783,770 | 5773,765 | 5760 |
| 5760 | 5766,3 | 5775,182 | 5774,63 | 5784,21 |
| 5795,91 | 5803,1[illegible] | 5827,442 | 5819,041 | 5811,74 |
| 5887,4 | 5831,895 | 5855,216 | 5857,511 | 5874,75 |
| 5870,75 | 5876,66 | 5854,773 | 5828,73 | 5840 |
| 5805,595 | 5807,64 | 5790,504 | 5784,69 | 5780,3 |
| 5777,256 | 5781,775 | 5700,506 | 5793,55 | 5789,713 |
| 5796,667 | 5798,37 | 5810,801 | 5807,224 | 5841,4 |
| 5875,756 | 5855,635 | 5852,943 | 5880 | 5880 |
| 5880 | 5880 | 5856,610 | 5850,382 | 5825,008 |
| 5842,09 | 5807,986 | 5800 | 5796,234 | 5794,991 |
| 5791,181 | 5790,542 | 5800,59 | 5790,952 | 5797,572 |
| 5797,061 | 5801,627 | 5802,779 | 5823,275 | 5816,946 |
| 5840,925 | 5842,445 | 5880 | 5880 | 5880 |
| 5880 | 5880 | 5863,110 | 5841,074 | 5845,84 |
| 5824,634 | 5840 | 5811,003 | 5805,8 | 5803 |
| 5811,40 | 5799,647 | 5797,122 | 5795,951 | 5801,26 |
| 5798,12 | 5800 | 5810,201 | 5805,521 | 5832,7 |
| 5829,223 | 5858,960 | 5851,776 | 5880 | 5880 |
| 5880 | 5873,47 | 5840,67 | 5840,063 | 5840 |
| 5842,394 | 5825,541 | 5817,493 | 5814,55 | 5813,879 |
| 5806,22 | 5801,332 | 5800,6 | 5785,086 | 5785,041 |
| 5760 | 5779,83 | 5782,277 | 5800 | 5813,00 |
| 5840 | 5844,661 | 5826,328 | 5880 | 5880 |
| 5870,29 | 5869,13 | 5840 | 5840,634 | 5843,295 |
| 5840 | 5840 | 5826,445 | 5825,77 | 5817,671 |
| 5812,467 | 5804,50 | 5780,234 | 5700,092 | 5760 |
| 5760 | 5760 | 5700 | 5721,589 | 5812,825 |
| 5825,327 | 5848,75 | 5821,657 | 5880 | 5880 |
| 5868,23 | 5848 | 5840 | 5841,313 | 5839,866 |
| 5841,521 | 5835,457 | 5836,651 | 5830,233 | 5824,657 |
| 5819,680 | 5810 | 5791,708 | 5760 | 5766,989 |
| 5760 | 5760,406 | 5700 | 5783,931 | 5804 |
| 5807,304 | 5841,003 | 5800,204 | 5800 | 5880 |
| 5864,21 | 5845 | 5840 | 5840,061 | 5841,357 |

| | | | | |
|---|---|---|---|---|
| 5830,707 | 5840,834 | 5780,615 | 5740 | 5840,2 |
| 5820,39 | 5816,3 | 5785,512 | 5700 | 5760 |
| 5761,064 | 5760 | 5700 | 5782,175 | 5802,9 |
| 5872,067 | 5845 | 5857,42 | 5809,063 | 5880 |
| 5865,45 | 5845 | 5840 | 5841,807 | 5840,379 |
| 5843,097 | 5833,368 | 5842,067 | 5841,403 | 5834,856 |
| 5843,03 | 5812,048 | 5796,67 | 5760 | 5760 |
| 5760 | 5760 | 5760 | 5771,786 | 5804,7 |
| 5825,61 | 5840 | 5855,59 | 5808,513 | 5880 |
| 5866,89 | 5852 | 5840 | 5840,6 | 5845,631 |
| 5842,087 | 5843,964 | 5840 | 5843,47 | 5848,799 |
| 5835,565 | 5830,846 | 5806,724 | 5736,625 | 5783,312 |
| 5765 | 5700 | 5789,702 | 5797,900 | 5814,542 |
| 5829,921 | 5840 | 5856,432 | 5868,136 | 5880 |
| 5871,7 | 5869,06 | 5840 | 5850,030 | 5842,021 |
| 5847,494 | 5846,583 | 5843,2 | 5856,011 | 5853,755 |
| 5859,790 | 5841,6 | 5829,831 | 5819,240 | 5800 |
| 5800 | 5800 | 5800 | 5807,02 | 5822,455 |
| 5833,75 | 5847,579 | 5850,396 | 5869,696 | 5880 |
| 5880 | 5869,421 | 5844,745 | 5840 | 5850,815 |
| 5845,393 | 5850,005 | 5852,143 | 5880 | 5880 |
| 5855,988 | 5855,622 | 5830,860 | 5830,33 | 5824,092 |
| 5830,284 | 5819,345 | 5811,255 | 5825,409 | 5830,942 |
| 5842,449 | 5849,517 | 5867,318 | 5870,329 | 5880 |
| 5880 | 5874,513 | 5861,996 | 5843,208 | 5841,11 |
| 5840,52 | 5851,89 | 5863,048 | 5880 | 5871,892 |
| 5800 | 5856,704 | 5850,465 | 5840,918 | 5849,136 |
| 5833,2 | 5808 | 5839,18 | 5840 | 5840 |
| 5840 | 5859,814 | 5864,127 | 5873,202 | 5880 |
| 5830, | 5880 | 5873,846 | 5854,559 | 5864,467 |
| 5861,797 | 5866,127 | 5871,893 | 5880 | 5879,177 |
| 5871,670 | 5880 | 5860,30 | 5861,068 | 5857,332 |
| 5860,902 | 5852,106 | 5852,254 | 5853,039 | 5854,823 |
| 5859,919 | 5862,77 | 5876,570 | 5874,67 | 5880 |
| 5880 | 5878,461 | 5800 | 5879,2 | 5875,13 |
| 5874,94 | 5877,07 | 5880 | 5877,42 | 5877,722 |
| 5879,29 | 5880 | 5878 | 5870,9 | 5869,438 |
| 5665,91 | 5866,119 | 5865,736 | 5866,834 | 5868,24 |
| 5860,396 | 5872,624 | 5874,90 | 5877,644 | 5880 |
| 5880 | 5800 | 5880 | 5870 | 5880 |
| 5880 | 5800 | 5880 | 5800 | 5878,911 |
| 5879,307 | 5879,069 | 5880 | 5880 | 5879 |
| 5877,8 | 5877,8 | 5880 | 5880 | 5800 |
| 5800 | 5880 | 5880 | 5880 | 5880 |
| 5880 | 5800 | 5879,999 | 5879,909 | 5879,992 |
| 5879,996 | 5879,956 | 5879,975 | 5879,605 | 5879,765 |
| 5879,31 | 5879,74 | 5879,656 | 5879,677 | 5880 |
| 5880 | 5880 | 5880 | 5880 | 5880 |
| 5880 | 5800 | 5000 | 5980 | 5880 |
| 5880 | 5880 | 5880 | 5879,996 | 5879,998 |
| 5879,974 | 5879,395 | 5879,849 | 5879,913 | 5879,662 |
| 5879,839 | 5879,677 | 5879,814 | 5879,878 | 5879,094 |
| 5879,991 | 5879,902 | 5880 | 5990 | 5880 |
| 5880 | 5880 | 5880 | 5580 | 5080 |
| 5080 | 5800 | 5879,999 | 5879,909 | 5879,992 |
| 5879,996 | 5879,956 | 5879,975 | 5879,977 | 5879,998 |
| 5879,835 | 5879,913 | 5879,889 | 5879,927 | 5879,967 |
| 5879,972 | 5879,990 | 5879,998 | 5880 | 5880 |
| 5880 | 5800 | 5880 | 5880 | 5880 |
| 5880 | 5980 | 5880 | 5880 | 5900 |
| 5800 | 5800 | 5880 | 5880 | 5880 |

DATE : 12-11-84.

850 MBS

| | | | | |
|---|---|---|---|---|
| 1200 | 1480 | 1480 | 1400 | 1480 |
| 1480 | 1480 | 1480 | 1420 | 1480 |
| 1480 | 1480 | 1400 | 1400 | 1480 |
| 1480 | 1480 | 1480 | 1480 | 1480 |
| 1490 | 1400 | 1400 | 1480 | 1400 |
| 1480 | 1400 | 1400 | 1400 | 1480 |
| 1400 | 1407,8 | 1495,8 | 1480 | 1480 |
| 1480 | 1480 | 1480 | 1480 | 1480 |
| 1400 | 1480 | 1480 | 1400 | 1480 |
| 1480 | 1400 | 1480 | 1480 | 1480 |
| 1480 | 1480 | 1403 | 1497,7 | 1500 |
| 1501,2 | 1500,2 | 1495,6 | 1490 | 1483 |
| 1450 | 1480 | 1480 | 1480 | 1400 |
| 1400 | 1400 | 1480 | 1480 | 1480 |
| 1480 | 1470 | 1480 | 1480 | 1480 |
| 1480 | 1490 | 1501,2 | 1505,9 | 1508,3 |
| 1508,7 | 1507,6 | 1504,9 | 1500 | 1492,7 |
| 1487,5 | 1481,3 | 1480 | 1480 | 1480 |
| 1480 | 1480 | 1480 | 1480 | 1480 |
| 1480 | 1480 | 1480 | 1480 | 1400 |
| 1490 | 1504,7 | 1510,2 | 1514,5 | 1515,9 |
| 1516 | 1514,9 | 1512,1 | 1507,5 | 1500 |
| 1497,1 | 1488,1 | 1489 | 1485,5 | 1483,9 |
| 1480,7 | 1480 | 1480 | 1480 | 1480 |
| 1470 | 1480 | 1480 | 1480 | 1490 |
| 1400 | 1512,2 | 1518,4 | 1520 | 1520 |
| 1520 | 1520 | 1517,1 | 1513,2 | 1507,4 |
| 1503,1 | 1497,9 | 1496,6 | 1493 | 1492 |
| 1408,8 | 1487,4 | 1486,5 | 1484,5 | 1482,4 |
| 1480 | 1490 | 1480 | 1480,8 | 1487 |
| 1490,2 | 1520 | 1520 | 1540 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1516 |
| 1513,7 | 1508,4 | 1507,9 | 1501,3 | 1493,7 |
| 1492,7 | 1491 | 1491,7 | 1491,4 | 1490,9 |
| 1490 | 1489,7 | 1489,9 | 1491 | 1493 |
| 1500 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1517,6 | 1513,6 | 1510,7 | 1507,1 | 1503,9 |
| 1500 | 1497,9 | 1498 | 1500 | 1500 |
| 1499 | 1499 | 1500 | 1502 | 1503 |
| 1505 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1513,1 | 1506,8 | 1504,8 | 1502,6 | 1501,4 |
| 1500 | 1502 | 1500 | 1500 | 1500 |
| 1500 | 1500 | 1500 | 1500 | 1500 |
| 1500 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1513,3 |
| 1508,6 | 1500 | 1498,9 | 1498,2 | 1499 |
| 1500 | 1504 | 1501 | 1500 | 1500 |
| 1500 | 1500 | 1500 | 1500 | 1500 |
| 1500 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1513,5 | 1507 | 1493 |
| 1493,6 | 1492,5 | 1491,2 | 1492,4 | 1493,7 |
| 1497 | 1495 | 1500 | 1500 | 1500 |
| 1500 | 1500 | 1500 | 1500 | 1500 |
| 1500 | 1520 | 1520 | 1520 | 1520 |
| 1518,6 | 1511 | 1501,9 | 1496,4 | 1487,5 |
| 1488,8 | 1483 | 1482,8 | 1485,4 | 1487,9 |
| 1494 | 1497 | 1500,5 | 1500 | 1500 |
| 1500 | 1500 | 1500 | 1500 | 1500 |
| 1500 | 1520 | 1520 | 1500 | 1516,7 |

| | | | | |
|---|---|---|---|---|
| 1510 | 1517,1 | 1492,5 | 1485,2 | 1475,1 |
| 1465,7 | 1464 | 1465,9 | 1477,5 | 1482,8 |
| 1488,8 | 1494,5 | 1500 | 1505 | 1504 |
| 1503 | 1503 | 1505 | 1509 | 1510 |
| 1500 | 1520 | 1515,6 | 1511,2 | 1508,3 |
| 1503,7 | 1496,4 | 1486,4 | 1477,6 | 1460 |
| 1460 | 1460 | 1460 | 1461,2 | 1477,2 |
| 1481,7 | 1483,8 | 1486,1 | 1492,7 | 1493,5 |
| 1493,8 | 1494,4 | 1496,9 | 1500 | 1504 |
| 1506 | 1512,3 | 1505,5 | 1501,8 | 1498 |
| 1492,9 | 1488,3 | 1481 | 1468,9 | 1460 |
| 1460 | 1460 | 1460 | 1466,6 | 1477,8 |
| 1481,5 | 1483,3 | 1485,2 | 1487 | 1486,7 |
| 1487,4 | 1488,2 | 1489,6 | 1493,2 | 1498,9 |
| 1502,8 | 1504,6 | 1493,2 | 1493,5 | 1490 |
| 1487 | 1484,2 | 1480,6 | 1473,1 | 1465,6 |
| 1463 | 1466,2 | 1470 | 1479 | 1485,9 |
| 1486,2 | 1485 | 1480 | 1490 | 1480 |
| 1480 | 1480 | 1480 | 1480 | 1487,1 |
| 1494,5 | 1497,5 | 1489,5 | 1482,2 | 1480 |
| 1480 | 1480 | 1485,4 | 1482,3 | 1480,9 |
| 1481,6 | 1485 | 1487,1 | 1492 | 1487,1 |
| 1492,5 | 1488,7 | 1484,6 | 1480 | 1480 |
| 1480 | 1480 | 1490 | 1480 | 1483,7 |
| 1490,1 | 1490,6 | 1490 | 1480 | 1480 |
| 1480 | 1490 | 1488,1 | 1499,3 | 1491,3 |
| 1493,8 | 1497,2 | 1500 | 1502 7 | 1502,9 |
| 1499 | 1492,5 | 1486,2 | 1480 | 1480 |
| 1480 | 1480 | 1480 | 1480 | 1484,7 |
| 1491,2 | 1495 | 1490 | 1480 | 1480 |
| 1480 | 1480 | 1487,7 | 1515,4 | 1501,9 |
| 1504,3 | 1506,3 | 1508,6 | 1511,4 | 1511,3 |
| 1507,7 | 1500 | 1494,1 | 1486,5 | 1480 |
| 1480 | 1480 | 1481,9 | 1493,3 | 1492,1 |
| 1499 | 1480 | 1480 | 1480 | 1480 |
| 1480 | 1480 | 1492,6 | 1501,9 | 1506,3 |
| 1509,4 | 1514 | 1517,5 | 1520 | 1520 |
| 1515,8 | 1508,7 | 1503,2 | 1496,3 | 1492,7 |
| 1491,1 | 1491,1 | 1497,2 | 1496,9 | 1499,1 |
| 1504,3 | 1480 | 1480 | 1480 | 1480 |
| 1480 | 1485 | 1496,9 | 1505,7 | 1511,6 |
| 1517,3 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1512 | 1506,6 | 1503,7 |
| 1503,4 | 1503 | 1500 | 1504,3 | 1506,2 |
| 1510 | 1483,2 | 1480 | 1480 | 1480 |
| 1480,8 | 1492,7 | 1502 | 1509,7 | 1515,9 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1515,5 | 1511,9 |
| 1510,9 | 1510 | 1509,8 | 1510,9 | 1511,7 |
| 1515,8 | 1485,8 | 1485,9 | 1483,3 | 1487,7 |
| 1495,9 | 1502,9 | 1509,8 | 1516,4 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1492,1 | 1490,5 | 1492,7 | 1496 |
| 1503,3 | 1509,3 | 1515,3 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1520 | 1520 | 1520 | 1520 |
| 1520 | 1495,7 | 1497,2 | 1500 | 1505,4 |
| 1510,7 | 1515,3 | 1500 | 1520 | 1520 |

BVE2.BAS

```
320 F5=810 DIM PSI(26.26),CF(26)
20 INPUT "file name for the data of psi";I$:OPENIN I$
30 H=112.12*1.2
40 G=9.8/10^3
60 DEF FNCF(LAT)=2*W*SIN(PI/4)
70 W=7.29/10^5
80 D=ATN(1)/45
90 DEFFNDPSI(I.J)=(PSI(I+1,J)+PSI(I-1,J)+PSI(I,J+1)+PSI(I,J-1)-4*PSI(I,J)/H^2
100 KK=0
110 FOR I=1 TO 25
130 FOR J=1 TO 25
150 INPUT #9, PSI(I,J)
160 NEXT:NEXT
190 CLOSEIN
200 PRINT "next comes the values of F"
210 KK=0
215 INPUT "name of the file";I$:OPENOUT I$
220 FOR I=2 TO 24
230 LAT=(25-I+1)*1.2*D
240 FOR J=2 TO 24
245 IF J+1>24 THEN F1=0:GOTO 270
250 IF J+1>24 THEN F1=0:GOTO 270
260 F1=(PSI(I+1,J+1)-PSI(I-1,J-1))*FNDPSI(I,J+1)
265 IF J-1<2 THEN F2=0:GOTO 280
270 F2=(PSI(I+1,J-1)-PSI(I-1,J-1))*FNDPSI(I,J-1)
275 IF I+1>24 THEN F3=0:GOTO 290
280 F3=(PSI(I+1,J+1)-PSI(I+1,J-1))*FNDPSI(I+1,J)
285 IF I-1<2 THEN F4=0:GOTO 300
290 F4=(PSI(I-1,J+1)-PSI(I-1,J-1))*FNDPSI(I-1,J)
300 F5=(PSI(I+1,J)-PSI(I-1,J))/(2*H)
310 B=2*W*COS(LAT)/6375.6
320 F5=B*F5
330 F=(F1-F2-F3+F4)/(4*H^2)
340 F=F+F5:XX=F
350 PRINT F:PRINT #9, F
```

CONPHI.BAS

```
10 DIM PHAI(26,26)
20 INPUT "nameg of the data file for values of psi";I$:OPENIN I$
30 H=112.12*1.2
40 G=9.8/10^3
45 DEF FNCF(LAT)=2*W*SIN(PI/4)
70 W=7.29/10^5
110 FOR I=1 TO 25
130 FOR J=1 TO 25
150 INPUT #9, PSI
160 PHAI=G*P*10^-3
170 PHAI(I,J)=PSI*FNCF(LAT)*10^3/G
175 PRINT PHAI(I,J)
180 NEXT:NEXT
185 CLOSEIN
```

genz.bas

```
10 DIM P1(26,26), P(26,26)
20 INPUT "i,j,p(i,j)";I,J,P1(I,J)
30 IF I+J=0 THEN GOTO 100
40 GOTO 20
100 FOR K=1 TO 15
110 PRINT K
120 FOR I=1 TO 24
130 FOR J=1 TO 24
140 IF P(I,J)<>0 THEN GOTO 160
150 P(I,J)=(P(I+1,J)+P(I-1,J)+P(I,J+1)+P(I,J-1))/4
160 NEXT
170 NEXT
180 NEXT
200 INPUT "file name to store data";F$:OPENOUT F$
210 FOR I=1 TO 25
220 FOR J=1 TO 25
230 PRINT #9, P(I,J)
240 NEXT:NEXT
250 CLOSEOUT
260 END
```

# CONT1.BAS

```
10 DIM P(30,30)
20 INPUT "xl,yl,xmx,ymx,xmn,ymn,xd,yd";XL,YL,XMX,YMX,XMN,YMN,XD,YD
22 INPUT "data file name";F$:OPENIN F$
23 INPUT #9,QQ
24 FOR I=1 TO 25
25 FOR J=1 TO 25
26 INPUT #9,P(I,J)
27 NEXT:NEXT
28 CLOSEIN
30 AX=XL/(XMX-XMN):AY=YL/(YMX-YMN)
31 X0=45:Y0=30
32 INPUT "contour maximum, minimum, interval";VM,VN,VD
33 CLS
36 XX=30:YY=30
38 TAG
40 FOR P=XMN TO XMX STEP XD
50 X=X0+(P-XMN)*AX
60 MOVE X-10,Y0-10:PRINT ROUND(P,2);
70 MOVE X,Y0:DRAW X,Y0+Y1
80 NEXT
90 FOR Q=YMN TO YMX STEP YD
100 Y=Y0+(Q-YMN)*AY
110 MOVE 0,Y+5:PRINT ROUND(P,2);
120 MOVE X0,Y:DRAW X0+XL,Y
130 NEXT
140 TAGOFF
145 AX=X1/24:AY=Y1/24
210 FOR V=VN TO VM STEP VD
215 ID=1:JD=1
220 FOR I=1 TO 24
230 FOR J=1 TO 24
240 C=0
250 IF(P(I,J+1)-V)*(P(I,J)-V)<0 THEN GOTO 1000
260 IF (P(I+1,J)-V)*(P(I,J)-V)<0 THEN GOTO 1020
270 NEXT:NEXT
980 GOTO 1060
990 C=1
1000 IF (P(I,J+JD)-V)*(P(I,J)-V)<0 THEN GOSUB 4000 ELSE ID=-ID
1010 J=J+JD
1020 IF (P(I+ID,J)-V)*(P(I,J)-V)<0 THEN GOSUB 3000 ELSE JD=-JD
1030 I=I+ID
1035 X=INT(X):Y=INT(Y)
1036 IF X<X0 THEN X=X0
1037 IF Y<Y0 THEN Y=Y0
1038 IF X>X0+X1 THEN X=X0+X1
1039 IF Y>Y0+Y1 THEN Y=Y0+Y1
1040 DRAW X,Y
1045 IF C=0 THEN GOTO 990
1050 IF C=1 AND (ABS(X-XX)+ABS(Y-YY))>1 THEN GOTO 990
1060 NEXT V
1070 END
3000 IF C=0 THEN XX=X0+(J-1)*AX
3001 YY=Y1+Y0-(I-1)*AY-ID*(P(I,J)-V)/(P(I,J)-P(I+ID,J))*AY
3002 XX=INT(XX):YY=INT(YY):MOVE XX,YY
3010 X=X0+(J-1)*AX
3011 Y=Y1+Y0-(I-1)*AY-ID*(P(I,J)-V)/(P(I,J)-P(I+ID,J))*AY
3040 RETURN
4000 IF C=0 THEN XX=X0+(J-1)*AX+JD*(P(I,J)-V)/(P(I,J+JD))*AX
4001 YY=Y1+Y0-(I-1)*AY:XX=INT(XX):YY=INT(YY):MOVE XX,YY
4010 X=X0+(J-1)*AX+JD*(P(I,J)-V)/(P(I,J)-P(I,J+JD))*AX
4020 Y=Y1+Y0-(I-1)*AY
4040 RETURN
```

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