METEOROLOGICAL ASPECTS OF THE ENVIRONMENT OF COCHIN

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By

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CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by Mrs. Bindu G. in the Department of Atmospheric Sciences for the Ph.D. degree of the Cochin University of Science and Technology and no part of it has previously formed the basis for the award of any degree in any University.

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CONTENTS

PREFACE

For a proper environmental and urban planning the climatological information of various weather elements and their variations are very much essential. Variability in weather is generally induced by natural processes. However, in recent decades, man-made causes are also contributing in the modification of weather. Cochin is an important coastal city located in the southwest part of India. Meteorologically, Cochin is unique in many respects with extensive water bodies and Vembanade lake, bordering on the south and west. Many portions of the region are water logged for most part of the year. The region has a population of over 11 lakhs by 1991 and it is expected to go beyond that by 2000AD. The city has various types of industrial units including oil refinery, fertilizers, chemicals and engineering industry. Besides these complexes, the city has a shipyard, dockyards etc. Vehicular population in the city is highest in the state. The number of high-rise buildings is also increasing year-by year .

The changing environmental settings yield Cochin very susceptible to meteorological problems which unless given due consideration can result in damages which may turn out to be irreparable. Hence due consideration to urban meteorological aspects is of paramount importance in planning for the healthy development of this harbor city. As a first step studies on different surface meteorological parameters have been carried out. To find out the interrelationship between the surface and the upper air parameters, the upper air data also has been analyzed. Knowing the existing meteorological scenario, different environmental aspects such as air pollution, human comfort indices, spatial temperature and relative humidity variations, rainwater analysis etc. have been carried out.

The thesis is presented in eight chapters.

In the first chapter, the general introduction about the topic chosen, the background and physiographic features of the study area and the objectives are presented.

Description of the data used for the study, quality control, interpolation technique used and the different techniques of analysis employed in the present study are discussed in chapter 2.

In the third chapter detailed literature review on analysis of surface and upper air parameters, pollution studies and environmental aspects conducted in India as well as other parts of the world are presented.

The analysis of surface meteorological parameters such as temperature, pressure and RH are discussed in the fourth chapter.

The upper air characteristics such as vertical time sections of temperature and RH are presented in the fifth chapter. Troposheric lapse rate for different levels are calculated and correlated with surface temperature. The study of precipitable water content in the lower levels and its temporal variations are analyzed.

Chapter six deals with air pollution studies. The spatial distribution of pollutant concentration has been presented for the four seasons. The areas suitable for industrial growth have been pointed out.

In chapter seven, different environmental aspects such as land-breeze, sea-breeze, rainfall characteristics, spatial variation of temperature and RH , incidence of fog, and comfort indices are discussed.

In chapter eight, the outcome of the present study have been briefly summarized.

References are listed at the end of the thesis in alphabetical order.

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Man, like all living creatures, is dependent upon his natural environment. However, unlike other living creatures, he uses his intelligence to acquire knowledge of the environmental processes and utilizes this knowledge to serve his needs and wishes. The agriculturist, the biologist, the hydrologist, the meteorologist, the oceanographer and others may all, in their different ways, be said to have been engaged over a long period in acquisition and application of knowledge of the environmental processes for useful, constructive purposes.

It is, however, only in the last few decades, that the world as a whole has become conscious that, whatever overall definitions of the human environment may be adopted, the atmosphere also must be considered as an important component. This means that one must give due considerations to the meteorological aspects of his environment, too.

All over the world, urban areas are expanding by migration and natural population increase. Already 30% of the world population live in towns of five thousand or more persons, 18% in cities of more than 1 lakh persons. These proportions are increasing fast and it has been estimated that by the year 2000 AD, three out of every five people will live in towns. In almost every country, towns are expanding to consume more and more land. With moderate rates of growth of urban populations, it is estimated that by 2015 AD over 50% of the Indian population will be living in urban areas and there will be over 50 cities with a population of one million or more. Almost everywhere in the developed and developing world, brick, stone, concrete and macadam are replacing field, farm and forest.

It is clear that the urban environment provides the setting for the live framework of a large and growing proportion of the world population and it is therefore important to realize that, because of this, urban dwellers spend much of their lives in a quiet distinctive type of man modified climate indoor and out.

The increase in population intensify meteorological and climatological changes in the atmospheric boundary layer, where motions and other properties of air are closely controlled by the nature of the earth surface. Clearly, surface conditions, natural or man-made are of paramount importance in the atmospheric energy budget and by changing these conditions man has inadvertently affected atmospheric properties, more especially in the earth atmosphere interface or planetary boundary layer (PBL).

The overall quality of urban environment has deteriorated over the years with the larger cities reaching saturation points and unable to cope with the increasing pressure on their infrastructure. In built-up areas, the effect of complex geometry of the surface, shape and orientation of individual buildings, their particular thermal and hydrological properties, roads and other urban factors, the heat from metabolism and various combustion processes taking place in the cities, the pollutants released into the atmosphere over the city all combined, create a climate which is quite distinct from that of rural or suburban areas. The changes caused due to urbanization can be listed as follows:

a) Replacement of natural surface by buildings, often tall and densely assembled, cause increase in roughness, which reduce surface wind speeds. The irregularity of the surface from streets and parks to various roof heights leads to increased turbulence.
b) Replacement of natural surface by impermeable pavements and roofs combined with the drainage system reduces evaporation and humidity and leads to faster run off.
c) Pavements and building materials have physical constants substantially different from natural soil. They generally have lower albedos and greater heat conductivity. This leads to considerable alteration of lapse rate in the lower levels of the atmosphere.
d) Heat added by human activity is a substantial part of the local energy balance. This also leads to an increase in temperature above the surroundings. This may, combined with the effect such as increased turbulence and heat storage from solar radiation lead to rise of air and cloudiness which promote precipitation. It will also promote a tendency for

airflow into built up areas. Addition of foreign substances from combustion and industrial processes cause an increase in the number of nuclei which leads to formation of fog together with the added turbulence and convectional effects, and reduces visibility.

The characteristics of urban air pollution are influenced by the nature of dominant effluents and climatology of the area. For any distribution of pollutant sources, the dispersion that occurs is largely determined by the existing fields of temperature, and wind in the urban environment. The entrainment of dust into the air from the ground surface is related to wind speed.

Within each regional climate, there are mesoscale variations from place to place because of climatic control exercised by the local topography including altitude, surface morphology, proximity to water etc., . Finally, within each mesoclimate, there are variations over distances up to a few tens of metres because of changes in soil type, and vegetation.

The city of Cochin is a fast growing industrial region where increasing urbanization has been affecting the quality of the atmospheric environment. The influence of urbanization and industrialization is already being felt on the weather and climate of the region. A detailed study of the meteorological aspects of the urban environment of Cochin would enable us to understand the inter-relationships between urban growth and mesoscale climatic variations.

Cochin is an important coastal city of Kerala State located in the southwest part of India, bounded between 9^{o} 52' and 10^{o} 10' N , and 76^{o} 10' and 76^{o} 25' E. The city of Cochin is flanked by the Arabian sea on the west and criss-crossed by backwaters, of which the most prominent is Vembanad lake. Many portions of the region are water logged for most part of the year. The study region includes Cochin and Kanayannur Taluks, and portions of Alwaye , Kunnathunadu and Parur Taluks of Ernakulam district (Fig.1).

The climate is dominated by heavy rainfall during the southwest monsoon season and moderate rainfall during the post monsoon months. Being a coastal station, the city is influenced by the effects of land and sea breezes. Winds are generally light to moderate through out the year.

Cochin is considered as the industrial capital of Kerala State. This is because of the availability of land, and skilled labours, abundant water supply, nearness to the all-weather port of Cochin and the facility of a navigable canal connection to the port. The establishment of FACT in 1947 and the subsequent establishment of a number of industries in the city such as Cominco Binani Zinc Ltd., Travancore Cochin Chemicals, FACT (Udyogamandal,Ambalamugal), Hindusthan

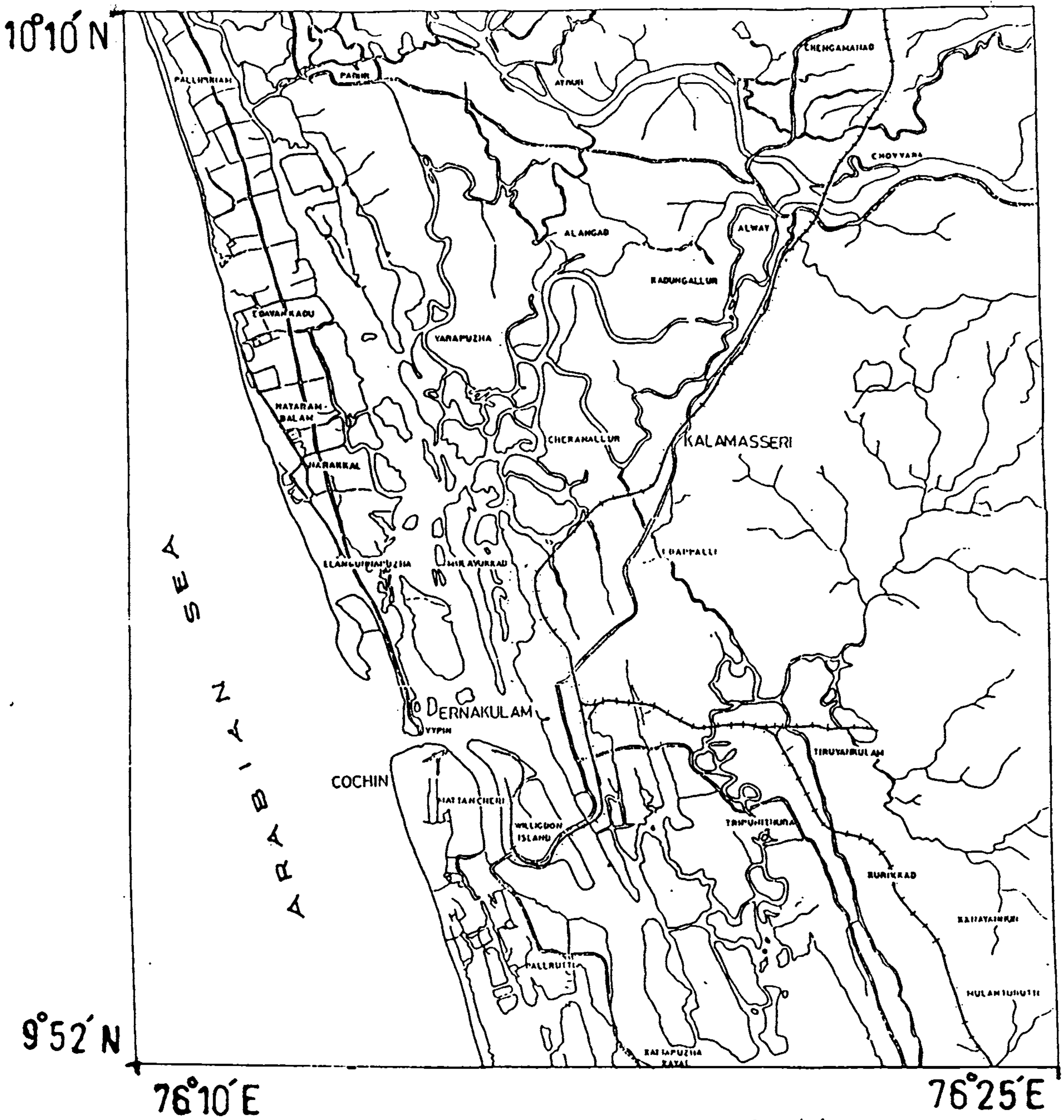


Fig.1 Area under study - Cochin

Insecticides, Indian Rare Earths, ASCL Caprolactam, Cochin Refineries, Carbon and Chemicals and many small scale industries have accelerated the industrial growth in the area. The establishment of the Cochin Shipyard and later the Cochin Export Processing Zone (CEPZ) has given a tremendous boost to the economic growth of the region.

The location of the Southern Naval Command, the Cochin Port Trust and the naval airport has led to a tremendous growth of urbanization. The existence of a large number of sea-food processing industries, basically catering to the export market has also added to the development of the city. All the above industries and projects have generated employment avenues for a large number of people. This has resulted in the expansion of the city area to meet the needs of the increasing population. The development of the city has been accomplished by the rapid spreading of the urban area in all directions swallowing up small villages and hamlets.

The rapid increase in the city area as well as the population growth has inevitably lead to the phenomenal increase in the transportational needs of the city dwellers . However, the enormous increase in the number of vehicles on the road has not been matched by any significant increase in the total length of the road network. This has resulted in deterioration in the ambient air quality due to the gaseous effluents emitted from exhausts of automobiles, which may be considered as a line source of pollution.

Of late, since there is tremendous pressure on land resources available, there has been tremendous vertical growth of the city in the form of tall, residential and commercial complexes. This new phenomena threatens to change the skyline of the city and turn the once coconut palm fringed " Queen of the Arabian Sea" into a concrete jungle.

Such a rapid urbanization and industrialization of the region cannot be without their influences on the meteorology and climatology of the city. The changing environmental setting makes Cochin susceptible to meteorological problems and hence it is imperative at this stage to have a clear appraisal of the meteorological aspects of the environment. Such a detailed survey of all the important weather parameters over the area is a pre-requisite for any environmental planning exercise.

The present investigation becomes relevant in the context of the need for judicious planning of the environmental resources of the region for its overall development. The study envisages a detailed survey of all the surface meteorological parameters and the vertical profiles of temperature and humidity. An analysis of these parameters is necessary since they influence the quality of life in the area, through their effects on the different environmental aspects such as air pollution and human comfort.

Surface wind is the single most meteorological variable for using in air pollution studies. The direction and speed of transport of pollutants released from industrial and vehicular sources are governed by the wind vector. The vertical temperature structure is another important factor which determines the dispersal of air pollutants through its effects on the stability of the atmosphere. Highly unstable conditions result in mixing and dilution and a consequent reduction in pollution concentration. On the other hand, stable conditions characterized by low mixing, result in the build-up of pollutant levels. A detailed knowledge of the spatial and temporal variations of surface and upper air temperature and wind structure are, therefore, essential for proper environmental planning.

Such an inventory of the meteorological parameters in space and time would be of immense help in planning strategies for the development of industrial areas vis a vis the residential sectors. Such planning could also include scientific location and orientation of individual houses or residential complexes to increase the comfort level of the residents. It will also help in planning an efficient network of roads and highways to cater to the transportation needs of the area.

The objectives of the present study include an appraisal of the meteorological features over the city to provide the basic climatological information for practical applications. The investigation also envisages an analysis of the meteorological aspects of air pollution through the use of an appropriate Gaussian model. Through this approach, the spatial distribution of air pollutant concentration over the region in the different seasons is projected. It would be possible to demarcate areas suitable for location of new industries and zones where residential sectors can be expanded.

Another aspect which is envisaged in the study is the spatial and temporal variation of human comfort indices. Other important environmental aspects such as the incidence of fog, occurrence of land and sea breezes and chemical analysis of rain water to check for the occurrence of acid rain are other important areas under purview of this study.

It is expected that the results of this study would be of help to the planners entrusted with the overall development of the Greater Cochin area. It would also aid decision making for short term operational purposes in the day to day management of the ever increasing environmental problems of the city.

CHAPTER II

DATA AND METHODOLOGY

The general introduction of the topic, meteorological background of Cochin and the relevance of the study carried out are explained in the preceding chapter. The details of the actual data collected, quality control, interpolation technique used and the methods adopted for all the major studies carried out are presented in this chapter. The methodology for some other studies conducted are not given in this chapter. Those are explained along with the respective studies.

2.1 Data and its sources

The data collected for the entire study can be grouped as follows. 1. Surface meteorological observations, 2. Upper air observations, 3. Field observations on meteorological parameters like air temperature, humidity and precipitation, 4. Emission inventory. To study the temporal variation of surface parameters over Cochin, meteorological parameters such as temperature,pressure, relative humidity and wind are collected at three hourly interval for a period of ten years from 1983 to 1992. Surface observations of these meteorological parameters were collected from India Meteorological Department (IMD), Pune.

The radiosonde data which was available for the period 1983-1989 for Cochin at 00GMT is also collected to study the upper air characteristics. Daily temperature and dew point values at every 50 mb from surface to 650 mb are obtained. Upper air data for three years from 1987 to 1989 taken at 12GMT is also made use.

To study the spatial distribution of SO_2, the emission inventory such as name of industry, SO_2 discharge, stack height, stack diameter at exit, stack velocity and temperature at exit for all the major factories in Cochin are collected from the Kerala State Pollution Control Board.

Field studies are conducted by the author to find out the spatial variation of temperature and relative humidity both in the heart of the city and in and around the city . This was done for two years during 1992 and 1993. In order to study the chemical composition of rainfall, rain water samples from different localities were collected before and after the onset of south west monsoon period of 1995.

2.2 Quality control

A summary of the various data collected is also shown in Table 2.1 and Table 2.2 From the statistical point of view, the study of meteorological variations is a problem of time series analysis. This is because the basic data of the various parameters are in the form of time series. In many instances,

Table 2.1 Summary of meteorological data collected

PARAMETER	YEAR	SOURCE	DETAILS
SURFACE METEOROLOGICAL ROUTINE OBSERVATIONS			
TEMPERATURE	1983-1992	IMD	THREE HOURLY
PRESSURE	1983-1992	IMD	THREE HOURLY
RELATIVE HUMIDITY	1983-1992	IMD	THREE HOURLY
WIND	1983-1992	IMD	THREE HOURLY
UPPER AIR ROUTINE OBSERVATIONS			
TEMPERATURE	1983-1989	IMD	SURFACE-650mb (50mb. Interval)
DEW POINT	1983-1989	IMD	SURFACE-650mb (50mb. Interval)
FIELD STUDY OBSERVATIONS			
AIR TEMPERATURE	1992-1993		CONTINUOUS RECORDING
RELATIVE HUMIDITY	1992-1993		THERMOHYGROGRAPH
AIR TEMPERATURE	1995 (WINTER)		USING PSYCHROMETER
RELATIVE HUMIDITY	1995 (WINTER)		USING PSYCHROMETER
RAINFALL	1995 (MONSOON		BEFORE AND AFTER ONSET DATE

Table 2.2 Baseline salient features of industrial stacks

NAME OF INDUSTRY	SO_2 DISCHARGE Q KG/DAY	STACK HEIGHT m	STACK DIAMETER AT EXIT m	STACK VELOCITY AT m/sec	TEMP °C AT EXIT
1	2	3	4	5	6
<u>SOURCE I</u>					
TRAVANCORE	1987.20	15.0	1.10	3.0	250
COCHIN	3974.40	25.0	1.20	2.5	300
CHEMICALS	1987.20	24.6	0.40	9.0	200
HINDUSTAN ORGANIC CHEMICALS	321.50	39.0	1.45	6.5	130
	321.50	51.0	1.85	11.5	275
FACT (UDYOG MANDAL)	9936.00	75.0	2.50	1.00	65
	13478.40	25.0	1.22	1.07	200
	5529.60	16.6	1.22	1.07	200
HINDUSTAN INSECTICIDES	5616.00	12.17	0.78	3.50	180
INDIAN RARE EARTHS	816.48	18.0	0.77	3.13	132
COMINCO BINANI ZINC LTD.	201517.00	40.0	0.80	3.85	400
ASCL	1656.28	90.0	3.35	5.54	150
CAPROLACTAM	47.52	30.0	0.36	8.64	343
<u>SOURCE II</u>					
FACT	14005.00	65.0	1.8	8.60	65
(AMBALAMUGHAL)	2634.00	105.0	--	8.58	185
	1945.80	39.0	2.75	16.89	45
	4980.40	33.4	1.85	11.35	55
CARBON AND CHEMICALS	2901.00	40.0	2.70	12.00	450
COCHIN	802.00	45.0	1.25	7.13	300
REFINERIES	1776.60	60.0	1.55	6.42	235
	395.08	21.0	1.44	9.67	240
	446.69	32.0	2.21	8.17	272
	583.74	80.0	--	--	--

successive values of such time series are not statistically significant, owing to the presence in the series of persistence, cycles, trends or some other non random component. Therefore the data collected was first subjected to standard quality control tests. Observations of each parameters are made to fall within an acceptable range of values. For this a finite screening of the data is made and the values which lay outside the acceptable range are then replaced. This first screening was not enough to catch all the bad data. So we looked for spikes, single datum whose value was markedly different from the value that preceded it and the value that followed it, in the time series. In order to remove the outliers in the data they are subject to despiking routine available in Matlab. For this purpose the standard deviation r is computed for the time series using 50% overlap. Any data point which deviate more than $\pm 2\sigma$ are then eliminated. By this process about 10% of the erraneous data points were removed. After removing the spikes the data set is screened again numerically. Then the missing data were calculated using cubic spline interpolation (Krishnamurthy and sen (1991) and Press et al. (1993)).

Cubic spline interpolation

Spline may be defined as a flexible strip which can be held by weights so that it passes through each of the given point, but goes smoothly from each interval to the next according to the loss of beam flexure . The mathematical adaptation of this method is termed spline approximation.

The starting point of a study of the spline functions is the cubic spline. This spline proves to be an efficient tool for approximation and interpolation. The cubic spline to places draughtsman's spline normally by set of cubics (cubic polynomial) through the points, using a new cubic in each interval. To correspond to the idea of the draughtsman's plan it is required that both the slope (dy/dx) and the curvature (d^2y/d^2x) are the same for the pair of cubics that join at each point. The mathematical spline thus possesses the following properties.

1) The cubic and their first and second derivatives are continuous.
2) The third derivatives of the cubics usually have jump discontinuities at the junction points.

We shall consider cubics spline which is perhaps the most important one from the practical point of view. By definition a cubic spline $g(x)$ on $a <= x <= b$ corresponding to the partition (1) is a continuous function $g(x)$ which has continuous first and second derivatives every where in that interval and each sub interval of that partition, is represented by a polynomial of degree not exceeding 3. Here $g(x)$ consists of cubic polynomials one in each sub interval.

Given a tabulated function $Y_i = Y(x_i)$, $i = 1, \dots n$, focus attention on one particular interval, between x_j and x_{j+1}. Linear interpolation in that interval gives interpolation formulae

$$y = Ay_j + By_{j+1} \text{ where} \qquad (1)$$

$$A = \{x_{j+1} - x\} / \{x_{j+1} - x_j\} \text{ and}$$

$$B = 1 - A = (x - x_j) / (x_{j+1} - x_j)$$

These are the special cases of general lagrange interpolation formula. Since it is linear, equation (1) has zero second derivative in the interior of each interval , and undefined or infinite , second derivative at the abscissas , x_j. The goal of cubic spline interpolation is to get an interpolation formula that is smooth in the first derivative and continuous in the second derivative , both within an interval and at its boundaries.

A little side calculations show that there is only one way to arrange this construction namely replacing one by

$$y = Ay_j + By_{j+1} + Cy_j'' + Dy_{j+1}'' \qquad (2)$$

$$C = 1/6(A^3 - A) \ (X_{j+1} - x_j)^2$$

$$D = 1/6(B^3 - B) \ (X_{j+1} - x_j)^2$$

Notice that the dependence on the independent variable x is entirely through the linear x dependents of A and B and the cubic x dependents of C and D. We can readily check that Y" is in fact the second derivative of the new interprolating polynomial. Taking derivatives of equation (2) with respect to x,

$$dy/dx = (y_{j+1} - y_j)/(x_{j+1} - x_j) - (3A^2-1)/6 * (x_{j+1} - x_j)y_j'' + (3B^2 -1)/6 \quad (x_{j+1} - x_j)y_{j+1}'' \qquad (3)$$

for the first derivative and

$$d^2y/dx^2 = Ay_j'' + By_{j+1}'' \qquad (4)$$

for the second derivative

since A = 1 at x_j and A = 0 at x_{j+1} while b is just the otherway around equation (4) shows that y" is just the tabulated second derivative and it will be continuous across the boundary between the two intervals (x_{j-1}, x_j) and (x_j, x_{j+1}).

The key idea of cubic spline is to require this continuity and to use it to get equations for the second derivatives, y".

The required equations are obtained by setting equation (4) evaluated for $x = x_j$ in the interval (x_{j-1}, x_j) equal to the same equation evaluated for $x = x_j$ but in the interval with some re-arrangement , this gives (for j = 2,.............,n-1)

$$= (y_{j+1} - y_j)/(x_{j+1}-x_j) - (y_j-y_{j-1})/(x_j-x_{j-1}) \qquad (5)$$

these are n-2 linear equation in the 'n' unknowns . y_i'' , i = 1 to n therefore there is a two parameter family of possible solutions. For a unique solution we need to specify two further conditions and typically taken as boundary conditions at x and x_n. The most common ways of doing these are either

i) set one or both of y1" and yn" equal to zero giving this so-called natural cubic spline which has zero second derivative on one or both of its boundaries.

ii) Set either of y1" and yn" to values calculated from equation (3) so as to make the first derivative of the interpolating function have a specified value on either or both boundaries.

One reason that cubic spline are especially practical in that the set of equations (5) along with the two additional boundary conditions, are not only linear but also tridiagonal. Each of y_j" is computed only to its nearest neighbors at $j \pm 1$.

Methodology

The methodology adopted for the major type of studies carried out using the surface meteorological parameters and upper air meteorological parameters are explained below.

2.3.1 Surface meteorological parameters

The surface meteorological parameters namely temperature, pressure, RH and wind collected for ten year period are analyzed. Three hourly mean values of these parameters are computed for all the months. These three hourly mean values are plotted for all the twelve months and the isolines showing the temperature distribution with respect to month and time are drawn.

In order to study the tendency of variation, three hourly tendency values, ie., the difference between two consecutive values are computed for all the eight hourly observations for all the months. These values are plotted against month and time to get the tendency pattern.

In order to study the yearly variation of the surface parameters mean values of 0830hrs and 1730hrs observations are considered and plotted.

Mean monthly maximum values, mean monthly minimum values, monthly mean values and the range between maximum and minimum values are computed for all the surface observations. The values are presented in table. Standard deviation of different parameters from the three hourly mean values are also computed and presented.

In order to study the periodic phenomenon like annual, semiannual or daily cycles of meteorological elements the three hourly mean values are subjected to harmonic analysis. The details of harmonic analysis is explained below.

Harmonic analysis

Harmonic analysis is a convenient technique for studying periodic phenomenon like annual , semi annual or daily cycles of any time series. The mathematical expression for a time series can be expressed as a periodic relationship between two variables y and t . Most of these representations in atmospheric science involve time series data. Thus the formulae are developed for y as a function of t. y(t) we write: $y(i) = A_0 + A_1 \sin(ti+\pi_1) + A_2 \sin(2ti+\pi_2)+......+ A_n \sin(nti+\pi_n)$

or

$y(i) = A_0 + \Sigma_{j=1}^{n} A_j \sin(jti+\pi_j)$

$y(i) = A_0 + \Sigma_{j=1}^{n} (a_j \sin(jti)+b_j \cos(jti)$

$a_j = A_j \cos \pi_j$

$b_j = A_j \sin \pi_j$

i ranges from 0 to p-1

Usually P is identical with N , that is the number of observations. It is the largest non negligible period . In the case when

$y(i) = A_0 + \Sigma_{j=1}^{n} A_j \cos(jti+\pi_j)$

it affects only the value of π_j which will differ by 90° from the sine term. Occasionally the available set of observations consists of n data of which we know that the largest non negligible period is P then

N = kp

Primarily two methods have been developed to calculate periods. The total setup data up to N is treated as t he basic period and the first terms are omitted until the first term with A_j not= zero is reached ie, the term kt_i which corresponds to the kth period in the data set of N. A second solution involves a reduction of original set of observations.

Y_i by calculating

$\hat{y_{(i)}} = 1/k\ \Sigma y_{ik}$

when the basic period is Pagain and equation one is suitable. This technique can also be applied if one special periodicity (wave) is single out and others are of negligible interest.

The computation estimators for the coefficients A(j) (the amplitudes of half ranges of the sine waves) and the estimators for the reference angles π_j is performed via an auxiliary pair of estimators a_j and b_j.

$A_0 = 1/N \sum_{i=1}^{n} y_i = \hat{y}$

$a_j = 2/p \sum_i^p y_i \sin jt_i$

$b_j = 2/p \sum_i^p y_i \cos jt_i$

subsequently we find

$A_j^2 = (a_j^2 + b_j^2)^{1/2}$

$\tan\psi = b_j/a_j$

The number of terms is limited to j=N/2. The last term j=n always renders

$a_n = 0$

$b_n = 1/p\sum_i^p (-1)^i\ y_i$

This can be deduced from

$\sin (ji\ 2\pi/p) = \sin(i\pi N/p) = \sin(ik\pi) = 0$ for all ik.

Similarly the cosine sums are $\cos(ik\pi) = \pm 1$.

This can be further observed that the sequence of Fourier terms is an orthogonal system. Hence, we can add any term without re computing the coefficients of the prior terms. It is generally taken N as an even number. If it is odd $j = (N-1)/2$. The number of coefficients is always N. For even N, N/(2-1) coefficients of A_n and N/2 coefficients of b_n exist, plus a_0, which again renders N coefficients.

from

$$\sigma_y^2 = \Sigma_i^p (y_i^2 - A_0)^2/p = \Sigma_i^n A_j^2/2$$

we derive

$$\Sigma_i^n A_j^2 = 2\sigma_y^2$$

Thus for the individual terms

$$C^2A_j = A_j^2/2\sigma_y^2$$

The total reduction is

$$R^2{}_R = (\Sigma A_j^2)/2\sigma_y^2 = \Sigma C^2 A_j$$

or $100 * \Sigma C^2 A_j$ in percentage , where m denotes the number of terms, the accounted variance is $(\Sigma_1^m A_j^2)/2$

where m, n, and the residual variance can be calculated from

$$\sigma_y^2 - (\Sigma_i^m Aj_2)/2$$

The quantity 'j'in the Fourier analysis is called the number of harmonics or the wave number. It measures the number of complete cycles in the basic period. The number of cycles is also called the frequency (the number of repetitions within a determined time frame).

$$p_i = p/j$$

$$y_{(i)} = A_0 + B(x_t - \bar{x}_t) + \Sigma_1^n A_j \sin(jt_i + \varphi_i)$$

where B is the coefficient for the linear trend, calculated from regression line. The trend variate $x_{(t)}$ corresponds to the chosen basic period p, in most cases t=1,.....,p for $x_{(t)}$. It is very rear that more than the linear trend is eliminated. The Y = trend + fourier series. Because of the polyncmial and fourier series terms are not necessarily orthogonal to each other, the addition of terms in the trend requires a recomputation of fourier coefficients.

The minimum number of data N which must be available is specified by N = kp. The data must have the length of at least one period. Sometimes a dominant climatic cycle (quasiperiodicity) is used in forecasting and the reoccurrence is predicted. In this case it is a handicap that amplitude and phase angles can only be deduced after the data have been observed for outlast one length of the cycle.

2.3.2.Upper air parameters

Upper air data for the period of 1983-1989 has been made use to study the upper air temperature and humidity structure over Cochin. The upper air data taken during 00GMT is used. Upper air data for 00GMT and 12GMT for 1983 to 1985 is used for studying the lapse rate.

Using the daily temperature and specific humidity values at every 50mb intervals, the vertical time section for these two parameters are drawn. The specific humidity at various levels are computed using Teten's formula (WMO.No.669). precipitable water content at every 50mb interval has also been computed making use of specific humidity values. The seasonal variation of precipitable water content at different levels has also been studied.

2.3.3 Development of meteorological model for air pollution studies

The atmospheric dispersal capacity and the spatial concentration of SO_2 over Cochin have been studied and discussed in chapter six. Despite the presence of a number of models, most of the current models in use are based upon Gaussian plume concept. The development of the model is presented in between.

As the plume moves down wind from a chimney of effective height h, grows through action of turbulent eddies. Large eddies simply move the whole plume and diffusion is most effective with eddies of the order of plume size (Perkins, 1974). As the plume moves it grows in the vertical and cross wind directions. The distribution in the vertical and cross wind direction is assumed to be Gaussian. Along the wind direction the convection is greater than diffusion, so diffusion along wind direction is neglected. The Gaussian function gives a mathematical representation of this physical behavior. Groundlevel concentration of pollutants emitted from a point source is calculated using gaussian plume model. It is a function of wind speed. The higher the wind speed the faster the dispersion of pollutants in the downwind direction.

$$X \propto 1/u$$

Gaussian function gives the distribution of pollutants in the vertical and cross wind directions. Along the wind directions the concentration is proportional to the source strength. The Gaussian function in the crosswind direction is

$$X \propto A \exp\left[-1/2 \ (y/\sigma_y)^2\right]$$

A is a function of σ_y

$$X \propto B \exp\left[-1/2 \ (z-h/\sigma_y)^2\right]$$

Gives Gaussian function in the vertical direction. B is a function of r_z, h is the effective height of emission.

As it reaches the ground, the earth surface acts as barrier which prevent further diffusion and in the model perfect reflection is assumed from the ground. So the earth acts as a secondary source and the concentration at any point is a combination of concentration due to the source directly and that due to perfect reflection from the ground. So the concentration at a height of z is calculated by taking the real source at a height of z-h and that due to the image source at a height of z+h

$$X \propto B \ [\exp(-1/2 \ (((z-h)/\sigma_z)^2) + \exp(-1/2 \ (((z+h)/\sigma_z)^2)$$

Since the distribution is assumed to be Gaussian , it is considered that the area under the curve has a unit value .

This is done by taking A and B as $1/\sqrt{2\pi}\sigma_y$ and $1/\sqrt{2\pi}\sigma_z$ respectively.

Area under the curve is taken as the

integral of $-\infty$ to $+\infty$ exp $[-1/2\ (y/\sigma_y)^2]$ dy = $\sqrt{2\pi}\ \sigma_y$

Therefore

$1/\sqrt{2\pi}\ \sigma_y$ integral of $-\infty$ to $+\infty$ exp $[-1/2\ (y/\sigma_y)^2]$ dy = 1

Similarly B = $\sqrt{2\pi}\ \sigma_z$

So in a coordinate system considered the origin at the groundlevel at or beneath the point of emission, x axis extending horizontally in the direction of meanwind and plume travailing along or parallel to x axis, the concentration x of a gas at (x,y,z) from a containers source with a effective height of emission , H is

$$X\ (x,y,z,H) = Q/(\sqrt{2\pi}\sigma_y\sigma_z u)\ \exp\ [-1/2\ (y/\sigma_y)^2\ *$$
$$\{\ \exp\ [-1/2\ ((z-H)/\sigma_z)^2\ +\ \exp\ [-1/2\ (z+H/\sigma_y)^2]\}$$

H is the effective stack height which is a sum of physical stack height and plume rise. Some essentials are made in calculating the concentration.

a) Plume spread has a Gaussian distribution in both horizontal and vertical of σ_y and σ_z respectively.

b) Total reflection of the plume takes place at the earth surface, since there is no deposition or reaction at the surface.

c) Diffusion in the direction of plume travel is neglected. It is true only if the release is continuous or duration of release is equal to or greater than travel time (x/u) from source to locations of interest. For calculating the ground level concentrations Z = 0, the equation becomes

$$X\ (x,y,0,H) = Q/(\sqrt{\pi}\sigma_y \sigma_z u)\ \exp\ [-1/2\ (y/\sigma_y)^2 * \exp\ [-1/2\ ((H)/\sigma_z)^2$$

If the concentration along the center line of the plume is calculated the equation still simplifies to

$$X\ (x,0,0,H) = Q/(\sqrt{\pi}\sigma_y \sigma_z u)\ \exp\ [-1/2\ (H/\sigma_z)^2$$

For the parameter values taken the sampling time is assumed to be about 10 minutes, lowest several hundred meters of the atmosphere considered and surface considered is assumed to be open country. For long term concentration of the order of one tenth or more the Gaussian function is modified. Sixteen wind directions are considered and in each sector wind directions are distributed randomly over a period of a month or season. So the affluent is assumed to be distributed uniformly within each sector. The appropriate equation used was by Turner (1970).

$$X = 2Q/\ (\sqrt{2\pi}\sigma_z u\ (2\pi x/16)) * \exp\ [-1/2\ (h/\sigma_z)^2]$$

This calculates concentration in each 22.5 degree sector of the complex.

If a stable layer exist aloft it acts as a barrier preventing further diffusion. Such an effect was incorporated in this equation . If the height of stable layer is L , at a height

$2.15\sigma_z$. Above the plume center line , the concentration is 1/10 of the plume center line concentration at the same distance. When this extends to stable layer at L then the distribution is affected. In that case σ_z increases with distance to a value of L/2.15 or .47L. up to this distance x_1 1 the plume is assumed to have Gaussian distribution in vertical. Up to a distance of $2x_1$1 the plume assumed to be distributed uniformly between ground and height 1. For distances greater than $2x_1$ the concentration up to 1 is constant at a particular distance. For short term concentration it was given by

$$X\ (x,y,z;h)=Q/(\sqrt{2\pi}\sigma_y\ Lu)\ \exp\ [-1/2\ (y/\sigma_y)^2]$$

and for long term concentration

$$X = Q/(Lu(\sqrt{2\pi}x/16) = 2.55\ Q/Lux$$

the height of a stable layer is taken as the mixing height or in the case of inversion the base of inversion . Mixing height is obtained for each month . x is estimated for each downwind distance and for each downwind directions by solving the equation. The average concentration can be obtained by summing all the concentration at each distance.

CHAPTER III

LITERATURE REVIEW

Data and methodology of the different aspects studied in the present work have been explained in the preceding chapter. In this chapter the work done on these aspects by various authors have been reviewed sequentially. Review of literature on the studies carried out in chapters four and five of this thesis is given under the total title Analysis of meteorological parameters. A review of studies carried out in chapter six is given under the title Air pollution studies and that of chapter seven is given under the title Environmental aspects.

3.1 Analysis of meteorological parameters

During the dawn of scientific meteorology it became customary to record consistently the change of various elements then accessible to measurement. Regular series of thermometer observations were started. Some of these have been maintained since the late seventeenth and early eighteenth century. It was quite natural that sooner or later differences between the city and country side were noted in the observations. The the use of an instrumented motor vehicle for making traverse across a metropolitan area to obtain data for comparative purposes, hinged on a number of fixed stations was the decisive advance in studying the climate of cities Meteorological data from a network set up to study the local air pollution problem were used to study local flow patterns at Louisville by Pooler (1963). Stability conditions are discussed in terms of temperature differences obtained from thermohygrographs installed at different ground elevations. To observe the urban micro-climate during moderate wind, night-time conditions, Clarke (1964) used helicopters and car traverses to construct the temperature cross section across Cincinnati.

For some cities the changes in weather elements can be noticed from long term records. A particularly noteworthy case is Paris. This has been placed in records by Dettwiller (1970). He showed that in the absence of any appreciable regional trend in the last eighty years the Paris temperature mean has risen about 1.1^{o}C compared with the environment. In Paris the temperature surplus not only affected the air temperature but also to the soil.

The latitudinal variation of the mean surface temperature and the percentage variance associated by the first 15 harmonics are studied by Appa Rao and Brahmananda Rao (1971) for the months January to July. It accounts for 95% of variation at higher latitude and only up to 60% in lower latitude. Time series analysis of mean annual temperature and characteristic parameters representing seasonal variation of temperature for different Indian cities was done by Jagannathan and Parthasarathy (1972). The mean annual temperature shows an increasing trend at Calcutta, Bombay, Bangalore and Allahabad and a decreasing trend at Fort Cochin.

Time series analysis of surface air data was done by Misra (1973). The mean periodicities in the pressure tendency oscillations show values scattered between 4 and 5 days. If pressure changes of the order, ordinarily noticed are due to convergence, then a direction confirmation of the same may be obtained by a study of pressure tendencies.

Analysis of urban-rural differences in tower measured winds at St. Louis by Shreffler (1979) showed that there exits a systematic difference between urban and rural wind speed and direction, at nearly calm conditions. Ananthakrishnan et. al (1979) studied the variations in the meteorological parameters namely temperature, pressure, relative humidity, wind and rainfall for different districts in Kerala state. Some of the major features of the meteorology of Kerala against the background of the meteorology of the Indian subcontinent dominated by the summer and winter monsoon circulations have been highlighted in the study. A preliminary study of weather and climate of Cochin was studied by Ramesh kumar and Ananthakrishnan (1986).

Wanner and Hertig (1984) gave an assessment of the factors that are responsible for urban climate change along with climatological studies and peculiarities of some Swiss cities. Heat islands and city induced air flows, the influence of synoptic winds on boundary layer air flows and the significance of local air flows in complex terrain were studied in detail. Harmonic analysis of time series data of temperature and geopotential fields in the troposphere of northern hemisphere was done by Geliyev and Zveryayev (1990) for investigating climatic variability. The amplitude, phase characteristics of temperature data showed annual and semi-annual temperature fluctuations propagating in opposite directions.

Katherina and Fred (1964) studied the temporal and areal distribution of monthly precipitation normals over the Indian subcondinent by harmonic analysis. The amplitude and phase angle charts of the first three harmonics illustrates the regional boundaries for different rain patterns. A secondary maximum during February is well established over the mountains of west Pakistan and Kashmir. The face angle charts show that it is propagated in two geographic directions, from northwest to southeast along the south side of Himalayas and north to south along the west side of Baluchistan mountain. The only area where the intensity of winter rains exceeds that of summer precipitation was found to be the inter-mountain region of Baluchistan. Such distribution is distinctly different from that prevailing over India, where the rain intensity is greater during summer than winter.

Attempts to study a clear cut evidence of any climatic change or trend over India with particular reference to rainfall, surface temperature, atmospheric pressure and total ozone content was made by Thapliyal and Kulshreshta(1991). While there are year to year random fluctuations in these atmospheric variables and there are certain epochal increases and decreases in respect of rainfall and surface temperature, there appears to be no systematic climatic change or trend over India and also there is no ozone depletion. Trends and periodicities of monsoon and annual rainfall of districts of Haryana state and Delhi were analyzed by Bhukan Lal et al (1992). It was seen that monsoon and rainfall have similar variability and is least when rainfall is maximum. Increase in mean rainfall for 45 years period showed a gradient from east central to western parts of the state with a maximum value over the east central parts.

In several approaches to determine the thermodynamic structure of the atmosphere, use is made by profile measurements in the atmospheric boundary layer (ABL). The variations in thermodynamic structure with differing seasons is studied for India and neighborhood areas by Srinivasan and Sadasivam (1975). The mean dry bulb and dew point temperatures and equivalent potential temperatures during active and weak monsoon period showed that there is no significant change in the dry bulb temperature at any level and the moisture content in the lower tropospheric levels remain high without any appreciable variation. During active monsoon, synoptic disturbances pump up the low level moisture and the atmosphere is highly moist from surface to very high level. The moisture flux computations show that there is a large net flux divergence over the Arabian sea during active monsoon. Ramamurthy and Jambunadhan (1976) studied some aspects of moisture distribution over Arabian sea during active and weak spell of southwest monsoon in the year 1973. Radiosonde data were used for this study and showed stratification of moisture field over Arabian sea during weak monsoon except the equatorial region. During active monsoon, there is building up of a deep moist layer over this area from surface to 400mb.

Segal et. al (1992) studied the temporal variations of specific humidity during morning hours by analytical and numerical models scaling as well as by observational means. The relation of the pattern to the early thermal stratification and the Bowen ratio was estimated. The moisture variation pattern may be modified when the background moisture within the inversion layer decrease significantly with height. Padilla et al (1993) studied mixing ratio of water vapour at different hours of the day in a high altitude tropical plateau in Mexico. The results indicate that in the absence of synoptic perturbations an analysis of time elapse between the beginning of mixing ratio increase and the beginning of rain can help to show the diurnal air circulation that controls rain cloud formation. The study of the seasonal and geographical variations of precipitable water is of interest from meteorological and hydrological stand points. The onset of monsoon along the west coast of India is marked by the commencement of squally weather and rough seas accompanied by heavy rain. Mukherji (1962) computed the precipitable water in the atmosphere over Trivandrum using radiosonde data. But the results arrived at do not indicate any spectacular build up of precipitable water before or on the date of onset of monsoon. The maximum moisture level is attained before or after the date of onset, and the moisture content of the atmosphere is much less than that expected on the basis of psuedoadiabatic lapse rate. Ananthakrishnan et al (1965) calculated the mean monthly precipitable water vapour at twelve Indian radiosonde stations. The seasonal and diurnal variations brought out the rapid changes that occur with the onset and withdrawal of southwest monsoon. The diurnal variation is found to be least during monsoon months.

The sensitivity of the world climate system and its models to a variety of effects and variations in parameters is highly dependent on the relation between tropospheric lapse rate and the surface temperature regime. Estimation of instability for the purpose of forecasting local weather of convection type has to be based on the available radiosonde data. Using the method of vertical wind shear vector difference, the change in lapse rate brought about by advection alone was estimated for Calcutta by Gangopadhyaya and Bose (1958). This change applied to morning tephigram is found to provide is moderately successful tool for prediction of local afternoon thunderstorms. Mary Alice Rennick (1977) studied the relationship between lapse rate of temperature, and the surface temperature, by comparing the zonally averaged temperature structure of the atmosphere to that which is generated by several assumptions concerning lapse rate. It was found that, lapse rate is constant for a given temperature, but varies with latitude and season. The ratio of lapse rate to that along a moist adiabat at the surface is found empirically to have a cubic dependence of the surface temperature. The parameterisation of lapse rate in terms of surface temperature can be a useful tool in understanding response of surface temperature to changes in other climatic factors. Gulev et al (1991) studied the relation between tropospheric lapse rate in the northern hemisphere, the surface temperature, in the year to year variability and annual cycle is analyzed on the basis of fifteen years of monthly average data. It was noted a rising trend in the global cloud cover with both positive and negative variations in the global surface temperature in the year to year variability relative to mean regime.

3.2 Air pollution studies

Atmospheric stability is an important parameter in air pollution studies. Highly unstable conditions result in thorough mixing and dilution and consequent reduction in the ground level concentration of pollutants. Stability is a function of temperature and wind speed. There are a number of studies to determine stability using various methods. From the Parcel and Slice method, it was shown that stability can be determined purely from the temperature structure in the vertical. Hess (1959) gave a broad categorizations. Atmospheric stability is the most of stability as follows : a) absolutely unstable (if atmospheric lapse rate (ALR) is greater than dry adiabatic lapse rate (DALR), b) conditionally unstable (if ALR is in between DALR and saturated adiabatic lapse rate (SALR)), c) neutral (dry) (if ALR is equal to DALR), d) neutral (moist) (if ALR is less than SALR) and e) absolutely stable (if ALR is less than SALR).

The absolutely stable conditions do not necessarily include the restricted lapse conditions but can include isothermal and inversion conditions. In air pollution climatology these conditions are more important and to directly apply to air pollution studies, a more specific categorization is needed. Moreover, the data on vertical thermal structure are not available everywhere which prompted the emergence of a number of schemes for stability with minimum and easily available data.

A subjective classification of the horizontal wind direction fluctuation was given by Singer and Smith (1953) which states that fluctuation exceeding 90^{o} be classified as highly unstable (A) and fluctuations not exceeding 15^{o} be classified as stable (D) with intermediate classes B_1,B_2 and C. Pasquill (1961) proposed six stability categories to describe the diffusive potential of the lower atmosphere. These categories are A (very unstable), B (moderately unstable), C (slightly unstable), D (neutral), E (slightly stable) and F (moderately stable). This was originally developed for open or rural terrain. However, Turner (1961,1964) modified slightly the above classes so that they can be determined objectively from the routine meteorological data. He successfully applied the above scheme to the urban environment. By far, this scheme is the most popular, probably because many of the diffusion parameters in meteorological models were developed for each of these categories and secondly this is relatively easy to compute with wind speed and cloud amount alone at any given place.

The frequency of occurrence of Pasquill categories has been determined seasonally in Great Britain by Bannon et al. (1962). The effect of change of atmospheric stability on the growth rate of puffs used in plume simulation models was examine by Ludwig (1982). The relation between wind speed, atmospheric stability and plume rise at a distance of 2.5 km from a multiple source region was investigated by East and Renaud (1978). By using an integrated form of the Businger Dyer flux-gradient equations, Wang et al (1978) suggested that since the surface wind speed and vertical temperature difference are related to the low level atmospheric turbulence and stability, these parameters can be used directly to determine the plume diffusion parameter for unstable conditions, without using the Pasquill's stability.

Studies on stability in relation to the atmospheric dispersal capacity of air pollutants were carried out by Viswanadham et al (1981) for four major urban centers in India. The study revealed that the coastal cities and inland cities differed significantly in the percentage occurrence of the stability categories. Sadhuram and Vittal Murthy (1986) computed Pasquill's stabilities for the coastal station Visakhapatanam. The study revealed that neutral condition was present during day and night with high percentage frequencies at the time of just after sun rise and just before sunset. Pasquill's stability is studied for some other cities also in India. They are due to Anil Kumar (1986), Santhosh (1987) and Suneela (1989).

Mixing height is the vertical extent up to which vigorous mixing takes place in the atmosphere. Studies on the mixing height were mainly initiated by Holzworth (1964). Holzworth estimated the mean maximum mixing height for 45 stations in the Contiguous United States based on the radio sonde observations and normal maximum surface temperatures. Holzworth (1967,1972) estimated morning and afternoon mixing heights and average wind speeds through the mixing layer. Vittal Murty et al (1980a) computed mixing heights and ventilation coefficients for India and pointed the regions of good and poor dispersal of pollutants. The diurnal, seasonal and spatial variation of these has been studied in detail by them. Vittal Murty et al (1980b) studied the yearly variation of mixing heights for all the Indian radio sonde stations during the period 1959 to 1961. Vittal Murty et al (1980c) computed for Visakhapatnam, the mixing heights at two points in the city under different stability conditions. Padmanabhamurthy and Mandal (1980) studied the mixing heights for the winter season for Visakhapatnam. A simple model of urban mixing height was developed by Henderson (1980). An equation for the height of the inversion as a function of distance downwind into the city in the case of non-planar topography is also obtained from the model. The model enables the rapid calculation of mixed layer depths, ground level concentration and distribution of aerosols. Sadhuram (1982) computed the mixing height for a 10 year period for Visakhapatnam. Padmanabhamurthy (1984) has studied the spatial variation of mixing heights for India taking into account the data from 27 radio sonde stations in the country. Mixing heights are also studied for different cities in India. Some of the studies are: Variation of mixing height in various months for Cochin, by Anilkumar (1986), variation of mixing height for various seasons for four major cities in India namely Bangalore, Hyderabad, Mangalore and Nagpur by Santhosh (1987) and mixing height variations for Trivandrum by Suneela (1989).

Robert Buxter (1991) analyzed the meteorological and air quality sounding data to develop a database for mixing information. There was considerable variability in the mixing heights, throughout the study region with the overland region reflecting the diurnal changes and the over water region influenced more by the mesoscale and synoptic meteorological pattern. A comparative study of mixing height estimates from different measurement system was performed by Marsik et al (1995) to evaluate the consistency of the estimates between the different system and to evaluate the relative performance of the system. There is often disagreement in the mixing height estimate between various systems, particularly in the early morning and late afternoon hours.

Meteorological modelling or urban air quality simulation model is a numerical technique or methodology based upon physical principles, for estimating pollutant concentrations in space and time as a function of the emission distribution and the attendant meteorological and geophysical conditions. A review of the past work was made earlier by Stern (1970), Wanta (1968), Moses (1969), Seienfield et al. (1972), Eschenvoeder and Mastinez (1972), Fan and Horia (1971) and Turner (1979). Gaussian diffusion model is the most popular as it is relatively easy to apply. This model is nothing but the fundamental solution to the classic Fickain diffusion equation. Robertz et al (1970) developed Gaussian puff model for tracking individual pollutant plume. However, there were no extensive application of puff model due to its large computational requirements. In addition to the Gaussian model there are two other main classes of model based on the equation of mass conservation - 1) Eularian model and 2) Lagrangian model. While Gaussian model calculates concentration of pollutants source by source or receptor by receptor, the Eularian model calculates concentration throughout a region at one time.

For determining the concentration, Eularian model was made use of by Mac Cracken et. al (1971) for different regions. The Lagrangian models were used by Behar (1970) to investigate photochemical smog in Los Angeles. Leahey (1972) used the same model for SO_2 in New York. However, the box models assume complete vertical mixing, neglect diffusion between boxes and use first order . These would result in errors. The Lagrangian models should have many approximations to get the solution and thereby its applicability and the accuracy of solutions are limited (Johnson et al 1976) . Despite the presence of many other models Gaussian diffusion model is still the most popular model, and there have been considerable modification to improve the validity of the model.

Simultaneously there were some short term models which calculate concentrations for time periods of half hour to one day. Turner (1964) Clarke (1964), Koogler et al., (1967) have all computed concentrations ranging from two to twenty four hours. All these short term models use a single wind direction for each item period. However, Hilst (1968) developed a regional model that took account of the variations of wind. Gifford (1973) evaluated the performance of several simple models with available data to test other models which revealed that the estimates from the simple models are often as good as those of the more complex models. The main parameters required for the model computations are effective stack height and dispersion parameters σy and σz. Effective stack height is the sum of physical stack height and plume rise. A knowledge of effective stack height is a must for the evaluation of any models. There were a number of formulae to estimate the effective stack height. To name a few, Briggs (1965) Holland (1975), Davidson and Bryand (1975) , Lucas et al. (1963) and Slawson and Csanady (1967) . The formulae suggested by them are mostly functions of horizontal wind at stack height, ambient temperature, plume temperature, vertical velocity of the plume and physical stack parameters. Vittal Murty and Viswanadham (1978) have reviewed various plume rise formuale and concluded that no two formuale are giving the same result suggesting to choose a formula opposite to the local conditions. A comparative study of plume rise formulae was done by Padmanabhamurthy and Gupta (1980).

Das et al (1973) applied the gaussian model to study the dispersal of pollutants from Madhura Refinery in two parts. 1) The short period concentrations have been completed under the vast meteorological conditions to estimate the peak concentrations. 2) The long period concentrations have been studied for the planning purposes. Vittal Murty et al. (1977) presented a theoretical model for calculating ground concentration of SO_2 at Visakhapatnam. Viswanadham (1980) applied Gaussian model for multiple sources for the four major cities in India. For assessing the effects of radiative precipitation of elevated pollutant layers, a one dimensional transport model was developed by Venkataram and Viskanta (1977) . Manjukumari and sharma (1987) used profile relationship based on Monin - Obukhov similarity theory to compute turbulence parameter with friction velocity and friction temperature at the surface for applying in air pollution modeling. A detailed discussion on application of turbulence parameters was also given. Multiple Gaussian plume model was used by Santhosh (1987) to study the spatial variation of Sulphur dioxide concentrations for four major urban centers in South India.

Validating the result of the model is often difficult. However, Pooler (1961) applied a model to determine the monthly concentration of sulphur dioxide at a large number of points at Nashvilla with the help of emission inventory. These estimates were compared with monthly measurements of sulphur dioxide from a network of stations. One half of the observed concentrations were between 80 and 125 percent of predicted value for the five month test period. Martin (1971) formulated a long term model similar to that of Pooler and the same was applied extensively to estimate sulphur dioxide and particulate matter. Many long term model were developed subsequently (Zimmerman, 1971; Turner et al, 1972).

Mayhoub et al (1991) studied the emission in air pollutant from a elevated point source according to Gaussian plume model. An elementary theoretical treatment for both the highest possible ground level concentration and down wind distance at which the maximum occurs for different stability classes has been constructed.

Robert A Mc cormick (1970) studied some of the more theoretical aspects of pollution transport and dispersion in cities and analyzed the findings from the experiment studies. The potential advantages and limitations of wind tunnels in studies of aerodynamic flow around urban structures are evaluated. Summer time surface and upper air wind and temperature data from Catrobe valley in south east Australia was analyzed by Physick and Abbs (1992). Findings from the wind field analysis are used to examine the dispersion of plumes from these sources. A complex terrain dispersion model (CTDM PLUS) was described by Perry (1992). The model simulates the flow and plume distortion near user-selected, three dimensional terrain features. Yet retains simplicity by applying flow-distortion corrections to flat terrain, Gaussian, and bi-Gaussian pollutant distribution. The model requires a fully three dimensional description of individual terrain features in order to estimate flow (and plume) distortions. Using aerosol optical depth as a function of wave length obtained from ground based multi wavelength radiometer observations, Columnar size-distribution functions of aerosols have been derived by Krishnamoorthy et al (1991). The nature of derived size distribution is strongly dependent on season. Spangler and Keating (1990) studied the dispersion using tracer gases from offshore sources into severe coastal complex terrain in central California. Dispersion, surface concentration, trajectories and stability were studied. A conceptual model based on Gaussian model is conceptual model based on Gaussian model is formulated to describe the observed behavior and is compared to actual surface tracer gas concentration in the coastal terrain. There was an over prediction factor of 4.2 in the modified model. However, the model confirms the importance of extreme horizontal dispersion in the up wind zone and the use of virtual point source concept when terrain is near the coastline and the importance of correcting the reflection assumption. Hiromasa et al (1988) studied the flow mechanism for the long-range transport of air pollutants by the sea breeze causing inland night time high oxidants. It was found that air mass which passed over the large emission sources along the coastline was transported inland as a sea breeze in the form of a gravity current. A high concentration layer was created in the upper part of the gravity current which discented at the rear edge due to internal circulation, yielding highest concentration of oxide near the ground. A model for evaluating pollutant concentration near the ground was developed by Xiang (1988). The main advantage of this model was its ability to estimate the distribution and variation of ground level concentration under a non uniform or unsteady wind field with minimum computation and the elimination of numerical pseudodiffusion.

3.3 **Environmental aspects**

In order to understand the variations in meteorological conditions of any region due to urbanisation and industrial developments, studies on different environmental aspects have been suggested from time to time. Studies on local rainfall, wind pattern, spatial variation of temperature and humidity, human comfort and fog etc. can be used for this purpose.

Chemical analysis of rainwater can help in understanding the geochemical cycle of various elements and also in assessing the air pollution status of different regions. Das et al (1981) studied the chemical composition of monsoon rainwater over Bhopal. Results reveal that the total minerals of rainwater are governed by the meteorological and geographical parameters. Being an inland station almost all chemical constituents present are of terrestrial origin. pH measurements of monsoon rainwater in India indicate that pH values are near about 7 which is the neutral value of pure distilled water. An attempt was made by Mukherjee and Krishna Nand (1981) to explain the higher pH of tropical rainwater in terms of the temperature dependence of solubility and dissolution rate of CO_2 in rainwater. The higher atmospheric temperatures in tropics, lower solubility and dissolution rate of CO_2 with rapid process of cloud formation and precipitation result in higher pH. Greater depth of saturated air during southwest monsoon may be another contributing factor. Maske and Krishna Nand (1982) analyzed rainwater samples collected at Background Air Pollution Monitoring Network (BAPMoN) stations in India during the year 1979, for chemical constituents of precipitation, like chloride, sulphate, nitrate, sodium, potassium and calcium. They concluded that these are the major constituents of rainfall over India. pH was very low at all BAPMoN stations. Bay of Bengal and Arabian sea are the major sources of chloride and sodium in rainwater. Concentration values of chemical constituents in rainwater indicate anthropogenic processes also are responsible to generate these constituents. Handa et al (1982) have done the analysis of rainwater samples collected during the period June to September (1980) and showed no incidence of acid rain over Lucknow. The chemical composition varied from shower to shower. Relatively high concentration of NO_3 (6 - 8 mg/l) were obtained in certain cases. Among the trace constituents iron was the most predominant. Gopinathan and Ramaswamy (1983) analyzed rainfall data of 18 stations of Tamilnadu to find whether any association between the meteoritic dust and rainfall. Prominent peaks on dates corresponding to meteor shower with 30 days lag along with some other peaks which are not at all related to any meteoritic shower are observed. The significant peaks also appear only in the months of October and November during which the region gets good rainfall. Along with the concern about the effect of acid rain on the ecosystem, the area affected by acid deposition, the extent to which the spatial distribution of various anions and cations are deposited over the continent and whether this deposition pattern changes with time are of importance: Filkelstein (1984) studied the spatial variability and structure in acid precipitation data. Singh et al. (1987) have done an analytical treatment of an atmospheric washout and transport model for pollutants released from an elevated source over flat terrain. The rate of absorption is calculated and results show that the pollutants can be absorbed by raindrops over distances as long as hundreds of kilometers from the source. The nature of mean ambient concentration and the vertical profile of the ambient concentration are studied. Ferman and Samson (1990) studied the precipitation chemistry associated with the flow pattern of transport-derived clusters. The study showed that highest pollutant deposition over the widest areas resulted from mean transport pattern with large areas of slow air mass movement over the regions of high sulphur emissions and which are frequently persistent over several periods. Seasonal differences exist within each cluster, with sulphur deposition being more warmer months. Precipitation affects soil moisture which in turn affects current and future surface temperature by controlling the partitioning between the sensible and latent heat fluxes. Jin Haung and Van Den Dool (1993) studied the monthly mean precipitation - air temperature (MMP-MMAT) relation over the United States, to examine the possibility of using MMP as a second predictor in addition to the MMAT itself, in predicting the next months MMAT and to shed light on physical relationship between MMP and MMAT. They found some evidence for the role of soil moisture in explaining the negative MMP-MMAT and positive MMAT-MMAT lagged correlations, which suggests that some direct measure of soil moisture to improve MMAT forecasts instead of using the MMP as a proxy. The correlation between monthly total precipitation and monthly mean temperature were studied over United States by Weining Zhao and Khalil (1993) . Both local and field significance were tested by using statistical methods. Summer precipitation and temperature were negatively correlated. Dana (1994) conducted sequential precipitation and precipitation chemistry measurements in central Ohio. Spatial averages and variances in rainfall rate and inorganic chemical concentrations were calculated for hourly and total - event time period. Brooke and Samsan (1994) studied the relationship between changes in SO_2 changes and precipitation concentration of sulphate using multiple regression models. The variation in concentration depending on site, was found to be related to meteorology.

The climatology of wind speed and directions of any urban area is an essential first step to be determined for an effective environmental and urban planning. Ramakrishnan (1957) studied the occurrence of squalls at Cochin using animograms for ten year period. Occurrence of squalls that occurred were tabulated. A theoretical model to obtain wind flow inside a city area was described by Vittal Murthy (1974). A horizontally homogeneous stationary turbulent layer is considered and the construction like buildings etc., are considered as obstacles in the fluid flow and are further assumed to be uniformly placed and air is considered to be thermally neutral. The equation for the above said fluid flow are derived and a solution is obtained. Sudhakaran Nair and Narayana (1980) have analyzed the wind data from seventeen ascents conducted at Thumba. It was subjected to isopleth analysis, land - sea breeze study, wind shear analysis and harmonic analysis. The lower tropospheric winds show land - sea breeze effect on the prevailing northeasterly winds during August. The maximum amplitude of diurnal oscillation of zonal and meridional winds is 3 m/sec and that of semi diurnal oscillation is 2 m/sec. All atmospheric dispersion models require a complete and thorough knowledge of the wind climatology for any given locality. Thomas (1981) studied the frequency distribution of hourly values of winds of Baroda. Light, moderate, strong and very strong wind are analyzed with the objective of utilization of energy from the winds for the windmills. It was observed that the conditions in north Gujarat are more favourable for the operation of windmills than south Gujarat. For the proper planning for selection of site and design of windmills Albeez (1983) analyzed the surface wind data at Karaikal. The frequency distribution of wind were studied and presented. It was concluded that windmills can be effectively put into use from May to August in the region. Ranjith singh (1987) studied the diurnal variation of wind flow pattern in lower and upper atmosphere over Indian region as observed during the summer monsoon. Cyclonic vorticity is generated over sea in lower tropospheric layers during night and whenever strong conversion is present over Indian seas particularly during the formation of the monsoon depression, the upper air easterlies strengthen during night ahead of easterly trough. Joffre and Laarile (1988) analyzed wind speed and direction to study the behavior of their standard deviation. The larger scatter normally observed under low wind speed or non neutral conditions was related to autocorrelation at one minute. Wind speed was the main factor affecting the variability of standard deviation; stability had much less effect. In conjunction with INSAT I B low level cloud motion vectors, Yadav and Kelker (1989) at the accepted winds were analyzed to understand the windflow prior to and just after onset of monsoon over Kerala. It was observed that two or three days before the actual date there was a strong cross equatorial flow and strengthening of the winds in southeast Arabin sea as well as Somali coast. It was felt that there is considerable scope for the use of scrutinize CMV data in conjunction with the conventional wind data in day to day synoptic analysis and forecasting. The most important factor influencing the atmospheric pollution is wind. Viswanathan and Anilkumar (1989) have studied some climatological aspects of the seasonal and diurnal variations of wind over Cochin. For the four representative months wind roses are studied for every three hour. The diurnal variation of the percentage frequency of different sixteen wind directions have also been studied for the four months mentioned above. The calm conditions during night time and strong westerlies during day time are unique features observed, with strongest wind during July and weak winds in January. Hiroshi Yashikado (1990) analyzed three dimensional wind field using temporal and spatial interpolation methods followed by an adjustment using a variational analysis technique. From the study of the meteorological structure and transport mechanisms of long range transport of air pollutants from the coastal region to the mountaneous inland region it was found that The creation of thermal low and the wind blowing towards the thermal low was due to the difference in temperature between the air above the plain and that on the plateau. Naidu (1989) studied the sea breeze observations at Bhubaneswar. The increase in RH and decrease in in temperature were more than 14% and 1^{0} C respectively at the time of onset of seabreeze. Madan et al. (1992) analyzed the Leh air field from April to October. Surface winds with gale speed was observed and from November to March the winds are relatively weak. The contribution of katabatic and anabatic winds in the variation of surface wind is not a dominating factor. No change in surface humidity is observed with the onset of strong wind. From the available observations it appears that channeling and thermal effects are responsible for the strong surface wind. Yoshikado (1992) performed a numerical experiment using a two dimensional hydrostatic boundary layer model to examine the basic characteristic of a day time heat island circulation. The results show that a day time circulation can develop that is much stronger than the nocturnal circulation. It persists in sea breeze system and has a notable effect on the sea breeze pattern. Trajectory analysis for air parcels passing over the coastal city indicate that the heat island would prevent the dispersion of urban pollutant and delay their inland transport. Suneela (1995) analyzed the diurnal and seasonal variation of wind direction and wind speed fluctuation. Both wind speed and direction fluctuations show a good diurnal variation following the surface temperature pattern. Studying their seasonal variation and their relationship with mixing height it is seen that r_0 would be more appropriate being taken as a measure of surface turbulence. Their relationship with stability is insignificant. Only in the month of July due to more frequent occurrence of strong to very strong wind in south Gujarat conditions are more favourable for the operation of windmills than in north Gujarat.

The effect of urbanisation on temperature and humidity fields have been studied in great detail by various workers.

Krishna Nand and Maske (1981) analyzed the minimum temperature fields from 11 urban climatological stations in Delhi in different months. It has been found that maximum monthly mean heat island intensity at Delhi was of the order about 5^{O} C during March and minimum about 0.8^{O} C during July. A cold pocket was also observed. Mukherjee at al. (1986) studied the evolution of heat island pattern at Pune on the night of 22/23 January 1982. The fluctuating nature of solinoidal circulation has been determined by analyzing the changing shapes of isotherms. The role played by the nature of terrain and the areal extent of the vertical circulation have also been inferred from the study. Daily maximum temperature of Bhopal for four summer months have been studied by Dubey and Balakrishnan (1989). From the daily values of maximum temperature, changes from the previous day value were calculated. Daily temperatures were also calculated. Depending upon their ranges the changes are classified as per the standard meteorological convention. Results indicate that in the case of changes 'little change' together with 'no change' predominates. It was observed that for all the months there is a gradual fall in percentage frequency as the magnitude of variation of maximum temperature increases. Based on surface temperature, humidity and wind data collected from 77 points over a period of eight days in and around Madras using mobile surveys, the heat island characteristics at Madras was studied by Jayanthi (1991). The intensity was found to be 4^{O}C. The humidity pattern shows a minimum over the heat pocket. The mixing height calculated found to be more over urban area than over rural area, indicating lower pollution potential over the former due to the mixing over a larger depth than in the later.

The study of the effects of atmosphere on human health and well being is very important. Since it influences them in more subtle and less obvious ways, for their basic needs. In order to calculate the effective temperature, the instantaneous values of wind speed, humidity and temperature values are required. However these elements are not available for the same height for any station in India. To overcome similar type of difficulties in USA, Thom (1959) and US Weather Bureau (1959) have given a simplified relationship between temperature and humidity to determine a parameter which is called discomfort index (DI). It was used by Nieuwolt (1966) in studying the urban microclimate of Singapore. Heat strokes / sun strokes in Israel with the help of this equation was studied and concluded that the effective temperature and the discomfort index are one and the same thing when one is indoors or when there are light winds. However corrections are required to the above calculated DI values at high wind speed. However this correction for wind is not linear and is complicated. Malhotra (1967) has conducted experiment in this country and has given different comfort zones based upon effective temperature. The thermal comfort scale proposed by

Parthasarathy and Rakecha (1972) has been utilised in finding out comfort or discomfort regions of the country. This study has shown that Banglore is the place where most comfortable conditions exist almost throughout the year while June to September period is the best period so far as Srinagar is concerned. Padmanabhamurthy and Bahl (1981) , studied the temperature, humidity and wind fields at the surface over Delhi during winter period. Several warm pockets and cold pockets are identified. It was found that rural Delhi was comfortable in February, March and December. But at urban Delhi January, February and December are comfortable and in night time rural Delhi is comfortable in May and June only. Urban Delhi is comfortable in April, October and November. Manosi Lahiri (1984) studied the preference for the use of different bioclimatic indices. It was concluded that it is not only necessary to keep in mind the climatic characteristics, but also the cultural environment which includes food, clothing and shelter, is quiet distinct from the mid latitudes where most of the biomet indices have been developed. Suitable modifications must be made for Indian condition. Bangalore is having best climatic conditions in South India, throughout the year while Hyderabad excepting a few afternoon hours in summer months, when poor comfort conditions prevails, otherwise good climatic conditions prevails during the course of a year. Shivaramakrishnan and Prakash Rao (1990) studied the human comfort over Sriharikotta island. Except during May and June the thermal comfort over Sriharikotta is either comfortable or warm. The diurnal variation is large in February, March and least in November. The Webb's comfort index which include wind speed also was used.

Fog is considered to be dangerous weather phenomenon. Effect of temperature, dew point temperature, wind and synoptic situations were studied during the winter months at Calcutta by Basu (1952). Prediction diagram for temperature and dew point as well as fog have been prepared. It has been concluded that successful fog prediction is possible on the basis of forecast of dew point which is likely to prevail during late night hours, particularly during minimum temperature epoch and that such accurate due point forecast is only possible by watching hourly variation of dew point till 2200 IST. Kundu (1957) studied the incidents of fog over Safdarjung airfield. Relation between fog and humidity figures dew point temperature, surface wind, inversion are analyzed. Synoptic situation associated with fog was studied and also relation between minimum temperature and due point before and after fog days was also analyzed. Gangopadhyaya and George (1959) have suggested that horizontal convergence within the surface inversion was an additional factor which favored the formation of radiation fog or stratus at Calcutta. Natarajan (1962) studied the influence of horizontal convergence in the surface layers bounded by thermal inversions on the formation of radiation fog at Palam, Santacruz and Begumpet during the winter 1960-61. Puri (1971) has attempted to forecast fog for Delhi airport on the basis of Jacob's diagram. He compared the actual time of occurrence of fog and the time of fog likely to occur as per computation and found to be agreeing well. Deterioration visibility at Bombay airport was studied by Mukherjee et al (1980). The fog visibility condition seem to develop generally not due to most phenomena like mist or fog, but due to suspended particulate matter and smoke from chimneys and domestic fires which move or stagnate over the eastern side of aerodrome under the prevailing wind condition. Ground inversion at Bombay airport was studied by Manral and Dayakishan (1981). In it they studied the frequency, thickness and intensity of ground inversion in the morning. The study revealed that inversion during winter are steep but thickness is less whereas in summer these are weak but thickness is more. The influence of land and sea breeze circulation also was studied. It suggests that the nocturnal inversion over Bombay gets weakened or partially broken, particularly after 1900 GMT and its vertical profile is not continuous. Manikkam (1983) made an attempt to calculate time of occurrence of fog by applying Jacob's diagram which is based on Brunt's formula. A comparison of the forecast time and actual setting time of fog shows very good agreement in all the cases studied. Hill (1988) analyzed the fog effect of the great salt lake by use of fog reports, precipitation and temperature records to find a relationship between lake size and fog frequency. While a large winter to winter variability is found there is also a strong relationship with lake size. when fog is present throughout the day the difference between the maximum and minimum temperature will be low. Cerceda and schemenauer (1991) studied the occurrence of fog in chile. The variation in fog frequencies is related to persistent synoptic scale circulation patterns and to ocean current. The study demonstrated that data from standard meteorological stations are not suitable for identifying coastal locations. In order to improve air base operations, vertical profiles of attenuation coefficients caused by fog are investigated by Tomine (1991) using lidar system. The results show that, when the ceiling is about 30 meters, the attenuation coefficients near this level is generally larger than that near the surface. Attenuation coefficients in the upper levels increases slightly earlier than that near the surface when the ceiling is lowering.

CHAPTER IV

Analysis of surface parameters

The study of past climate over a region will help in understanding the behavior of the atmosphere. It is extremely useful to construct a comparable and comprehensive continuous climatic time series. Climate is not invariant. In greater or lesser it is everchanging. The regular seasonal heating and cooling is interfered with differing amounts of heat and moisture transported by winds and ocean currents from one year to another. The variations are sometimes rapid and sometimes slow. These changes are due to either natural or man made. The variations are not always in the same direction.

Climatology derives most of its basic concepts from an appreciation of various series of meteorological observations taken over extended periods of time. In this connection one usually deals with statistical data which are recorded at regular intervals of time. Extrapolations of climate trends and analysis for supposed cyclic variations have commonly been invoked. Identification of some of the physical controls that provoke climatic changes should enable a running watch to be kept upon significant weather elements. Intraseasonal oscillations in the atmosphere encompass any fluctuations with periods shorter than the seasonal cycle. Their low frequency components with periods greater than about 10 days comprise modes of variability that are important for long range predictions. To study periodic phenomena like annual, semi-annual or daily cycles of meteorological elements, harmonic analysis is a convenient technique.

In this chapter the temporal variations of three surface meteororological parameters, namely temperature, pressure and relative humidity (RH) have been studied for Cochin during the ten year period from 1983 to 1992. In the present study, detailed analysis on the surface wind and rainfall over Cochin has not been attempted, because extensive studies on the wind climatology (Anil Kumar, 1986) and rainfall characteristics (Rajan, 1988) over Cochin have already been carried out. However, some aspects of these two parameters are analyzed in the present study and the results are discussed in chapter 7.

4.1 Results and discussion

Temporal variation of three basic meteorological parameters, namely air temperature, pressure and relative humidity have been discussed as below.

4.1.1 Temporal variation of temperature

For tropical stations like Cochin (10°N), the annual range of temperature is small. Table 4.1 gives the 3 hourly mean values of temperature for all the months. The lowest value of 23.2°C is recorded at 0530 hrs during the month of January. The highest value of 32.4° C is recorded at 1430 hrs

Table 4.1 Three hourly mean values of temperature

MONTH	0230 hrs	0530 hrs	0830 hrs	1130 hrs	1430 hrs	1730 hrs	2030 hrs	2330 hrs
JANUARY	24.52	23.24	24.69	30.03	30.95	29.34	27.08	25.77
FEBRUARY	25.51	24.52	26.14	30.46	31.17	29.66	27.81	26.55
MARCH	26.70	25.94	27.86	31.35	31.82	30.45	28.46	27.47
APRIL	27.50	26.70	29.20	32.07	32.42	30.97	28.90	28.22
MAY	27.21	26.25	28.38	31.30	31.87	30.62	28.67	27.82
JUNE	25.71	25.24	26.57	28.74	29.16	28.09	26.79	26.44
JULY	24.84	24.56	25.70	27.86	28.50	27.61	25.95	25.34
AUGUST	24.77	24.44	25.57	27.72	28.26	27.23	25.81	25.20
SEPTEMBER	25.19	24.70	26.31	28.65	29.12	27.85	26.45	25.79
OCTOBER	25.26	24.65	26.63	29.43	29.77	28.16	26.82	25.92
NOVEMBER	24.99	24.40	26.56	29.90	30.41	28.83	27.37	25.77
DECEMBER	24.94	23.82	25.85	30.52	31.33	29.37	27.12	25.84

during the month of April. The temperature distribution with respect to month and time is illustrated in Fig. 4.1. It shows that the maximum temperature of 31.6^{o}C is noted around 1400 hrs in April and minimum temperature of 24.8^{o} C is observed around 0530 hrs in January. Monthly variation in temperature is more dominant during the noon time. Temperature values observed in the afternoon hours are lower in monsoon months. This is due to the overcast sky conditions which prevent the incoming solar radiation to reach the earth's surface. March - April is the period of highest intensity of solar radiation. These two months therefore have the highest temperatures for all the 3 hourly observations. Due to pre-monsoon thunder shower frequent in the month, May shows large variations in temperature within the month. Cochin being a coastal station the diurnal variation of temperature is less. The monthly mean maximum and minimum temperatures, their range and the mean values are given in Table 4.2. It is seen that the diurnal range decreases from January to June and increases from August to December. July, the month of maximum rainfall, the temperature range shows higher magnitude than that of the previous and the succeeding months. The mean temperature shows a gradual increase from January to April, then decreases during monsoon months till August and thereafter increases gradually. The increase is more conspicuous during March - April which is followed by a sudden decrease with the pre-monsoon thundershowers.

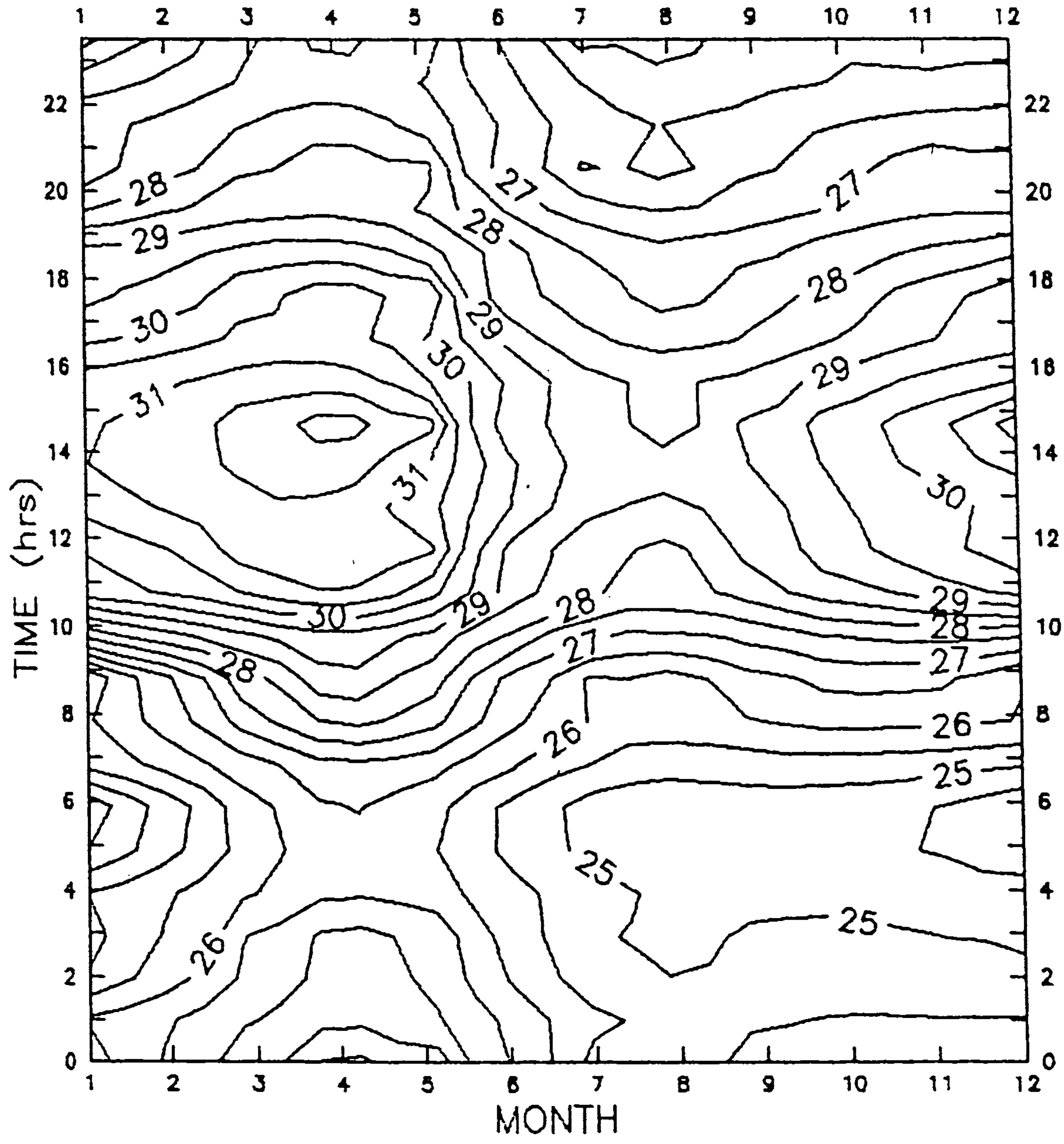


Fig. 4.1 Temperature distribution with respect to month and time

Table 4.2 Monthly mean maximum, minimum and mean values of temperature

Month	Maximum ^{0}C	Minimum ^{0}C	Range ^{0}C	Mean Temp
January	31.94	22.41	9.53	27.18
February	31.96	23.87	8.09	27.92
March	32.61	25.36	7.25	28.99
April	33.09	26.01	7.08	29.55
May	32.58	26.22	6.36	29.4
June	30.45	24.63	5.82	27.54
July	29.77	23.88	5.89	26.83
August	29.35	23.91	5.44	26.63
September	30.1	24.13	5.97	27.12
October	30.87	24.23	6.64	27.55
November	31.26	23.6	7.66	27.43
December	32.31	23.39	8.92	27.85

Table 4.3 gives the standard deviations of temperatures at every three hour intervals for the twelve months. These are the deviations from, the three hourly mean values. The range between the maximum and minimum standard deviations is least for 0230 hrs (0.89) and is maximum for 2030 hrs (2.04), ie., the transition period when the sea breeze changes to land breeze.

Temperature tendency, which gives change in temperature with time for every 3 hr interval is calculated and is illustrated in Fig. 4.2. It can be seen that the temperature tendency shows high value during winter months. Maximum tendency is noted at 1000 hrs during the January. During monsoon months the change in temperature with time is least. There is not much variation in temperature during late night and early morning hours when temperature is comparatively less. The temperature tendency increases with the rising of sun, till it reaches a maximum during 1000 hrs. It is comparatively less around maximum temperature epoch around 14 hrs local time. Sea breeze is at its maximum strength during this time. After 1430 hrs there is a reversal of temperature gradient accompanied by decrease in sea breeze. After that the negative temperature gradient attains its maximum value during 1900 hrs when sea breeze begins to disappear. Monsoon month shows lowest values of tendency.

Table 4.3 Standard deviation of temperature at every 3 hour interval

MONTH	0230 hrs	0530 hrs	0830 hrs	1130 hrs	1430 hrs	1730 hrs	2030 hrs	2330 hrs
JANUARY	1.34	1.84	1.99	2.12	1.32	1.59	1.30	1.36
FEBRUARY	1.25	1.45	1.31	1.36	1.54	1.32	0.89	1.71
MARCH	1.49	1.48	1.76	0.86	1.00	1.36	2.93	2.73
APRIL	1.54	1.38	1.23	0.85	0.92	1.63	1.93	1.85
MAY	1.89	2.46	2.59	2.07	2.00	2.01	2.44	2.01
JUNE	1.61	2.23	1.99	2.30	2.23	2.28	1.93	1.85
JULY	1.38	1.30	1.97	2.18	2.39	2.10	1.94	2.04
AUGUST	1.16	0.99	1.32	2.01	1.95	1.61	1.36	1.22
SEPTEMBER	1.00	0.87	1.35	1.59	1.44	1.28	1.18	1.08
OCTOBER	1.04	0.85	1.20	1.49	1.48	1.21	1.21	1.19
NOVEMBER	1.17	2.20	1.35	2.65	1.70	1.73	1.75	1.33
DECEMBER	1.63	2.00	2.20	1.51	1.38	2.21	1.68	1.70

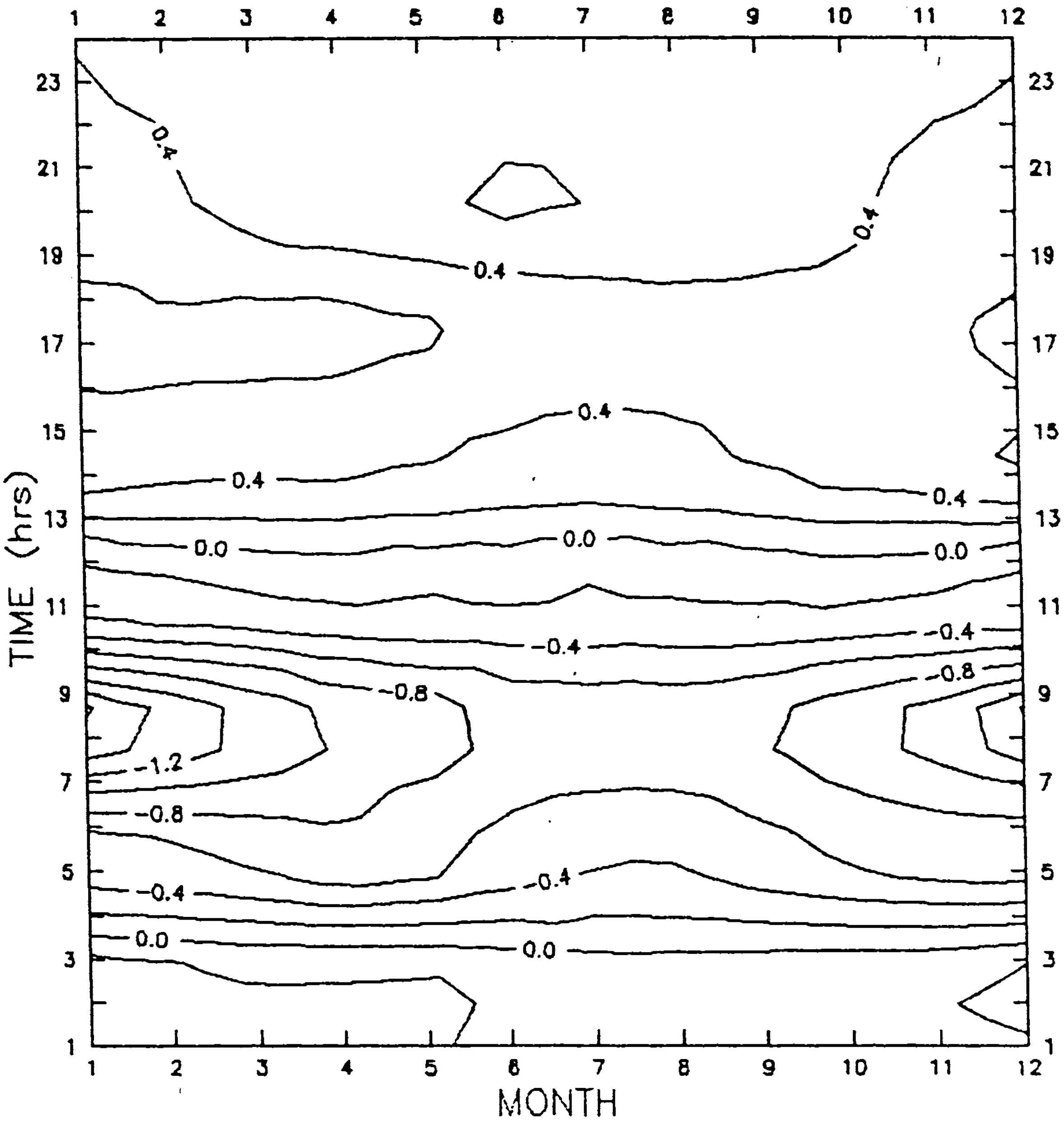


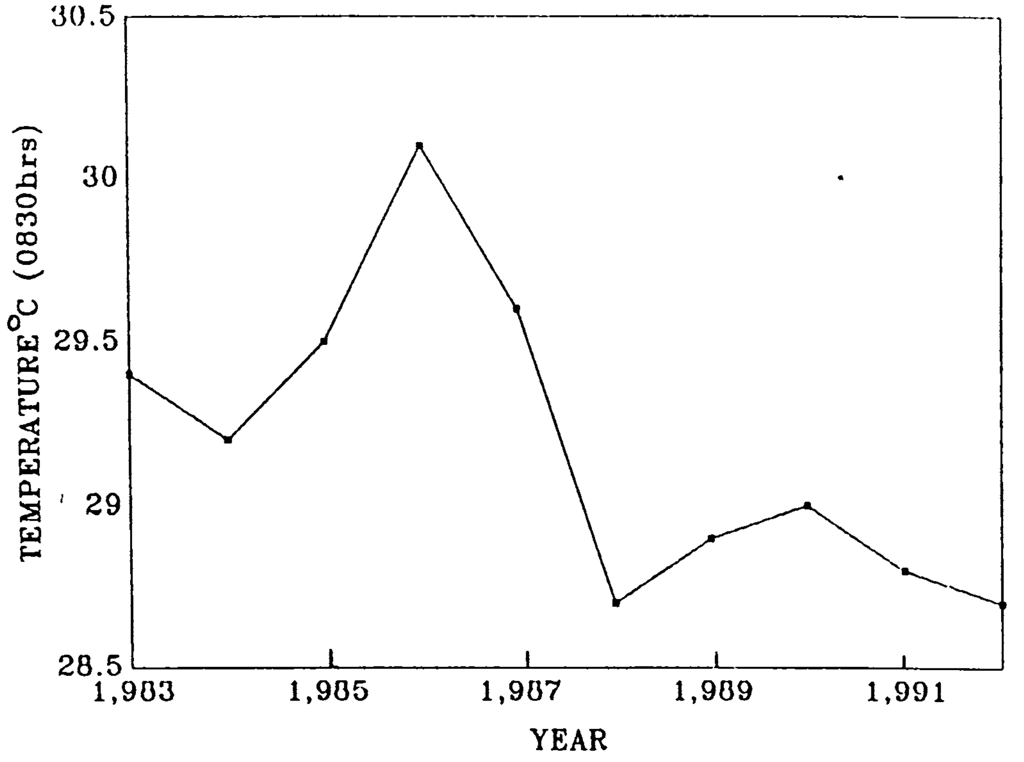
Fig. 4.2 Temperature tendency for three hour interval

Yearly variations in temperature are studied for 0830 hrs and 1730 hrs and it is noted that yearly variations is only around 1^{o}C. From Fig. 4.3 it can be seen that minimum temperature occurs in 1988 and maximum in 1986 for 1730 hrs. The variation is more during 1986 (drought year) to 1988 (good monsoon year). The temperature is maximum in 1987 and minimum in 1989 for 0830 hrs. The variations are more during 1987 to 1989.

4.1.2 Temporal Variation of Pressure

Diurnal variations of surface pressure with two maximal around 1000 hrs and 2200 hrs and two minima around 0400 hrs and 1600 hrs are one of the most conspicuous features of the tropics.

From Table 4.4 we can see that the mean pressure values for every 3 hourly intervals. There are two maxima around 0830 hrs and 2330 hrs and two minima around 0530 hrs and 1730 hrs pressure maximum at 0830 hrs is larger than at 2330 hrs and pressure minimum at 1730 hrs is lower than at 0530 hrs value. Pressure value is higher during winter months for all three hourly observations. January which is the month of lower temperature is showing higher pressure at all the three hourly observations and the values are least during May-June months. May is characterized by thundershowers and high convective activity in the afternoon hours.



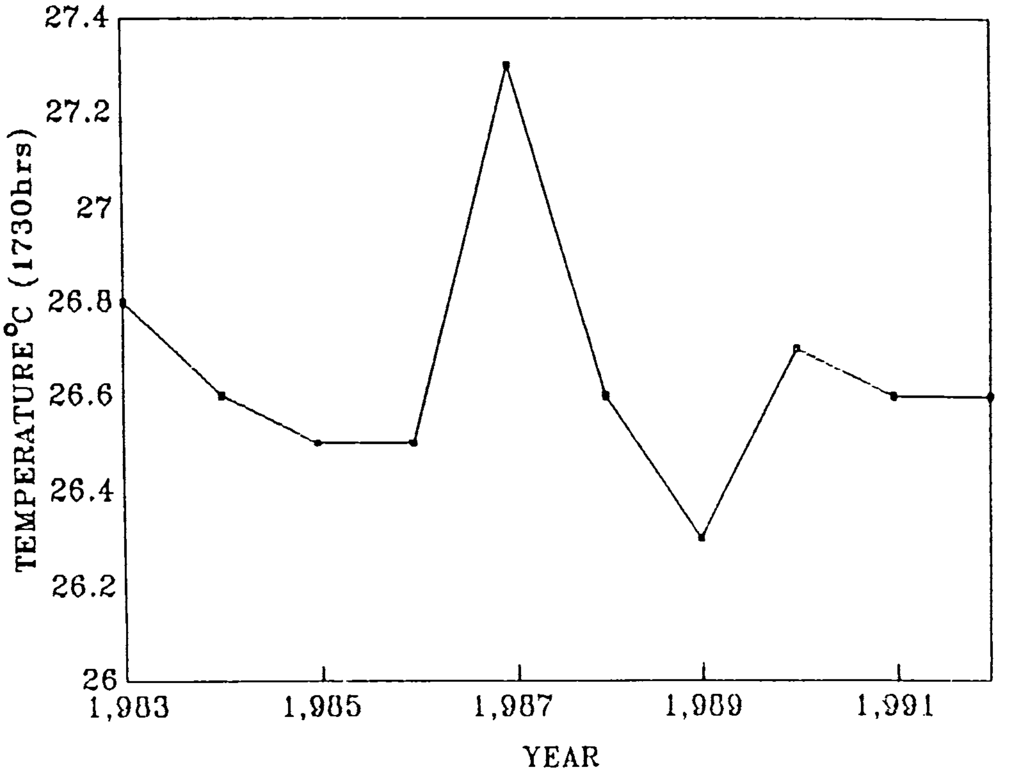


Fig. 4.3 Yearly variation of temperature (0830 hrs & 1730 hrs)

Table 4.4 Three hourly mean values of pressure

MONTHS	0230 hrs	0530 hrs	0830 hrs	1130 hrs	1430 hrs	1730 hrs	2030 hrs	2330 hrs
JANUARY	1011.63	1011.47	1013.54	1013.37	1010.12	1009.58	1011.83	1012.82
FEBRUARY	1011.41	1011.24	1013.26	1013.28	1010.14	1009.31	1011.65	1012.72
MARCH	1010.00	1009.85	1011.87	1011.77	1008.76	1007.89	1010.40	1011.52
APRIL	1008.88	1008.82	1010.72	1010.43	1007.68	1007.12	1009.48	1010.53
MAY	1007.82	1007.80	1009.46	1009.39	1007.21	1006.80	1008.73	1009.39
JUNE	1007.86	1007.77	1009.28	1009.35	1007.75	1007.22	1008.83	1009.48
JULY	1009.01	1008.82	1010.24	1010.26	1008.65	1008.17	1009.89	1010.18
AUGUST	1009.32	1009.04	1010.61	1010.67	1008.80	1008.37	1010.10	1010.92
SEPTEMBER	1009.41	1009.30	1011.06	1010.91	1008.48	1008.22	1010.32	1011.02
OCTOBER	1009.33	1009.41	1011.35	1010.86	1008.13	1008.17	1010.43	1011.03
NOVEMBER	1009.20	1009.27	1011.20	1010.73	1008.03	1008.03	1010.19	1010.71
DECEMBER	1011.35	1011.18	1013.11	1012.53	1009.66	1009.47	1011.86	1012.50

Figure 4.4 gives pressure distribution for different hours and months. It is seen that maximum pressure of 1012.8 mb occurs around 0800 hours during January and minimum pressure of 1007.2 mb occurs around 1730 hrs in May. The seasonal variation is found to be more towards the first maximum epoch and first minimum epoch. The seasonal variation is least during 1300 hrs and 1600 hrs. May, which is the transition month is showing least variation of pressure. For monsoon months monthly variation is also less.

The range from maximum to minimum pressure values during day and night are given in Table 4.5. It can be seen that the pressure range is more during day time. However the day time pressure variations are comparatively lower during monsoon months. Night time pressure variations are generally lower, and during winter months the variations in pressure is found to be the least.

Table 4.6 gives the standard deviations of pressure at every three hour intervals and for all the months. These represent the pressure fluctuations from every 3 hour mean values. The range between the maximum and minimum standard deviations is least at 2030 hrs. The corresponding value in the case of standard deviations of temperature is maximum at this hour.

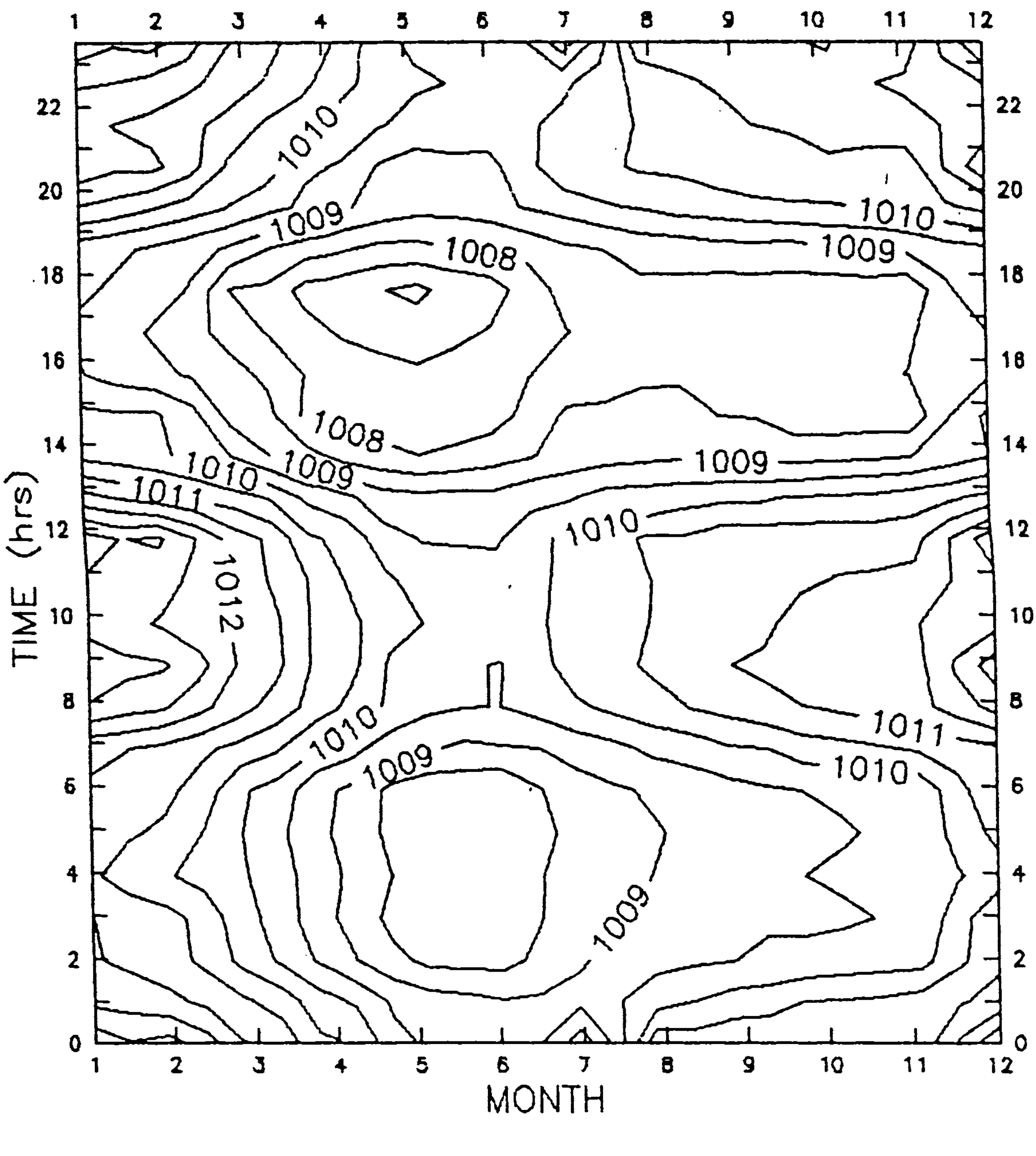


Fig. 4.4 Pressure distribution with respect to month and time

Table - 4.5 Range of Pressure values

Month	(830-1730) mb	(2330-0530) mb
January	3.96	1.35
February	3.95	1.48
March	3.98	1.67
April	3.6	1.71
May	2.66	1.59
June	2.06	1.71
July	2.07	1.81
August	2.24	1.88
September	2.84	1.72
October	3.18	1.62
November	3.17	1.44
December	3.64	1.32

Table 4.6 Standard deviation of pressure at every 3 hour interval

MONTH	0230 hrs	0530 hrs	0830 hrs	1130 hrs	1430 hrs	1730 hrs	2030 hrs	2330 hrs
JANUARY	1.45	1.27	1.53	1.25	1.30	1.64	1.95	1.57
FEBRUARY	1.27	1.50	1.89	1.62	1.25	1.64	1.45	.85
MARCH	2.20	1.75	1.90	1.66	1.81	1.72	1.58	1.24
APRIL	1.15	1.65	1.09	1.80	.85	1.63	1.43	1.49
MAY	1.62	1.33	1.63	1.32	1.65	1.35	1.37	1.51
JUNE	2.20	1.80	1.94	1.77	1.89	2.01	2.05	1.56
JULY	1.44	1.22	1.31	1.49	1.60	1.41	1.56	2.86
AUGUST	1.10	0.95	1.29	1.10	1.54	0.97	1.40	.96
SEPTEMBER	1.28	0.95	1.35	1.02	1.30	1.68	1.52	1.52
OCTOBER	1.51	1.47	1.35	1.81	1.38	1.34	1.58	1.66
NOVEMBER	2.65	2.72	2.66	2.58	2.26	2.54	2.46	2.31
DECEMBER	0.78	1.77	1.18	1.43	1.07	1.25	2.00	1.53

Figure 4.5 shows the pressure tendency distribution. Since the temperature is having two maxima, the pressure tendency is positive and maximum near 0700 hrs and 1900 hrs ie., before the occurrences of maximum values. Monsoon months show lower values. The positive pressure tendency increases from 0400 hrs till it reaches a maximum around 0700 hrs and then decreases till the first maximum pressure epoch. The negative tendency, ie., the decrease in pressure with time starts from about 1000hrs and continues till about 1730hrs. Pressure decrease is also showing lower values during south west monsoon months. Around 1000 hrs there is a reversal of gradient and sea breeze sets in. Negative pressure tendency reaches maximum around 1300 hrs after which sea breeze reaches its maximum intensity and then decreases. At about 1700 hrs, there is a reversal of gradient and it increases till around 1900 hrs after which land breeze sets in. Then the pressure tendency decreases.

Except in July, the pressure tendency show similar diurnal variations. In July positive pressure tendency decreases till round 0400 hrs. Thereafter it increases and reaches a maximum around 0700 hrs and decreases till around 1000 hrs. A reversal of pressure gradient is noted afterwards. The pressure tendency reaches maximum near 1300 hrs and decreases till around 1700 hrs. There is a reversal of gradient which increases to a maximum around 1900 hrs and then decreases till around 2100 hrs. The gradient reverses

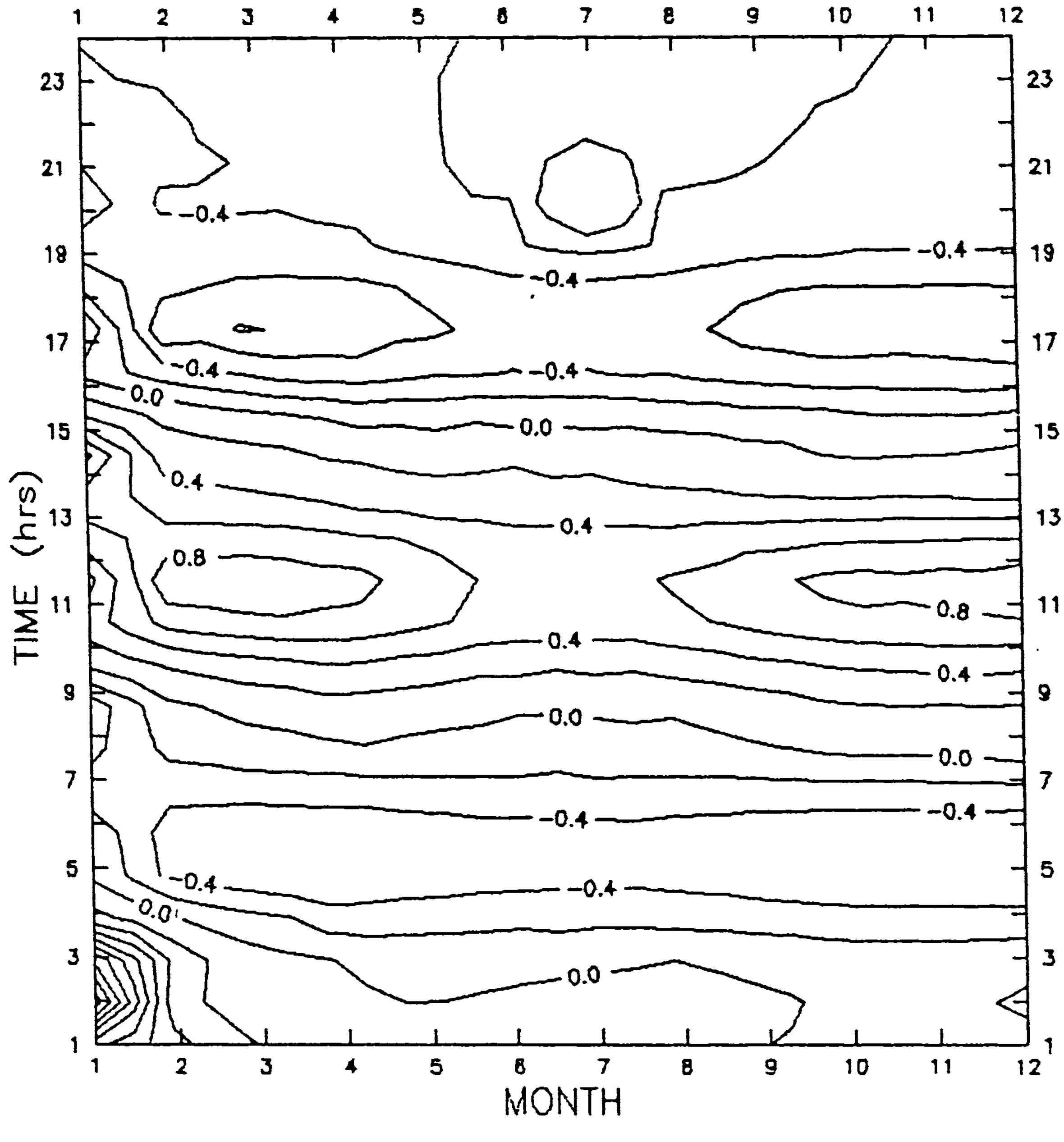


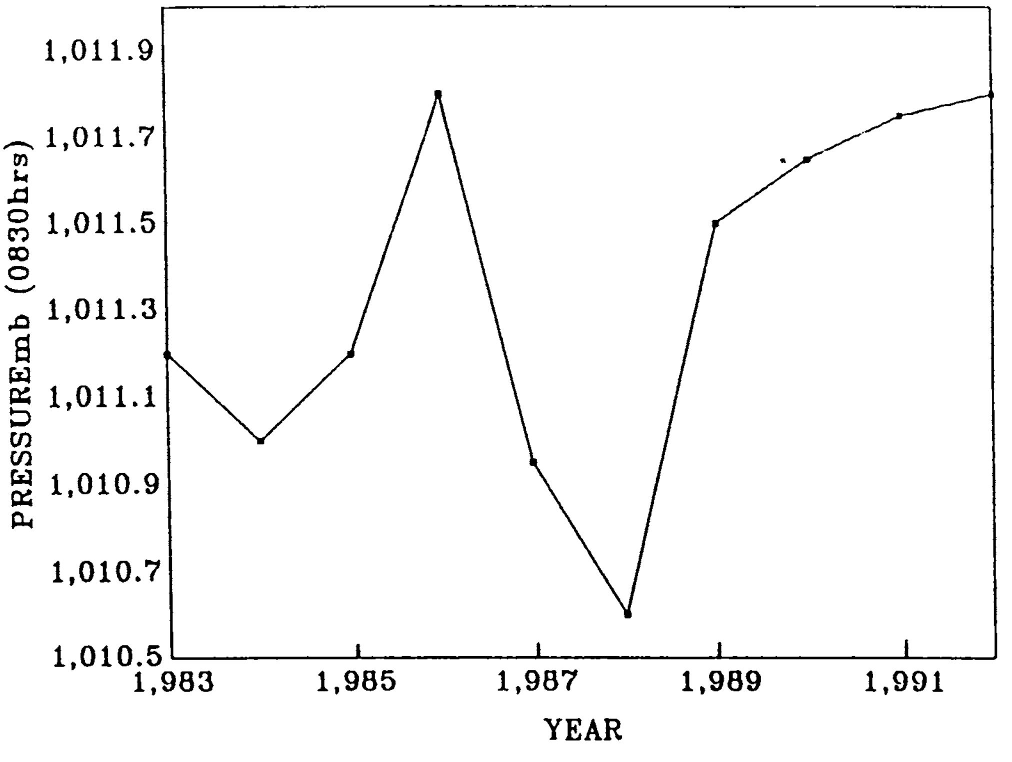
Fig. 4.5 Pressure tendency for three hour interval

thereafter. This shows that the effect of monsoon on surface level wind pattern is less. However the range of variation is less during July.

Yearly variation of pressure for 0830 hrs and 1730 hrs are shown in Fig 4.6. The yearly variation in pressure is of the order of 1 mb over Cochin. During ten years considered for the study, the minimum pressure is observed during 1988 and maximum in 1992. From 1986 to 1988 there is a sharp decrease. During the last three years the variation of pressure value was less.

4.1.3 Temporal variation of Relative Humidity (RH)

Atmospheric humidity is an important parameter in determining the climate of a region. Places on the same latitudinal belt can have either dry climate or humid climate according to the humidity conditions of the air. A coastal region will have a very humid climate throughout the year. An inland region will mostly experience a dry climate. The RH measured at every three hour interval at Cochin is used for analysis. The mean value of RH for each three hourly observation for every month is given in Table 4.7 . It is seen that RH is maximum around 0530 hrs, which is the minimum temperature epoch for all the months. The RH decreases till it reaches to a minimum around 1430 hrs, which is the time of maximum temperature epoch. June, the month of onset of southwest monsoon is having higher RH during all the three



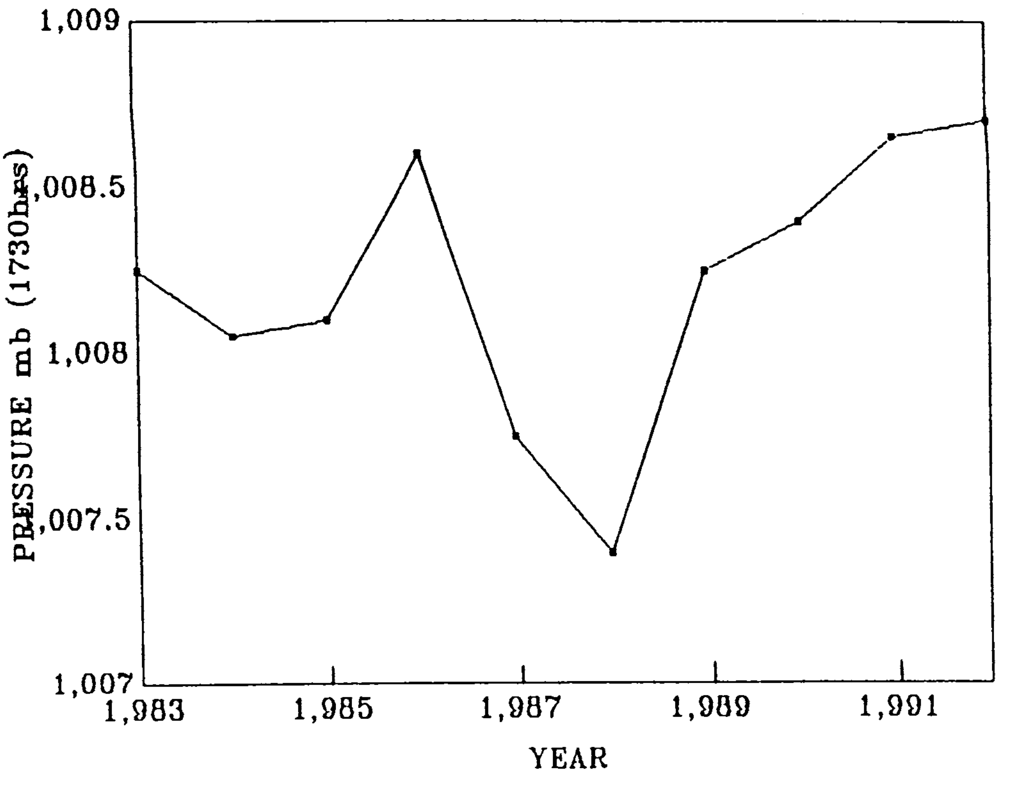


Fig. 4.6 Yearly variation of Pressure (0830 hrs & 1730 hrs)

Table 4.7 Three hourly mean values of RH

MONTH	0230 hrs	0530 hrs	0830 hrs	1130 hrs	1430 hrs	1730 hrs	2030 hrs	2330 hrs
JANUARY	83.96	85.21	74.24	55.31	54.42	60.98	73.17	79.92
FEBRUARY	84.66	87.75	77.26	59.08	57.51	64.70	74.39	80.93
MARCH	84.96	87.96	78.58	63.90	63.68	68.14	76.84	80.56
APRIL	84.87	88.20	77.81	65.94	65.71	70.86	78.17	81.41
MAY	87.22	90.65	83.44	73.70	72.42	75.47	81.76	82.89
JUNE	93.62	94.90	90.56	82.37	80.18	84.10	89.90	92.03
JULY	93.92	94.53	90.52	81.03	78.48	82.54	89.86	92.38
AUGUST	93.82	94.95	90.81	81.68	78.41	82.16	89.87	92.38
SEPTEMBER	92.83	94.35	87.93	76.75	73.88	79.45	86.73	90.33
OCTOBER	92.17	92.73	84.88	73.08	70.87	77.05	85.12	89.95
NOVEMBER	89.98	90.47	79.99	63.36	62.21	69.49	81.15	86.04
DECEMBER	83.30	84.27	71.96	52.14	52.07	60.38	72.84	79.92

hourly observations. RH shows comparatively low values during the winter months.

Fig. 4.7 gives RH distribution in relation to month and time. Maximum RH of 94% is observed near 0500 hrs of July-August. Sharp increase in RH starts in May which is the transition month from dry to wet season and there is a sharp decrease in October which is the transition month from wet to dry season. Monsoon months are having maximum RH for all the three hourly observations and minimum RH during winter months. Minimum RH of 54% is observed during noon hours of December. The diurnal variation in RH over Cochin shows that there is a sharp decrease in RH between 0630 hrs and 1130 hrs and an increase between 1800 hrs to 2000 hrs. Monthly variation is least during this intervals. It is maximum during noon hours.

Table 4.8 gives the maximum, minimum, mean and range values of RH for different months. It shows that range is maximum during winter months when RH is minimum and least during monsoon months when RH is maximum.

Table 4.9 gives standard deviations of RH at every three hour intervals for the twelve months. These are the deviations from the three hourly mean values. The range between maximum and minimum standard deviation is least for 0230 hrs. It is maximum for 1430 hrs which is the time of maximum temperature epoch.

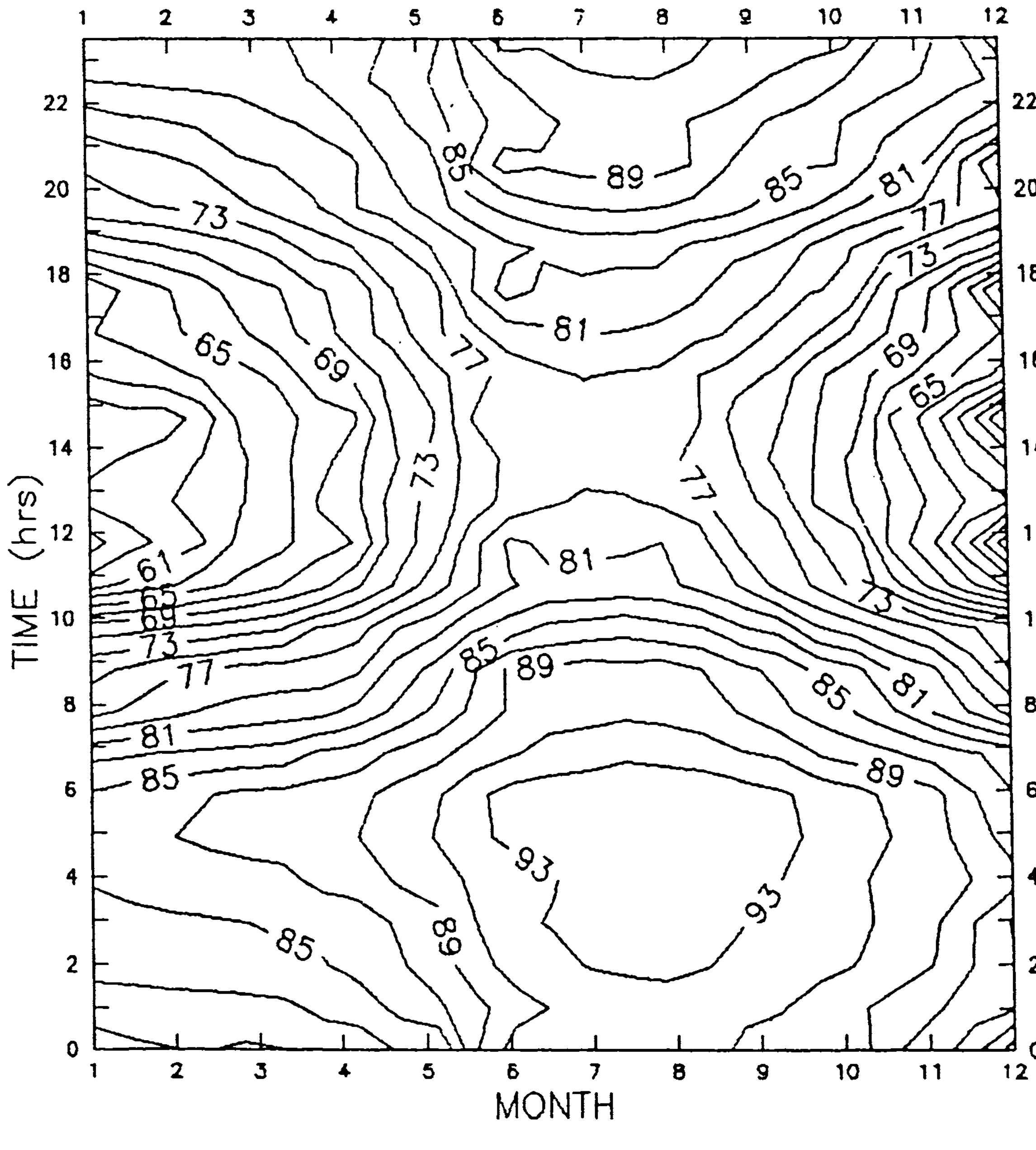


Fig. 4.7 RH distribution with respect to month and time

Table 4.8 Monthly Maximum, Minimum and range values of RH

Month	Maximum	Minimum	Range	Mean
January	85.21	54.42	30.79	69.82
February	87.75	57.51	30.24	72.63
March	87.96	63.68	24.28	75.82
April	88.20	65.71	22.49	76.96
May	90.65	72.42	18.23	81.54
June	94.90	80.18	14.72	87.54
July	94.53	78.48	16.05	86.51
August	94.95	78.41	16.54	86.68
September	94.35	73.88	20.47	84.12
October	92.73	70.87	21.86	81.8
November	90.47	62.21	28.26	76.34
December	84.27	52.07	32.20	68.17

Table 4.9 Standard deviation of RH at every 3 hour interval

MONTH	0230 hrs	0530 hrs	0830 hrs	1130 hrs	1430 hrs	1730 hrs	2030 hrs	2330 hrs
JANUARY	6.09	7.23	10.11	10.75	16.29	9.16	7.17	5.69
FEBRUARY	5.94	4.91	8.01	10.23	8.87	7.83	4.80	5.47
MARCH	6.42	4.75	6.33	7.46	7.17	6.27	6.56	8.72
APRIL	7.40	5.01	6.43	4.85	5.52	6.55	7.43	7.07
MAY	7.64	6.66	8.98	9.38	7.39	8.10	7.33	10.56
JUNE	5.10	4.82	6.81	10.50	12.59	10.62	7.26	5.32
JULY	6.80	7.57	7.74	11.42	10.04	9.63	7.75	6.53
AUGUST	4.94	4.47	6.85	13.09	10.55	9.24	6.32	7.60
SEPTEMBER	4.23	3.50	6.36	11.62	8.48	7.36	6.18	5.44
OCTOBER	4.42	8.31	8.45	9.63	9.01	9.08	7.02	6.34
NOVEMBER	7.14	8.34	12.89	13.01	13.03	14.08	10.02	9.30
DECEMBER	6.71	7.80	10.43	10.91	11.62	10.74	8.80	7.07

Relative Humidity tendency for each three hour interval is calculated, and is represented in Fig. 4.8. The sharp increase in RH starts in May (Pre-monsoon month) and sharp decrease in October (Post monsoon month). Minimum RH occur during noon hour of December January. The decrease is sharp during 0630 to 1130 hours till it reaches a minimum at around 1430 hrs and then there is a sharp increase during 1800 to 1930 hrs. Monsoon months show lower RH tendency values.

Yearly variation of RH is studied at 0830 hrs and 1730 hrs (Fig. 4.9). Yearly variation is less than 5% . At 0830 hrs maximum RH is in 1985 and minimum in 1989. At 1730 hrs the maximum RH is in 1990 and minimum in 1987.

4.2 Harmonic Analysis of Meteorological Parameters

Harmonic analysis is used to study periodic phenomena like annual, semi-annual , diurnal cycles of meteorological elements. Only known periodicities can be studies using this technique.

Three hourly data for ten years (1983-1992) is used for Harmonic analysis. Up to six harmonics are considered in the case of seasonal cycle ie., oscillations of twelve months(annual), six months(semi-annual), four months (triannual), three months, two and half months and two months are studied. The results include amplitude and phase of oscillations, variance, percentage of first harmonic, ratio of

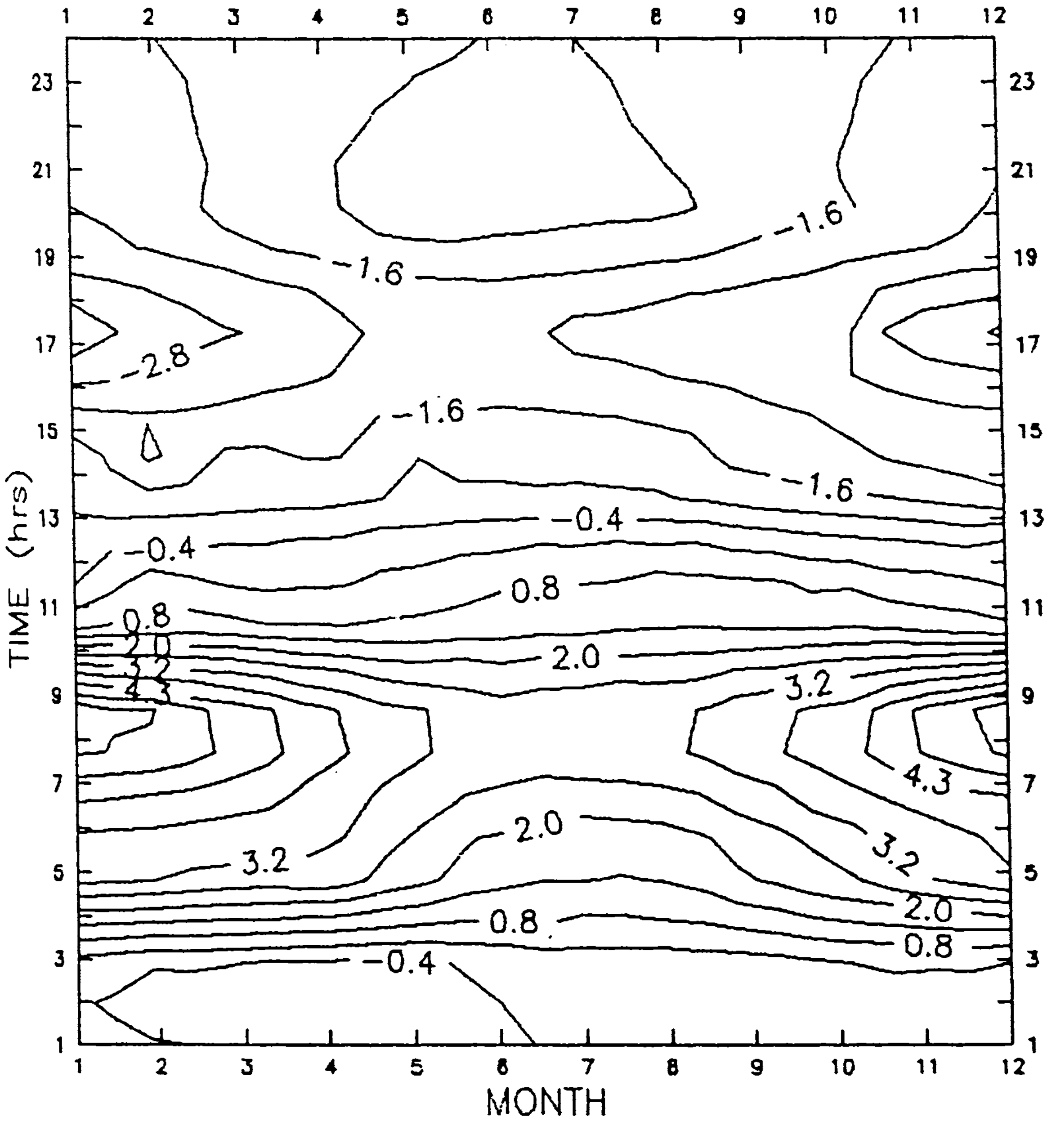
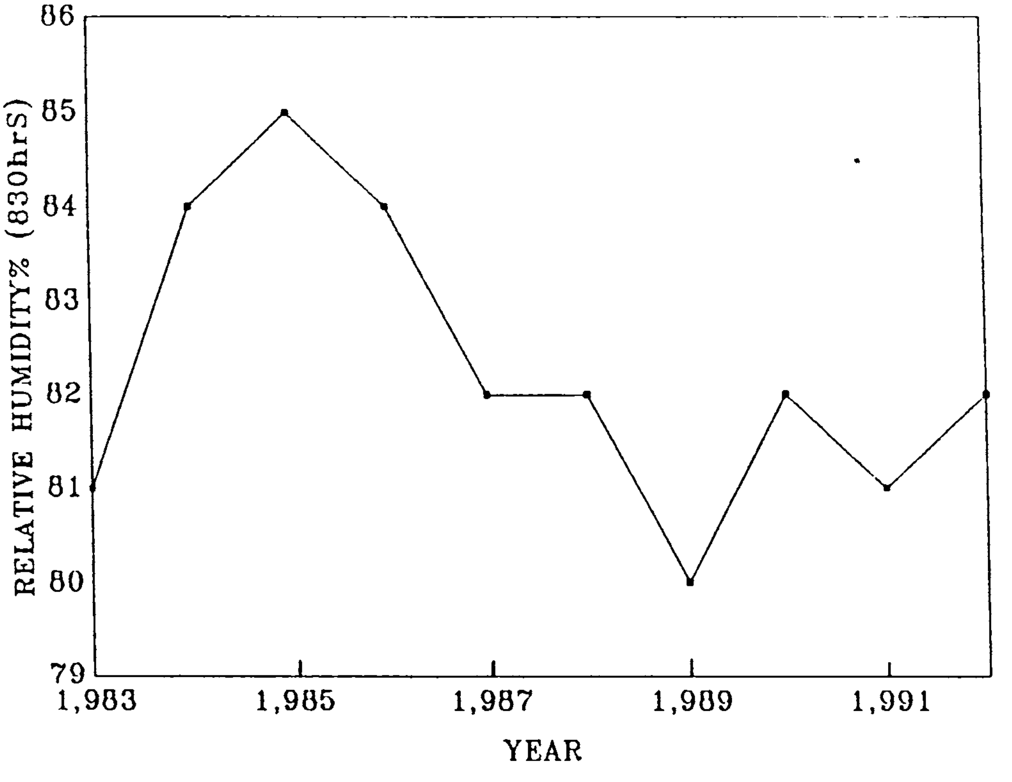


Fig. 4.8 RH tendency for three hour interval



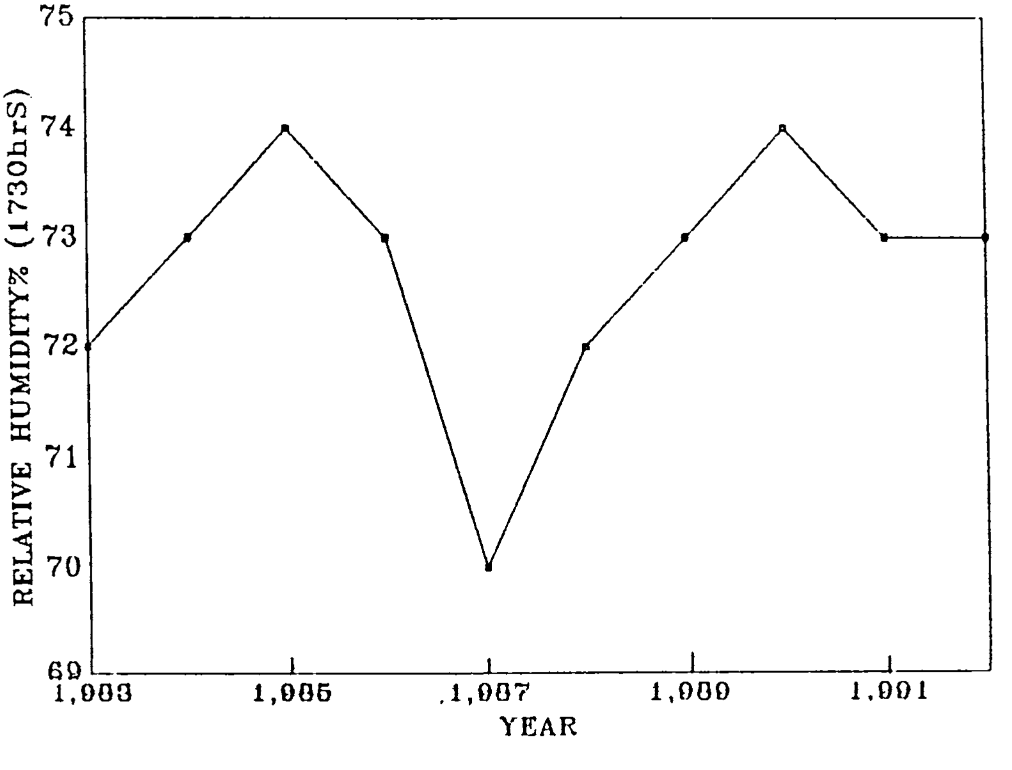


Fig. 4.9 Yearly variation of RH (0830 hrs & 1730 hrs)

the square of amplitude of second harmonic to that of first harmonic and ratio of square of sum of first three harmonics to the variance.

Three hourly data for different months are analyzed for studying the diurnal cycle. Up to four harmonics are considered ie,. diurnal cycle(twenty four hrs), semi diurnal cycle(twelve hrs), eight hours and six hours cycle are considered. The results include amplitude, phase, variance, percentage of first harmonic, ratio of square of amplitude of second to that of first harmonic and ratio of sum of squares of first three to the total variance.

4.2.1 Harmonic Analysis of Temperature

4.2.1.1 Seasonal cycle of temperature

Table 4.10 shows the results of harmonic analysis of seasonal cycle in temperature. For each data series nearly 99% is contributed by the first three harmonics. Of this there are 60% is due to first harmonic ie,. annual cycle itself. The ratio of square of amplitude of second harmonic to that of first harmonic is less than 0.7. The semi annual oscillation dominate only for 0830 hrs, which is the time of occurrence of maximum pressure. The variance due to different data series show that it increases from 0230 hrs up to 1430 hrs till it reaches a maximum and then decreases to a minimum around 2330 hrs. It can be seen from Fig. 4.10 that the amplitude of annual oscillation is maximum at 1430 hrs(1.66°C) and minimum at 0530 hrs(1.02° C). Fig. 4.10 also shows that phase varies between second week of March and fourth week of May. The semi-annual oscillation has maximum amplitude during 0830 hrs and then decreases. The phase is the time of occurrence of maximum value . It varies between first and second weeks of November and May for semi-annual oscillations. Here the phase of annual and semi-annual oscillations coincide in May for most of the series .

4.2.1.2 Diurnal cycle in temperature

Table 4.11 shows the results harmonic analysis of diurnal cycle of temperature. In the case of temperature both diurnal and semi-diurnal oscillations are dominant. They contribute more than 98% of the total variance. Of this, more than 88% is due to 24-hour oscillation itself. The ratio of square of amplitude of semi-diurnal oscillation to that of diurnal oscillation is less than 0.11. The variance of the data series is maximum for January (14.4°C) which decreases to a minimum of 3.51° C in June.

Fig 4.11 shows amplitude of diurnal as well as semi-diurnal oscillations. The maximum amplitude of diurnal and semi-diurnal oscillations are found in January. The amplitude of diurnal oscillation is minimum during June and that of semi-diurnal oscillation is noted the minimum during July. The

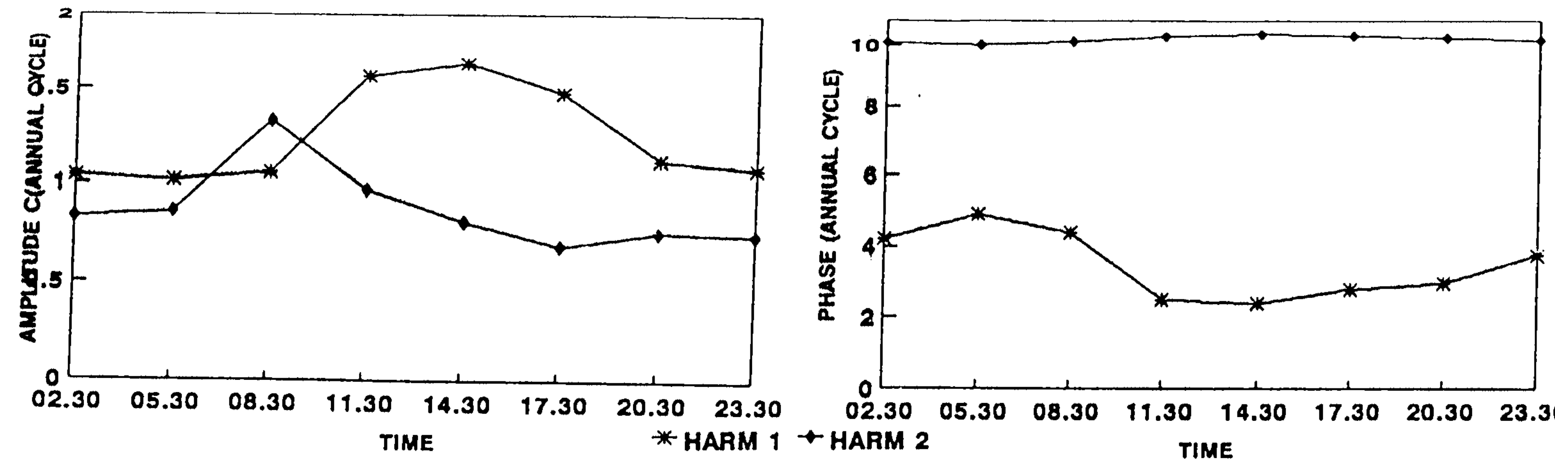


Fig. 4.10 Seasonal oscillation of temperature

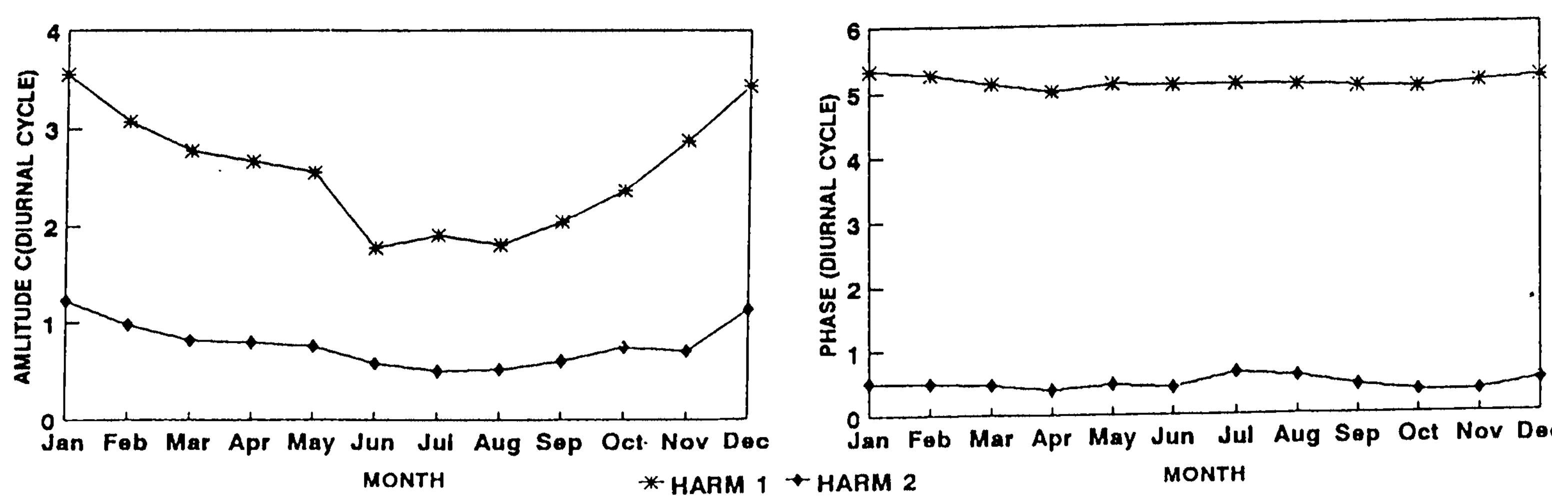


Fig. 4.11 Diurnal oscillation of temperature

Table 4.10 Harmonic analysis of seasonal cycle in temperature for eight synoptic hours

TIME	A1	Phase1	A2	Phase2	VAR.	$A1^2/VAR*100$	$(A1^2+A2^2+A3^2)*100/VAR$
0230	1.04	4.20	0.84	10.11	1.83	59.67	98.95
0530	1.02	4.89	0.86	10.02	1.84	57.18	99.14
0830	1.06	4.41	1.33	10.16	2.99	37.29	98.60
1130	1.58	2.49	0.97	10.33	3.58	69.71	98.90
1430	1.66	2.39	0.81	10.42	3.63	76.16	98.10
1730	1.49	2.78	0.69	10.35	2.89	77.01	97.10
2030	1.13	2.96	0.76	10.26	1.91	66.71	97.68
2330	1.09	3.74	0.75	10.16	1.79	66.93	99.57

Table 4.11 Harmonic analysis of diurnal cycle in temperature for twelve months

MONTH	A1	Phase1	A2	Phase2	VAR.	$A1^2/VAR*100$	$(A1^2+A2^2+A3^2)*100/VAR$
Jan	3.56	5.33	1.23	0.54	14.4	88.1	98.57
Feb	3.08	5.26	0.98	0.5	10.55	89.95	99.11
Mar	2.78	5.12	0.82	0.47	8.4	91.42	99.39
Apr	2.67	5.00	0.79	0.39	7.8	91.02	99.17
May	2.56	5.11	0.76	0.47	7.2	91.20	99.20
Jun	1.78	5.09	0.58	0.42	3.5	90.10	99.75
Jul	1.91	5.10	0.50	0.65	3.89	93.33	99.62
Aug	1.81	5.08	0.52	0.59	3.57	92.30	99.82
Sep	2.05	5.05	0.61	0.44	4.57	91.68	99.85
Oct	2.37	5.03	0.75	0.35	6.19	90.62	99.65
Nov	2.88	5.11	0.71	0.35	8.9	93.61	99.33
Dec	3.44	5.18	1.14	0.51	13.2	89.51	99.41

variation of amplitude of diurnal oscillation is less than 1.8^{o} C and that of semi-diurnal oscillation is less than $0.73^{o}C$.

Fig. 4.11 also gives the phase of diurnal as well as semi-diurnal oscillations in temperature. For diurnal oscillations,the time of maximum occurrence is at 1530 hrs and that for semi-diurnal oscillation is at 0130 hrs and 1330 hrs.

4.2.2 Harmonic Analysis of pressure

4.2.2.1 Seasonal cycle in pressure

Table 4.12 shows the amplitudes and phases of the seasonal cycles in pressure over Cochin. In the case of pressure both annual and semi-annual oscillations are dominant. More than 96% of the variance is contributed by the first three harmonics. At 2330 hrs some short period oscillations are also observed. Of the total variance more than 55% is contributed by the first harmonic and annual oscillation. Only in the case of 1430 hour, the semi-annual oscillation dominates. This is the time of occurrence of maximum temperature. The variance is maximum(3.8mb) at 2330hrs (time of occurrence of maximum pressure) and minimum (1.51 mb) at 1730 hrs (time of occurrence of minimum pressure). The ratio of square of amplitude of semi-annual oscillation to that of annual oscillation is less than 0.7, except for 1430 hrs.

Fig. 4.12 shows the amplitudes of annual as well as semi-annual oscillations. Amplitudes of annual. oscillation is maximum at 0830 hrs (1.73 mb) and minimum at 1430 hrs (0.83 mb). Amplitudes are more at 0830 hrs and 2330 hrs. The variation of amplitude of annual oscillation is less than 0.9 mb and that of semi-annual oscillation is less than 0.5 mb. Maximum amplitude of semi-annual oscillation is 0.96 mb at 1430 hrs for which it dominates over annual oscillations and is least at 2330 hrs.

Fig. 4.12 also shows the phase of annual and semi-annual oscillations. For annual oscillations it varies between fourth week of December to second week of January. For semi-annual oscillation it varies between third week of February to the first week of March and third week of August and first week of September.

4.2.2.2 Diurnal cycle in pressure

Table 4.13 gives the amplitude and phase of diurnal oscillations. In the case of pressure semi-diurnal oscillation predominates. The diurnal and semi-diurnal pressure oscillation contribute more than 99% of the total variance, except in July for which short period oscillations are also important. Of the total variance more than 68% is due to semi-diurnal oscillations. In July it is only 35%. The variance is maximum (3.64 mb) for March and minimum (1.38 mb) in June.

Fig. 4.13 shows the amplitudes of diurnal as well as semi-diurnal oscillations. Amplitudes of semi-diurnal oscillation is maximum(1.64 mb) in March and minimum (0.72 mb) in July. In the case of diurnal oscillation the amplitude is maximum in January (1.06 mb) which decreases a minimum (0.24 mb) in June. The variation is less than 0.82 mb.

Fig. 4.13 also shows phase of diurnal and semi-diurnal oscillations. Semi-diurnal oscillations has maximum amplitude around 2300 hrs (maximum pressure) and 1700 hrs (minimum pressure). The diurnal oscillation shows a phase of 0630 hrs except in July in which it is 1000 hrs.

4.2.3 Harmonic analysis of Relative Humidity

4.2.3.1 Seasonal cycle in RH

Table 4.14 shows the amplitudes of dominating harmonics, variance of the data series etc., Of the total variance more than 97% is contributed by the first three harmonics. In the case of RH both annual as well as triannual oscillations dominate. Most dominating oscillation is annual oscillation which contribute nearly 90% of the total variance. The variance is maximum at 1130 hrs and minimum at 0530 hrs (maximum RH). The ratio of square of amplitude of third harmonic to that of first is less than 0.08.

Table 4.12 Harmonic analysis of seasonal cycle in pressure for eight synoptic hours

TIME	HARMONICS						
	A1	Phase1	A2	Phase2	VAR.	$A1^2$/VAR* 100	$\frac{(A1^2+A2^2+A3^2)*100}{VAR}$
0230	1.44	0.59	0.89	1.65	3.01	68.56	96.43
0530	1.46	0.56	0.77	1.66	2.83	74.83	96.55
0830	1.73	0.63	0.74	1.78	3.66	81.71	97.37
1130	1.55	0.77	0.93	1.77	3.32	72.02	98.55
1430	0.83	0.53	0.96	1.53	1.66	41.32	97.14
1730	0.92	11.88	0.77	1.42	1.51	56.43	96.17
2030	1.21	0.22	0.68	1.63	2.03	72.15	95.16
2330	1.65	0.65	0.61	2.26	3.81	71.26	87.24

Table 4.13 Harmonic analysis of diurnal cycle in pressure for twelve months

MONTH	HARMONICS						
	A1	Phase1	A2	Phase2	VAR.	$A1^2$/VAR* 100	$\frac{(A1^2+A2^2+A3^2)*100}{VAR}$
Jan	1.06	2.2	1.57	7.61	3.6	68.5	99.43
Feb	1.01	2.26	1.6	7.65	3.6	71.3	99.8
Mar	0.97	2.14	1.64	7.64	3.6	73.9	99.98
Apr	0.86	1.98	1.55	7.6	3.1	76.58	99.93
May	0.48	2.06	1.31	7.59	1.95	87.76	99.89
Jun	0.24	2.16	1.15	7.63	1.38	95.13	99.23
Jul	0.59	3.36	0.72	7.34	1.5	34.48	58.17
Aug	0.36	1.77	1.23	7.65	1.6	92.00	99.66
Sep	0.57	1.87	1.41	7.57	2.3	85.88	99.89
Oct	0.69	1.83	1.53	7.5	2.8	82.8	99.74
Nov	0.70	1.96	1.47	7.5	2.7	81.4	99.7
Dec	0.95	1.91	1.48	7.53	3.1	70.3	99.31

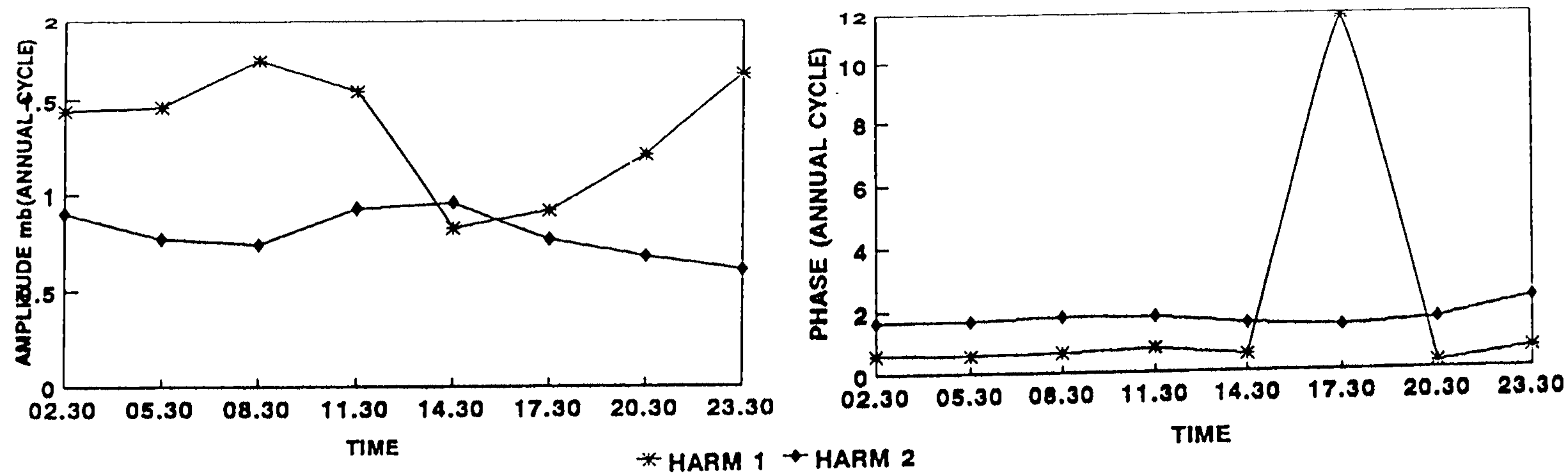


Fig. 4.12 Seasonal oscillation of Pressure

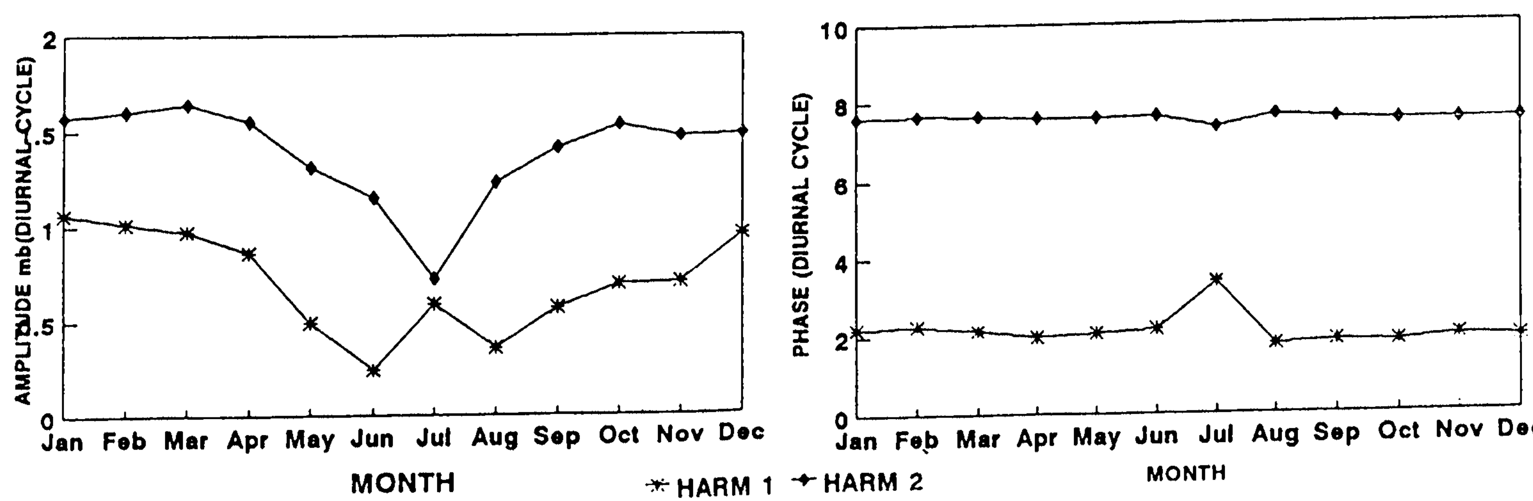


Fig. 4.13 Diurnal oscillation of Pressure

Fig. 4.14 shows of the amplitude of annual, semi-annual as well as triannual oscillations. Amplitude of annual oscillation is maximum at 1130 hrs and minimum at 0530 hrs. It increases from 0530 hrs till it reaches maximum at 1130 hrs and then decreases. Variation is more in the case of RH . The amplitude of triannual oscillation is also maximum at 1130 hrs and minimum 0530 hrs.

Fig. 4.14 also shows the variations of phase of annual as well as triannual oscillations also. For annual oscillations it varies between first and third week of August. And that of triannual oscillation it is first and second week of March , first and second week of July and first and second week of November.

4.2.3.2 Diurnal cycle in RH

The amplitudes and phases of harmonics, the variance etc., of the data series in studying the diurnal cycle is given in Table 4.15. In the case of RH both diurnal and semi-diurnal oscillations are found to be dominating. The first two harmonics contribute more than 98% of the total variance. The diurnal oscillations contribute more than 90% of the total variance. Variance is maximum in December and minimum in June. The ratio of square amplitude of semi-diurnal to diurnal oscillation is less than 0.09.

The amplitudes of diurnal as well as semi-diurnal oscillations are shown in Fig. 4.15. The amplitude of diurnal and semi-diurnal oscillations is maximum in December and minimum in June. Amplitude of diurnal oscillation varies more than 9% with the minimum amplitude of 7% in June and a maximum of 17.% in December. The amplitude of semi-diurnal oscillation varies only less than 2% .

Fig. 4.15 also shows the phase of variation of diurnal and semi-diurnal oscillations. The phase of maximum amplitude of diurnal oscillations occur around 0300 hrs for all the months. That of semi-diurnal oscillations occur around 1930 hrs and 0730 hrs.

4.3 Summary

The arithmetic mean calculated for each parameter gives an overall idea of mean value of parameters at any given time of the day and for the given month. April is the hottest month with a maximum temperature of 33.3 ^{o} C. January recorded the highest temperature of 22.4^{o} C. Maximum pressure of 1013.54 mb is observed during January at about 0830 hrs and minimum of 1006.8 mb during May at about 1730 hrs. Pressure shows semi-diurnal oscillations with higher maximum at 0830 hr than the secondary maximum at 2330 hr and 1730 hr minimum lower than 0530 hr minimum. Maximum RH of 94% is observed near 0500 hrs during July and minimum of 54% during noon hrs in December.

RELATIVE HUMIDITY

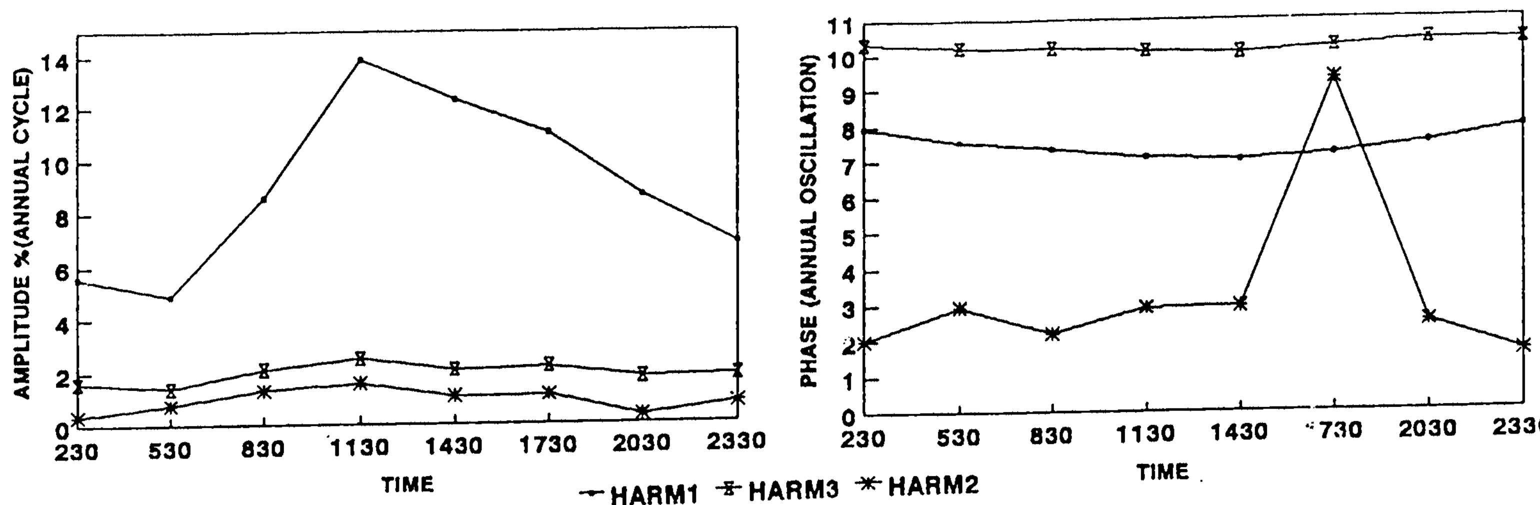


Fig. 4.14 Seasonal oscillation of Relative Humidity

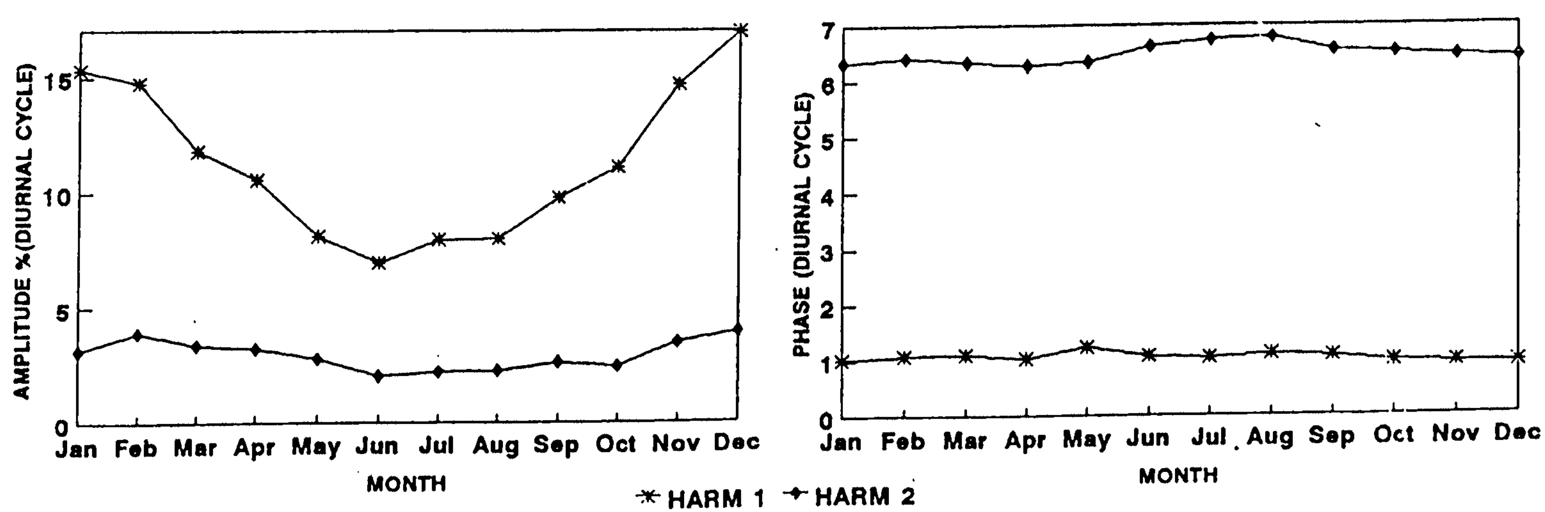


Fig. 4.15 Diurnal oscillation of Relative Humidity

Table 4.14 Harmonic analysis of seasonal cycle in RH for eight synoptic hours

TIME	A1	Phase1	A2	Phase2	VAR.	$A1^2$/VAR*100	$(A1^2+A2^2+A3^2)*100$ / VAR
0230	5.57	7.95	0.36	2.01	34.53	89.88	97.95
0530	4.87	7.54	0.76	2.93	26.89	88.19	97.65
0830	8.57	7.36	1.31	2.2	80.78	90.99	98.57
1130	13.88	7.13	1.56	2.91	203.39	94.65	98.92
1430	12.32	7.04	1.07	2.95	161.11	94.28	97.64
1730	11.05	7.22	1.10	9.32	129.37	94.43	99.08
2030	8.68	7.53	0.32	2.56	79.78	94.48	98.47
2330	6.80	7.94	0.78	1.64	52.15	89.74	97.22

Table 4.15 Harmonic analysis of seasonal cycle in RH for twelve months

MONTH	A1	Phase1	A2	Phase2	VAR.	$A1^2$/VAR*100	$(A1^2+A2^2+A3^2)*100$ / VAR
Jan	15.33	1.02	3.15	6.33	251.9	93.2	97.20
Feb	14.75	1.08	3.91	6.42	234.66	92.85	99.30
Mar	11.81	1.11	3.37	6.34	152.89	91.24	98.66
Apr	10.59	1.03	3.22	6.28	123.8	90.64	99.03
May	8.14	1.23	2.76	6.34	74.99	88.44	98.58
Jun	6.99	1.07	2.02	6.62	53.02	92.06	99.79
Jul	7.99	1.04	2.20	6.73	69.07	92.44	99.42
Aug	8.03	1.096	2.25	6.78	69.79	92.34	99.57
Sep	9.79	1.07	2.60	6.55	102.66	93.30	99.90
Oct	11.08	0.969	2.42	6.51	128.9	95.28	99.80
Nov	14.67	0.95	3.46	6.45	228.84	94.10	99.30
Dec	16.97	0.932	3.93	6.41	306.03	94.10	99.11

Difference between the maximum and minimum value of surface meteorological parameters i.e., the range is calculated. For temperature the diurnal range decreases from January to June and increases from August to December. The pressure range is more during day time. RH shows higher range values in winter months (RH minimum)and least during monsoon months (RH maximum).

Standard deviation of parameters give fluctuation from ten year mean. For temperature which is least at 0230 hour and maximum at 2030 hours. For pressure it is least at 2030 hrs and maximum at 2330 hrs. For RH it is maximum at 1430 hrs and minimum at 0230 hrs.

The tendency calculated for each parameter which gives increase in the value of parameter with time . In the case of temperature maximum is observed during 1000 hrs in January and is least during winter months. After 1430 hrs the gradient reverses that is negative gradient occurs. In the case of pressure positive pressure tendency is maximum during 0700 hrs and then decreases. Around 1000 hrs the gradient reverses and reaches maximum during 1300 hrs. In the case of RH the gradient is sharp between 0630 and 1130 hrs and reaches a minimum around 1430 hrs. Then there is a sharp increase from 1800 to 1930 hrs.

Harmonic analysis is used to study periodic variations in surface meteorological parameters. Both seasonal and diurnal oscillations are studied. In the case of temperature, annual as well as semi-annual oscillations dominate in the seasonal cycle and both diurnal and semi-diurnal oscillation dominate in the diurnal cycle. The time of occurrence of maximum amplitude is noted in May, for annual oscillation, and November and May for semi- annual oscillations. For diurnal oscillations the time of maximum occurrence is at 1530 hrs. Annual and semi-annual oscillations also dominate for pressure with maximum amplitude occurring in December - January for annual oscillation and February -March and August- September for semi-annual oscillations. In the case of diurnal oscillations, semi-diurnal oscillation dominate with maximum amplitude occurring around 2300 hrs and 1700 hrs for semi-annual oscillations and 0630 hrs for diurnal oscillations. RH shows annual as well as triannual oscillations in the seasonal cycle with maximum amplitude occurring in August for annual oscillation and March, July and November for triannual oscillations. RH shows diurnal as well as semi-diurnal cycle. The time of occurrence of maximum amplitude is 0300 hrs for diurnal cycle and 1930 hrs and 0730 hrs for semi-diurnal cycle.

CHAPTER V

ANALYSIS OF UPPER AIR PARAMETERS

5.1 Time sections

Objective of the present study is to study the time variability of the temperature and humidity variations in the atmospheric boundary layer to investigate the relationship with the monsoon intensity. This type of study has not been undertaken for Cochin. Analysis carried out by different authors clearly indicate the importance of humidity build up in the monsoon activity.

5.1.1 Results and Discussion

Data and methodology of the present work is discussed in chapter 2. The vertical time-height sections of temperature (fig 5.1.1) and specific humidity (fig 5.1.2) from May to September which includes pre-onset, onset, break and withdrawal phases of summer monsoon are drawn. In all years the maximum temperature at all levels are observed during pre-onset month (May). This pattern shows a drastic reduction with the commencement of the monsoon. In a typical drought monsoon year (1987) the surface level temperature were unusually high (28^{o}C in May) which decreases by about 2^{o}C during the active monsoon season. For the other years the surface level temperature was about 2^{o}C lower during May which also decreased by 2^{o}C by July - August. A drastic reduction of temperature (3^{o}C - 5^{o}C) in the upper levels in association with monsoon onset is observed

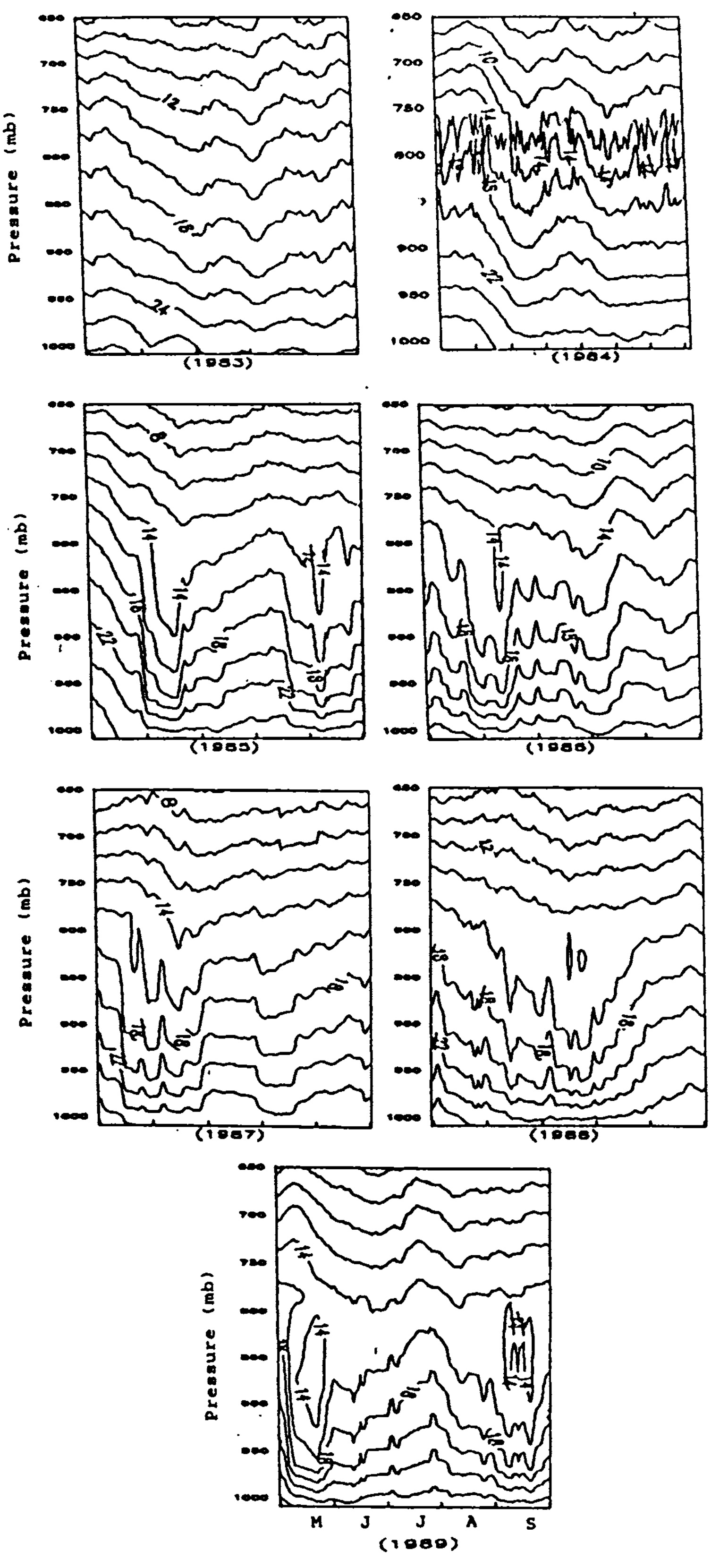


Fig 5.1.1 Time-height sections of temperature for the months May - september

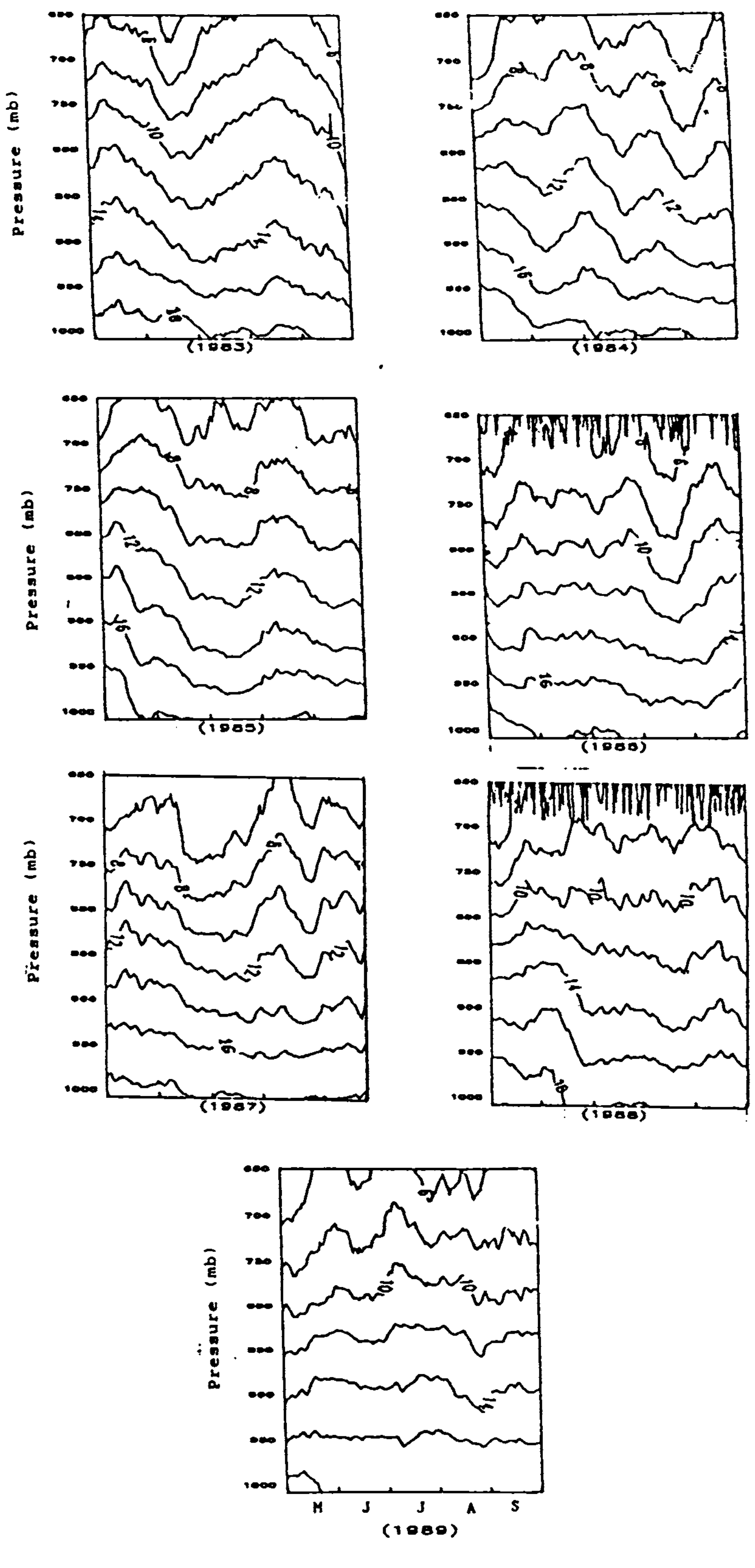


Fig 5.1.2 Time-height sections of specific humidity for the months May - september

compared to pre-onset month. Another notable feature is the drastic increase in the temperature (10°C in 250 mb) in May to 13°C in 250 mb in June) indicating a more thermally stable atmospheric boundary layer in May compared to June. However, the reduction in temperature gradient (14°C in 250 mb in May) is significantly lower for typical drought years (1983, 1987) which slightly increases to 15°C in 250 mb (1000 mb - 750 mb). With the advance of low level monsoon flow (July - August) temperatures at all level moderately increase which is all the more significant up to 750 mb.

The salient features of the specific humidity values during the study period, based on the time sections for seven years from 1983 to 1989 is as follows. The value of specific humidity at 1000 mb level of the atmosphere over Cochin, during May-June is around 18 gm/kg. The specific humidity value shows a slight decrease with the progress of the southwest monsoon in July. In August the values slightly increase almost to the same as that in June. The values again decreases slightly in September. The magnitude of month to month variation increases with height in the atmosphere.

5.2 Precipitable water content

The depth in centimeters of liquid water that would result by the precipitation of entire water vapour present in a vertical atmospheric column of 1 square centimeter cross section is known as precipitable water vapour in the column. Since the density of water is unity the depth in centimeters of the liquid water is also equal to its mass in grams. As it is a measure of total moisture content of the atmosphere, the study of the seasonal and geographical variations of precipitable water is of interest from meteorological and hydrological stand point. Padilla et al (1993) studied mixing ratio of water vapour at different hours of the day in a high altitude tropical plateau in Mexico. The results indicate that in the absence of synoptic perturbations an analysis of time elapse between the beginning of mixing ratio increase and the beginning of rain can help to show the diurnal air circulation that controls rain cloud formation. The onset of monsoon along the west coast of India is marked by the commencement of sqaully weather and rough seas accompanied by heavy rain. Mukerji (1962) computed the precipitable water in the atmosphere over Trivandrum using radiosonde data. But the results arrived at do not indicate any spectacular build up of precipitable water before or on the date of onset of monsoon. The maximum moisture level is attained before or after the date of onset. Ananthakrishnan et al (1965) calculated the mean monthly precipitable water vapour at twelve Indian radiosonde stations. The seasonal and diurnal variations brought out the rapid changes that occur with the onset and withdrawal of southwest monsoon are studied. The diurnal variation is found to be least during monsoon months. We have, therefore, undertaken such a study for the atmosphere over Cochin making use of the radiosonde data of Cochin for seven years from 1983 to 1989.

5.2.1 Methodology

From the data of upper air soundings for 00 GMT the values of specific humidity were computed for the surface and for the isobaric level 1000 mb , 950 mb, 900 mb , 850 mb, 800 mb, 750 mb, 700 mb and 250 mb . If the surface pressure in millibar is p_0 then the precipitable water in the layer from surface to 900mb is r/1000 * (p_0-900) gm where r is the mixing ratio.

If q is the specific humidity of the atmosphere (mass in grams of water vapour per kilogram of moist air) at a height of z where the pressure and density are p and r respectively, then the precipitable water in the atmospheric column is computed as

$$w = qrdz = - 1/g \int qdp \qquad (1)$$

since q = r / (1+r) , r is the humidity mixing ratio (mass of water vapour per gram of dry air), we can write

$$w = 1/g \int r/(1+r) * dp \qquad (2)$$

since g = 980 cm/sec2 and r is of the order of .01 to .02 near the surface, g*(1+r) = 1000 near the surface. At higher level although the value of g*(1+r) is slightly less than thousand, the error introduced by setting it equal to thousand is quite small in the computation of the total precipitable water content (Ananthakrishnan et al, 1965). Hence with sufficient accuracy we can write

$$w = \int r/1000 * dp \qquad (3)$$

If pressure is expressed in millibar, we have

$$w = \int rdp \qquad (4)$$

If r is expressed as grams of water vapour per kilogram of dry air, the precipitable water vapour in an isobaric layer of 50 millibar thickness whose mean mixing ratio is r gm/kg is

$dw = r/10$. If the atmosphere is divided into 50 mb layers whose mixing ratios are r1, r2, r3, etc., then the total precipitable water is given by

$$w = 1/10 \quad (r1 + r2 + \dots\dots\dots) \quad (5)$$

The mean of the values of r corresponding the bottom and top of an isobaric layer can be taken with sufficient accuracy as the mean mixing ratio for the layer. The value of r decreases with height and for all practical purposes the contribution to w from layers above 250 mb is negligible even when the atmosphere is highly humid as in the monsoon month.

5.2.2 Results and discussions

The monthly mean values of precipitable water contents in centimeters for isobaric layers were calculated. Fig.5.2.1 gives general features shown for different layers. There is a rise of precipitable water contents in the atmosphere from a minimum value of the order of 2cm in the winter months to a maximum value of the order of 4cm in the pre-monsoon months. Monthly variation decreases as we go up to higher levels mainly due to the low level transport of moisture during monsoon. The variation is more pronounced in the lower levels. The precipitable water changes very little during the months April, May and June (fig 5.2.2). This is due to the fact that the atmospheric boundary layer is

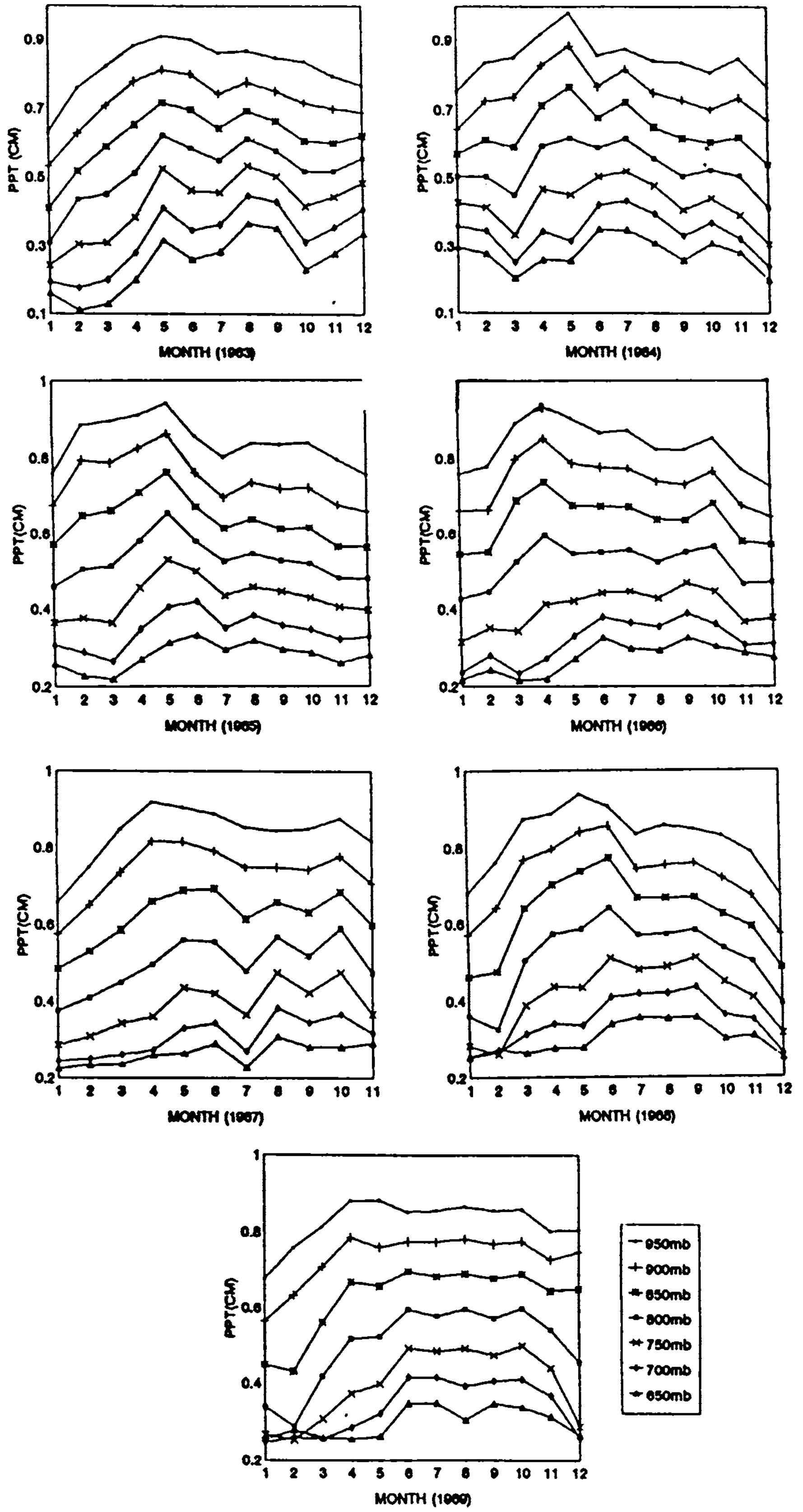
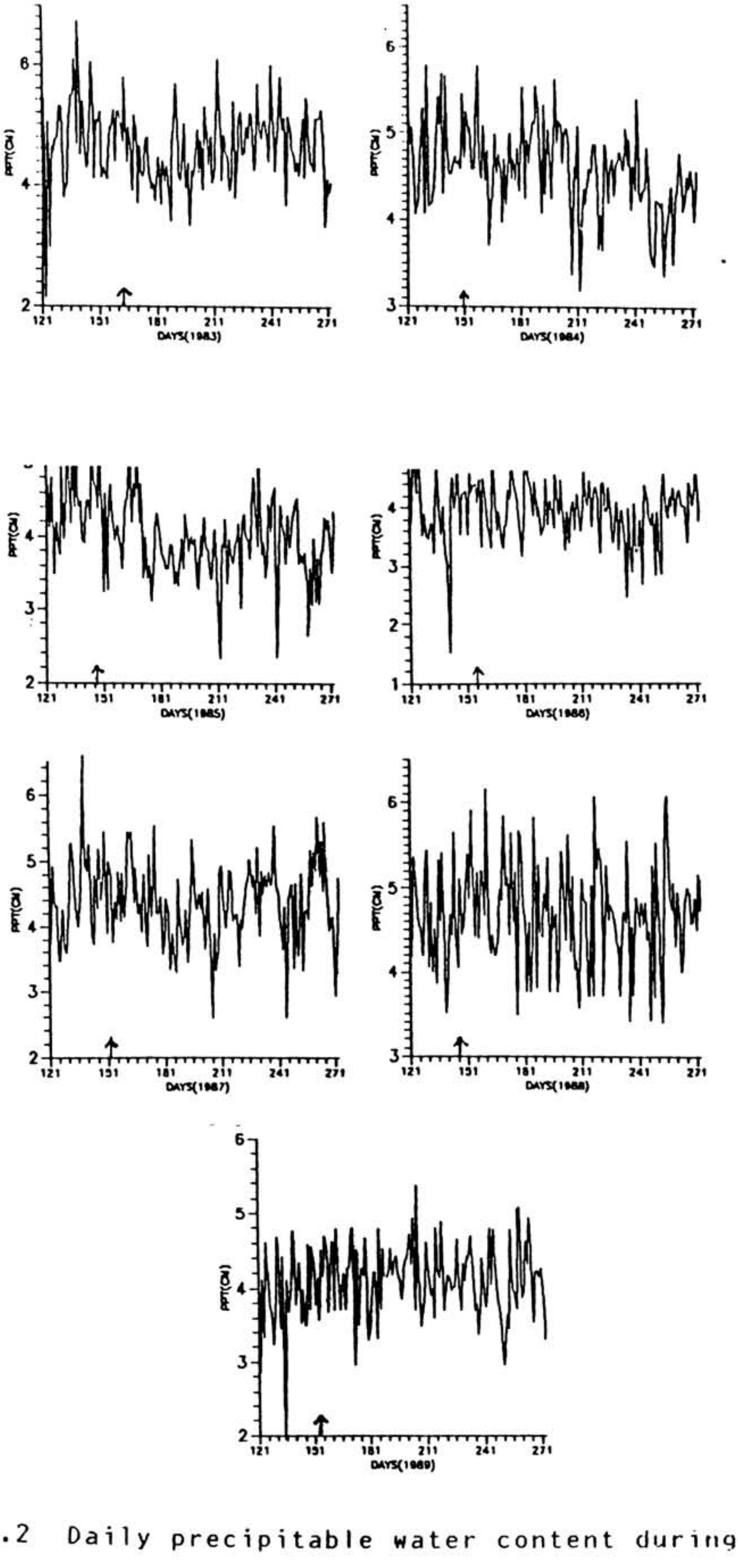


Fig. 5.2.1 Monthly precipitable water content for different layers



2.2 Daily precipitable water content during the months April, May and June (Arrow indicate the onset date) mostly saturated during this period. This shows that the presence of moisture by itself is only a necessary condition for rainfall; the synoptic - climatological features that give rise to vertical motions in the atmosphere have also to be considered for understanding rainfall variations. There is a second peak in the month of October indicating the contribution during north-east monsoon.

Day to day variations

The values of precipitable water content for April, May and June are shown in figure. The dates of onset of monsoon are indicated by arrows. There is an increase in the precipitable water contents a few days prior to the date of onset of monsoon. But the highest value of w during the onset is usually less than other peak value attained. Or in other words, the amount of precipitable water in the atmosphere is not necessarily the highest on the date of onset of monsoon, or a few days preceding the date of onset.

The figures do not indicate gradual increase in the value of precipitable water content w with the approach of monsoon. However due to large variations in the daily values, the presence of any increasing or decreasing tendency in the value of w is not brought out very clearly. The curves indicate the absence of any marked build-up of the precipitable water content in the atmosphere with the approach of onset of monsoon. They however bring out the pulsating nature of w which is in agreement with the fluctuating character of monsoon rainfall (Mukerji, 1962).

Variation with height

The daily values of w are computed for different layers of the atmosphere. It is found that for every increase or decrease in w at the lowest layer there is generally the corresponding increase or decrease at all layers up to 600 mb. This shows that influx of monsoon air in the atmosphere takes place at all heights up to at least 600 mb. The average values of w for different layers are shown in fig.5.1. It will be observed that the precipitable water content of the layers goes on diminishing with increasing height.

The precipitable water contents of 1983 for different layers are studied. It is maximum during May. It increases from January till May and slightly decreases till July. After that there is a slight build up in August which again decreases. The monthly variation is small in the lower layers . For upper layers the variation is less than 0.5 cm. In 1983 the maximum precipitation is in the month of July. August and September also show above normal precipitation values. North east monsoon is weak with less precipitation in October. Figure shows a considerable build up in moisture content before the onset of monsoon which decreases after the onset. There is not much variation in the total w during April and May.

The precipitable water content of 1984 for different layers shows there is an increase in precipitable water content from January to March and again a sharp increase in w till May. Then it decreases in June . There is a slight build up in July which again decreases with a slight increase November coinciding with North east monsoon. Above 800 mb maximum w is during monsoon months. Which decreases in September and there is a slight increase in October. In 1984 the onset date is on 30th May. Maximum precipitation in June. July also shows above normal values. There is heavy rainfall in October. Figure shows considerable decrease in w after the onset.

In the year 1985 there is a sharp increase in w in February which increases to a maximum in May . After the onset it decreases till July which again build up slightly in August with the advance of north east monsoon. And after November it decreases. Upper levels show lesser variation. The onset date is on 28th May where as maximum precipitation is in June. The rainfall was above normal in May also. North east monsoon is comparatively week. Figure shows considerable build up w before onset and a decrease in w afterwards.

Precipitable water content of 1986 show a sharp increase in w after February till it reaches a maximum in April. It decreases till June which slightly build up in July. Then there is a decrease. A second peek is observed in October with the north-east monsoon. Then w decreases. The onset date is on 4th

June. The maximum rainfall is in June. Comparatively lesser rainfall occurred during other months. Fig. shows there is not much variation in w between months of April, May and June.

In it increases from January to April reaches a maximum and then decreases till August. Then there is small increase till October, north east monsoon, and again decreases. It is more conspicuous in the lower levels. As we go up the variation decreases, only the pattern remains the same. Figure shows the precipitable water contents of April, May and June. Increase in precipitable water content before onset is observed. Peak value is attained weeks before onset date which decreases after the onset.

Precipitable water content of 1988 for different layers reaches a maximum in May in lower levels, above 950 mb it is in June. Then there is a sharp decrease till July. Below 950 mb a slight build up in August and above that it is more or less constant till September. After that it decreases. Figure shows precipitable water content of April, May and June. Peak value is observed days after onset date and then decreases.

In 1989 it reaches a maximum in April up to 850 mb. Above that the pattern changes. Maximum precipitation is in monsoon months, which decreases after October. The onset is on 3rd June and the pulsating nature decrease after onset date.

We may summarize the more important features brought out by the study as follows. The transport of moisture is not confined to any particular level in the atmosphere. The maximum moisture level in the atmosphere is not generally reached on the date of onset of monsoon. It is attained prior to the onset. There is no marked build up of precipitable water in the atmosphere with the advance of monsoon. The moisture content of the atmosphere decreases with height. Least moisture content is in January at all levels and maximum in May. After that there is a sudden decrease either in June or July at lower levels. The yearly variation of precipitable water content is small.

5.3 Lapse rate

The sensitivity of the world climate system and its models to a variety of effects and variations in parameters is highly dependent on the relation between the tropospheric lapse rate r and the surface temperature regime. An analysis of different relations between r and the surface temperature T_0 have been made. Cloud cover variability and vortex wave activity in the atmosphere have been attributed to the trend towards a variation in the lapse rate of the atmosphere and changes in its static stability.

This work analyses the relation between the lapse rate r and the surface temperature T_0 based on three years data (1985, 1986,1987) of daily temperature data between ground and 450 mb for 00 GMT and 12 GMT. According to the temperature data r for every 50 mb levels starting from ground to 450mb were calculated. these are then correlated with surface temperature T_O.

5.3.1 Methodology

Correlation is the relationship between two or more paired variables or two or more sets of data. The degree of relationship is measured and represented by the coefficient of correlation. A perfect positive correlation is +1 , and negative correlation is -1. A complete lack of relationship is zero. The most often used and the most precise coefficient of correlation is known as the Pearson product -moment coefficient t. There are a number ways to interpret the coefficient of correlation. One is to use crude criterion for evaluating the magnitude of correlation. Table gives the values of t and the degree of correlation.

Another interpretative approach is a test of statistical significance of the correlation based upon the concepts of sampling error and test of significance. Statistical significance of a coefficient of correlation. The null hypothesis states that the coefficient of correlation is zero. One test of significance of r is by the use of the formula $Tr = r * \sqrt{(n-2)}/\sqrt{(1-r^2)}$ with n-2 degrees of freedom, a coefficient of correlation is judged as statistically significant when the t value equals or exceeds the critical value in the t distribution table.

If a null hypothesis proposes that there is no difference between the mean values of two data samples, we would be concerned only with the difference and not with the superiority or inferiority of either group. If it is assumed that there is no difference it is two tailed test, and if superiority or inferiority is checked it is one tailed test.

For a large sample two tailed test, the 5% area of rejection is divided between upper and lower tails of the curve. For one tailed test 5 % area of rejection is either at the upper tail or at the lower tail of the curve.

5.3.2 Results and discussion

Table 5.3.1 gives correlation coefficient of lapse rate and surface temperature at 00GMT for different levels. The t value calculated and t critical value from students distribution table are also given. At almost all lower levels the correlation proved to be significant except between 900mb - 850 mb, which is showing negative correlation which statistically proved to be insignificant. Above 600 mb the correlation is proved to be insignificant. The t value is maximum between ground and 950 mb.

Table 5.3.2 gives correlation coefficient of lapse rate and surface temperature at 12 GMT for different levels. Calculated t values and t critical values from students distribution table are also given. Up to 700 mb the correlation proved to be significant, except between 950 mb - 900 mb. The t value was maximum between 1000mb - 950mb.

Table 5.3.1 Correlation Coefficient of lapse rate of surface temperature at 00 GMT

Levels (mb)	Correlation Coefficient (r)	$t = \frac{r\sqrt{n-2}}{\sqrt{1-R^2}}$	Two tailed test 0.05 (level of significance) (t)	significance
Ground - 1000	0.360	12.58	1.96	
1000 - 950	0.340	11.78	1.96	
950 - 900	0.090	2.95	1.96	
900 - 850	-0.030	- 0.98	1.96	not significant
850 - 800	0.120	3.94	1.96	
800 - 750	0.190	6.31	1.96	
750 - 700	0.150	5.01	1.96	
700 - 650	0.083	2.71	1.96	
650 - 600	0.079	2.58	1.96	
600 - 550	-0.056	- 1.83	1.96	not significant
550 - 500	0.030	0.98	1.96	not significant
500 - 450	0.011	0.36	1.96	not significant

No. of observations - 1064
Degree of freedom - 1062

Table 5.3.2 Correlation Coefficient of lapse rate and surface temperature at 12 GMT

Levels (mb)	Correlation Coefficient (r)	$t = \frac{r\sqrt{n-2}}{\sqrt{1-R^2}}$	Two tailed test 0.05 leve of of significance (t)	significance
Ground - 1000	0.069	2.26	1.96	
1000 - 950	0.300	10.24	1.96	
950 - 900	0	0	1.96	no correlation
900 - 850	0.110	3.61	1.96	
850 - 800	0.190	6.31	1.96	
800 - 750	0.220	7.35	1.96	
750 - 700	0.220	7.35	1.96	
700 - 650	0.055	1.80	1.96	not significant
650 - 600	0.030	0.98	1.96	not significant
600 - 550	0.061	1.99	1.96	
550 - 500	0.006	0.20	1.96	not significant
500 - 450	0.041	1.34	1.96	not significant

No of observations - 1065
Degrees of freedom - 1063

Table 5.3.3 gives the correlation coefficient of lapse rate at 00GMT and surface temperature at 12GMT for different levels. The correlation proved to be insignificant for many of the levels. It was significant only up to 1000mb ,850mb - 800 mb and 75mb-650mb. The t values are higher between 750mb - 650 mb.

Table 5.3.4 gives the correlation coefficient of lapse rate at 12 GMT and surface temperature at 00GMT. In this case it was significant up to 650mb except between surface and 1000mb and 850mb - 800mb. t values are highest between 750mb - 700mb.

Table 5.3.3 Correlation Coefficient of lapse rate at 00 GMT and surface temperature at 12 GMT

Levels (mb)	Correlation Coefficient (r)	$t = \frac{r\sqrt{n-2}}{\sqrt{1-R^2}}$	Two tailed test 0.05 (level of signifcance) (t)	significance
Ground - 1000	0.080	2.62	1.96	
1000 - 950	-0.091	2.98	1.96	
950 - 900	0.046	1.50	1.96	not significant
900 - 850	0.040	1.31	1.96	not significant
850 - 800	0.094	3.07	1.96	
800 - 750	0.022	0.72	1.96	not significant
750 - 700	0.130	4.27	1.96	
700 - 650	0.160	5.28	1.96	
650 - 600	0.039	1.27	1.96	not significant
600 - 550	-0.015	-0.49	1.96	not significant
550 - 500	0.026	0.85	1.96	not significant
500 - 450	0.003	0.098	1.96	not significant

Table 5.3.4 Correlation Coefficient of lapse rate at 12 GMT and surface temperature at 00 GMT

Levels (mb)	Correlation Coefficient (r)	$t = \frac{r\sqrt{n-2}}{\sqrt{1-R^2}}$	Two tailed test 0.05 (level of significance) (t)	significance
Ground - 1000	-0.052	1.697	1.96	not significant
1000 - 950	0.123	4.040	1.96	
950 - 900	-0.156	5.150	1.96	
900 - 850	-0.197	6.550	1.96	
850 - 800	0.050	1.630	1.96	not significant
800 - 750	0.190	6.300	1.96	
750 - 700	0.263	8.880	1.96	
700 - 650	0.150	4.950	1.96	
650 - 600	-0.003	0.098	1.96	not significant
600 - 550	-0.015	0.490	1.96	not significant
550 - 500	-0.013	0.420	1.96	not significant
500 - 450	-0.001	0.033	1.96	not significant

CHAPTER VI

GAUSSIAN PLUME MODEL

Cochin is presently witnessing a boom in industrialization and a consequent explosion on the population front. The trend towards urbanization and industrialization has resulted in severe and wide spread environmental pollution of the atmosphere. Air over Cochin is nourished with different gaseous effluents from industries and smoke discharges from locomotive and ships. The main contributors are Cominco Binani Zinc Ltd., Trvancore Cochin Chemicals, FACT (Udyogamandal, Ambalamughal), Hindustan Insecticides, Indian Rare Earths, ASCL Caprolactum, Cochin Refineries, Carbon and Chemicals and many small scale industries. A considerable amount of air pollutants is also contributed by traffic and domestic emissions besides the contribution of sulfate ion from salt water spray. The latter may also be regarded as a source of SO_2 owing to the fact that sulfate ion can be reduced to SO_2.

There are innumerable number of air pollutants of which the major types are oxides of sulphur and nitrogen, carbon compounds, particulate matter and photochemical products. Among the various air pollutants sulfur dioxide is the most important one. In almost most all industrialized areas of the world which happened to be densely populated, adverse concentration of so_2 has been reported (Zutshi et al, 1978). Sulfur is a common impurity in coal and other fossil fuels. Due to combustion it enters the atmosphere as sulfur dioxide, hydrogen sulfide; sulfuric and sulfurous acid and various sulfates.

In recent years, a number of models have been developed to predict the dispersion of air pollutants in the urban environment. These models require detailed information on various meteorological situations prevailing over the region. Accurate assessment of meteorological conditions leads to an accurate forecast of pollution level of an urban area. Simulation modeling which will predict the concentration of pollutants as a function of source strength and prevailing meteorological conditions have an important role to play in the air pollution control management for urban centers; especially in developing countries like India, because of the following reasons. Simulation modeling can help proper urban planning because the pollution map of future time can also be projected taking into account the existing meteorological conditions and the emission rates of coming up industries. Taking recourse to simulation modeling proper location of industries and proper zoning of industrial and residential sectors can be done effectively.

Some of the models used include 1) Gaussian, 2) NOAA Gaussian, 3) Geomat model, 4) Box model etc., . The first one is for flat terrain and second and third are for complexes terrain. In the first case the following assumptions are taken. a) Flat terrain considered, b) perfect reflection of the plume considered at the ground, c) diffusion in the x direction is neglected, d) turbulence generated by strong winds neglected, e) the pollutant under consideration is assumed to be inactive. The second model does not differ much the standard Gaussian plume model. It was developed by a group in National Oceanic and Atmospheric Administration (NOAA). It is Gaussian plume model having terrain related assumptions. Geomet model for complex terrain was developed by a group of scientists under the leadership of G.C. Holzworth for US Environmental Protection Agency (EPA). It is basically a Gaussian plume model with certain modifications. Another widely used model is Box model in which complete vertical mixing is assumed. Diffusion between boxes are neglected and first order differencing is used. This would result in errors. The Langragian models should have many approximation to get the solutions and there by it's applicability and accuracy of solutions are limited. Gaussian diffusion model is still the most popular model, and there have been considerable modification to improve the validity of the model. In the present chapter this model is applied to find out the spatial concentration of sulfur dioxide over the study region.

6.1 Discussion of parameters included in the model

6.1.1 Mixing Height

The concept of mixing lies in the principle that the heat transferred to the atmosphere from ground results in convection, vigorous mixing and establishment of dry adiabatic lapse rate.

extent of this vertical mixing is dependent on the initial erature structure of the atmosphere and the heat input at the face. Mixing height may be defined as the height above the nd at which relatively vigorous mixing occurs. Mixing height hes maximum in the afternoon hours and minimum in the early ing hours. The mixing height can be obtained by extending a adiabat from the surface temperature, to its intersection t the early morning temperature sounding. The height of the t of intersection from the ground is termed as Mixing height. erally the temperature sounding obtained from the suburban tions is used, so that the vertical thermal structure is free n any urban effects. For the computation of the mixing height any given time, the dry adiabat from the surface temperature responding to that time is followed up to the lifting densation level (LCL) and then from LCL onwards the saturated abat is followed till it intersect the early morning perature soundings. The change from dry adiabat to saturated abat is necessary because when an air parcel moves vertically ards, it moves dry adaibatically till LCL and saturated abatically from LCL onwards. This is because of the densation that takes place from LCL onwards, if the air parcel moist initially. Maximum mixing height is obtained by the dry abat of maximum surface temperature to its intersection with early morning temperature profile and minimum mixing height ained by extending the dry adiabat of minimum surface perature.

The computation of mixing heights at every three hour intervals have been carried out for the four months January, April, July and October which are representatives of winter, pre-monsoon, monsoon, and post monsoon seasons respectively. Fig. 6.1 shows the maximum mixing height occurring around 1430 hrs and minimum around 0530 hrs during all the four months. It is maximum for January which is the winter month and minimum for July. The highest value of maximum mixing height recorded in January is about 1.5km and that in July is about 0.9km. The highest values recorded in April and October are 1.25km and 0.95km respectively. In general, the winter representative month has shown the highest value and the pre monsoon and post monsoon representative months have shown in-between values. This gives a speculation as to whether January can be considered as representative for winter season. The normal winter characteristics are not normally found here, partly because the station is coastal. The minimum temperature occurs in the monsoonal months if one looks at the actual march of temperature. During monsoonal months the heat input in the surface is reduced and this results in the decrease of mixing height in this period. The diurnal range between the maximum and minimum value of the mixing heights is highest in the month of January followed by April, October and July.

The mixing height values for Cochin, in different seasons and the ranges between maximum and minimum values for the seasons are in good agreement with the results of the previous studies for this region by Anilkumar (1986). If one consider the major

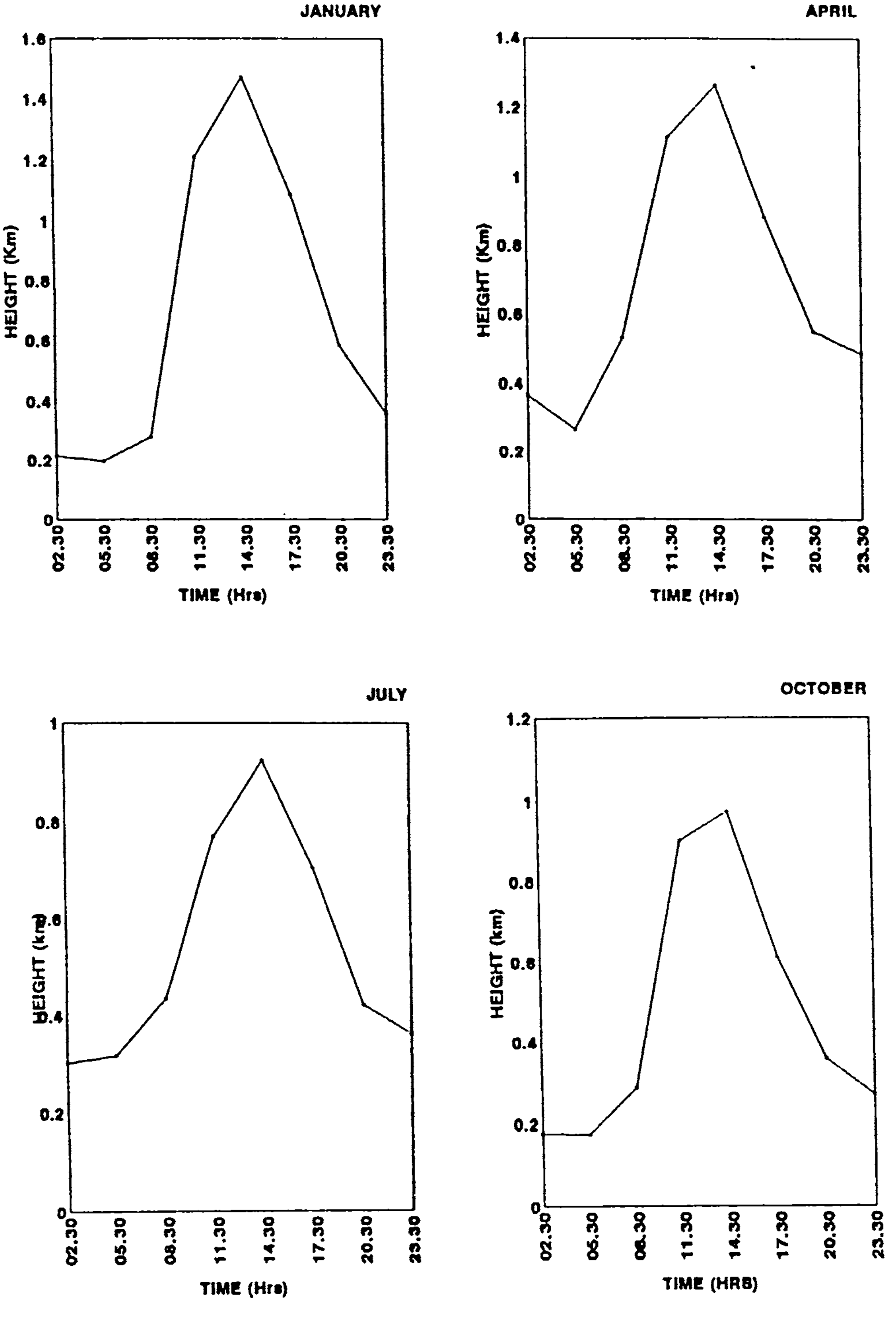


Fig.6.1 Diurnal variation of mean mixing heights for the four representative months

changes happened for this city due to urbanisation, during the last one decade, it implies that urbanisation does not cause much for the variation in mixing hights in Cochin. Days with low mixing heights during monsoon season should be viewed with caution because precipitation causes both for the wash out and rain out of air pollutants to the surface. The chances of built up of pollutant concentration is also more during low mixing heights days.

6.1.2 Wind

The plume moving away from the chimney, grows through the action of turbulent eddies, in the vertical as well as cross wind directions. Along the wind direction convection is more and diffusion in that direction is neglected. Wind is the only factor affecting the stretching of the plume.

Three hourly data of wind speed and direction are utilized. The wind speed and direction are split into five and sixteen classes respectively. The speed classes are 1 - 5 mph, 6 - 10 mph, 11 - 20 mph, 21 - 30 mph and greater than 30mph and the 16 directions are N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW and NNW. Frequency tables are prepared for the four representative months January, April, July and October. The weighted mean wind speed is then calculated for each of the sixteen directions. The weighted mean wind speed for the sixteen directions for the four representative months are calculated.

In the model the mean wind speed through the plume is considered. For this the vertical variation of wind has to be computed which is a function of stability. A simple power law profile is used for this purpose.

$$uz = ul * (z/zl)^{(1/p)}$$

where uz is the wind speed at height z , ul is the wind at height zl (10 meters). P, having values of 9 for unstable conditions, 7 for neutral conditions and 3 for stable conditions. At every downwind distance depending upon the stability the mean winds are obtained between H - $2\sigma_z$ to H +2 σ_z. Weighted mean wind speed in different wind directions are used.

6.1.3 Atmospheric Stability

Atmospheric stability is an important factor which affects pollutant dispersal. Highly unstable conditions result in thorough mixing and dilution and a consequent reduction in ground level concentration. Whereas high stable conditions cause for an increase in the ground concentration of the pollutants. So stability gives an idea of dispersion capacity of air. Diffusion coefficients are also dependent on stability.

Pasquill suggested a scheme for computing the six stability categories ranging from A to F, based on wind speed, cloudiness and net radiation index. Table 6.2 gives the stability classes as a function of wind speed and net radiation index. The net radiation index ranges from 4 ,highest positive net radiation (directed towards the ground) to -2, highest negative net

Table 6.1 Stability class as a function of net radiation and wind speed

Wind speed (Knots)	Net radiation index						
	4	3	2	1	0	-1	-2
0,1	A	A	B	C	D	E	F
2,3	A	B	B	C	D	E	F
4,5	A	B	C	D	D	E	F
6	B	B	C	D	D	E	F
7	B	B	C	D	D	D	E
8,9	B	C	D	D	D	D	E
11	C	C	D	D	D	D	D
12	C	D	D	D	D	D	D

Table 6.2. Insolation as a function of solar altitude

Solar Altitude (a)	Insolation class No.
$60^\circ < a$	4
$35^\circ < a < 60^\circ$	3
$15^\circ < a < 35^\circ$	2
$a < 15^\circ$	1

radiation (directed away from the ground). Instability occurs with high positive net radiation and low wind speed, stability with high negative net radiation and light wind and neutral conditions with cloudy skies or high wind speeds.

The net radiation index used with wind speed to obtain stability class is determined by the following procedure:

(1) If the total cloud cover is 10/10 and the ceiling < 7000 feet use net radiation index equal to zero (whether day or night).

(2) For night time (night is defined as the period from one hour before sunset to one hour after sunrise).

a) If the total cloud cover < 4/10, use net radiation index equal to -2.

b) If the total cloud cover is > 4/10, use net radiation index equal to -1.

(3) For day time:

a) Determine the insolation class number as a function of solar altitude from table 6.3.

b) If total cloud cover <5/10, use net radiation index in table 6.3 corresponding to the insolation class number.

c) If total cloud cover > 5/10, modify the insolation class number by following these steps:

i) Ceiling < 7000 feet., subtract 2.

ii) Ceiling < 7000 feet., but less than 16000 feet., subtract 1.

iii) Total cloud cover equal to 10/10, subtract 1. (This will only apply to ceilings < 7000 feet. Since cases with 10/10 coverage below 7000 feet are considered in item 1 above).

iv) If insolation class number has not been modified by steps (1), (2) or (3) above, assume modified class number equal to insolation class number.

v) If modified insolation class number < 1, let it equal to 1.

vi) Use net radiation index in table 6.2 corresponding to the modified insolation class number.

Accordingly, the stability for every three hour intervals are computed on all days for the four months selected. The percentage frequency of occurrence of each of the stability classes for every three hour interval are computed and presented in Fig 6.2.

In January, the highly stable category, 'F', is noticed most of the time during night hours. A small percentage of 'E' is also noticed during night time. From 0830hrs. onwards a combination of neutral 'D' and the different classes of unstable conditions (A, B, C) are observed. During 1130hrs 'A', the highly unstable category has grown up considerably. A small percentage of 'B' and a very small percentage of of 'C' is also noticed during this period. Around 1430hrs., 'B' is the dominating class

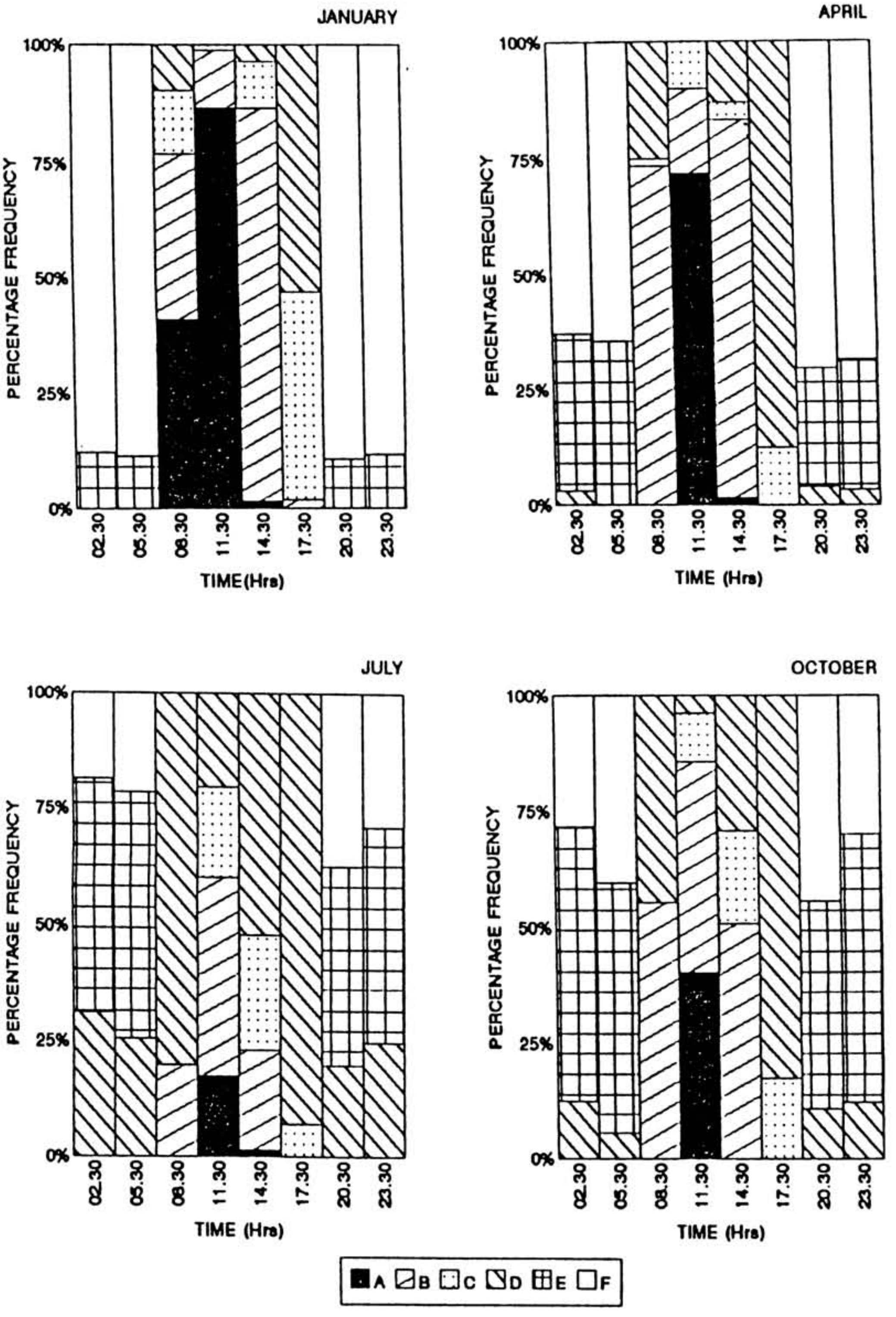


Fig.6.2 Diurnal variation of percentage frequency of Pasquill's stability classes for the four representative months

followed by 'C' and 'D' . In the evening hours about 50% is by 'D' and the remaining is by 'c', together with a very small percentage of 'B'.

In April, night hours is again having mostly 'F' and 'E' categories. A small percentage of 'D' category is also noticed during night hours in this month. Between 0830 and 1130 hrs 'B' is nearly 70%. The rest is mostly by 'D'. 'A' is the most occurring class between 1130 hrs and 1430 hrs. The percentage of 'C' has come down and the percentage of 'D' has gone up during the evening hours, compared to January.

The 'D' frequency is about 25% during night hours in July. The rest is followed by 'E' and 'F' during these hours. 'D' frequency is also observed in good percentage throughout the day. The percentage of 'D' is even more than 75% between 0830 hrs and 1130 hrs and also during 1730 hrs. The percentage of the occurrence is more for 'B' followed by 'C' and 'A' during noon hours.

In October more or less same conditions as in July are observed. However the frequency of 'D' has come down both day and night hours. Between 0830hrs and to 1130 hrs, both 'B' and 'D' are nearly equal in percentage. The percentage of 'A' during noon hours is higher than that in July , but lower than that in April or January. Afternoon hours showed 'B' category more followed by 'D' and 'C'.

Highly stable conditions during night hours and unstable conditions during day time is the common feature in all the four seasons. The occurrence of the neutral category 'D' is more in July, which is the peak monsoon season with overcast conditions and high wind speed occasionally. 'D' is observed almost throughout the day in different percentages in July this month and also in October. The highly unstable category 'A' is observed maximum during the noon hours in January followed by April, October and July.

6.1.4 Dispersion parameters

It is the standard deviation of the plume center line expressed in meters (Pasquill 1962). Mc.Elroy (1969) proposed to the relation between σ_Y and σ_Z in terms of downwind distance as follows.

$\sigma_Y = b^p$, $\sigma_Z = a^k$ where a, b, p and k are constants whose values are functions of stability . In the present study the nomograms developed by Turner (1970) are used to compute σ_Y and σ_Z. These values are representative only for a sampling time of ten minutes and for open country and may probably under estimate the plume dispersion potential. On clear nights with light winds for ground level sources free of topographic influences frequent shift in wind directions occur which serve to spread the plume horizontally. For elevated sources under the extremely stable conditions significant concentrations do not reach ground level until the stability changes. The weighted mean σ_z according to stability classes are computed.

6.1.5 Effective stack height

To determine the concentrations downwind from a source it is essential to estimate the effective stack height. Seldom this height corresponds to the physical height of the stack. High emission velocity and higher temperature of the effluents than the ambient air at the stack top, enhances the effective stack height above the physical stack height. Aerodynamic downwash, eddies caused by the flow around buildings or the stack and the evaporative cooling of moisture droplets in the effluent may cause lowering of the plume to the extent that it may be lower than the physical stack height. Several investigators have proposed formulae for the estimation of effective stack height under given conditions. A comparative study of different formulae suggest that there is no one formula which is outstanding in all respects.

Plume rise can be calculated as a function of source parameters such as buoyancy and meteorological conditions. Techniques for deriving this have been developed by several people and organizations, but hardly any of them agree either with each other or with new observations. There are many formulae such as, Holland's equation, Brigg's equation, TVA 1971 model, TVA 1972 model, Whaley's formula, CONCAWE formula, Lucas formula, Morton et al formula and Slawsen and Scandy formula. A most sophisticated formula needs additional parameters which are not conventionally measured at any meteorological observatory. Therefore a necessity arouse to seek simple formula which require minimum data and the accuracy secured by using more refined formula is not seriously affected. Among the various formula tested except Slawsen and Scandy formula, all other give under estimate values. Therefore Slawsen and Scandy formula is used for the present work. The formula can be written below.

$\delta H = 250\ FT\ /U^3$

where $FT = g w_0 R_0 (T/Ta)$

δH is the plume rise, U is the mean horizontal wind speed , W_0 stack gas velocity at the exit, T is the temperature difference between plume and ambient air, Ta is the ambient air temperature.

6.2 Results and Discussion

The spatial distribution of the concentration of sulfur dioxide by means of Gaussian Plume model for multiple sources is studied for Cochin . Fig 6.3 shows the 4km x 4km grids over Cochin in which two major sources are identified, namely source I and source II (fig.6.3). The major industries in source I are Travancore Cochin Chemicals, FACT (Udyogmandal), Hindustan Organic Chemicals, Hindustan Insecticides, Indian Rare Earths, Cominco Binani Zinc Ltd., ASCL, Caprolactum. The major industries in source II are FACT (Ambalamughal), Carbon and Chemicals and Cochin refineries. Source I have an emission of

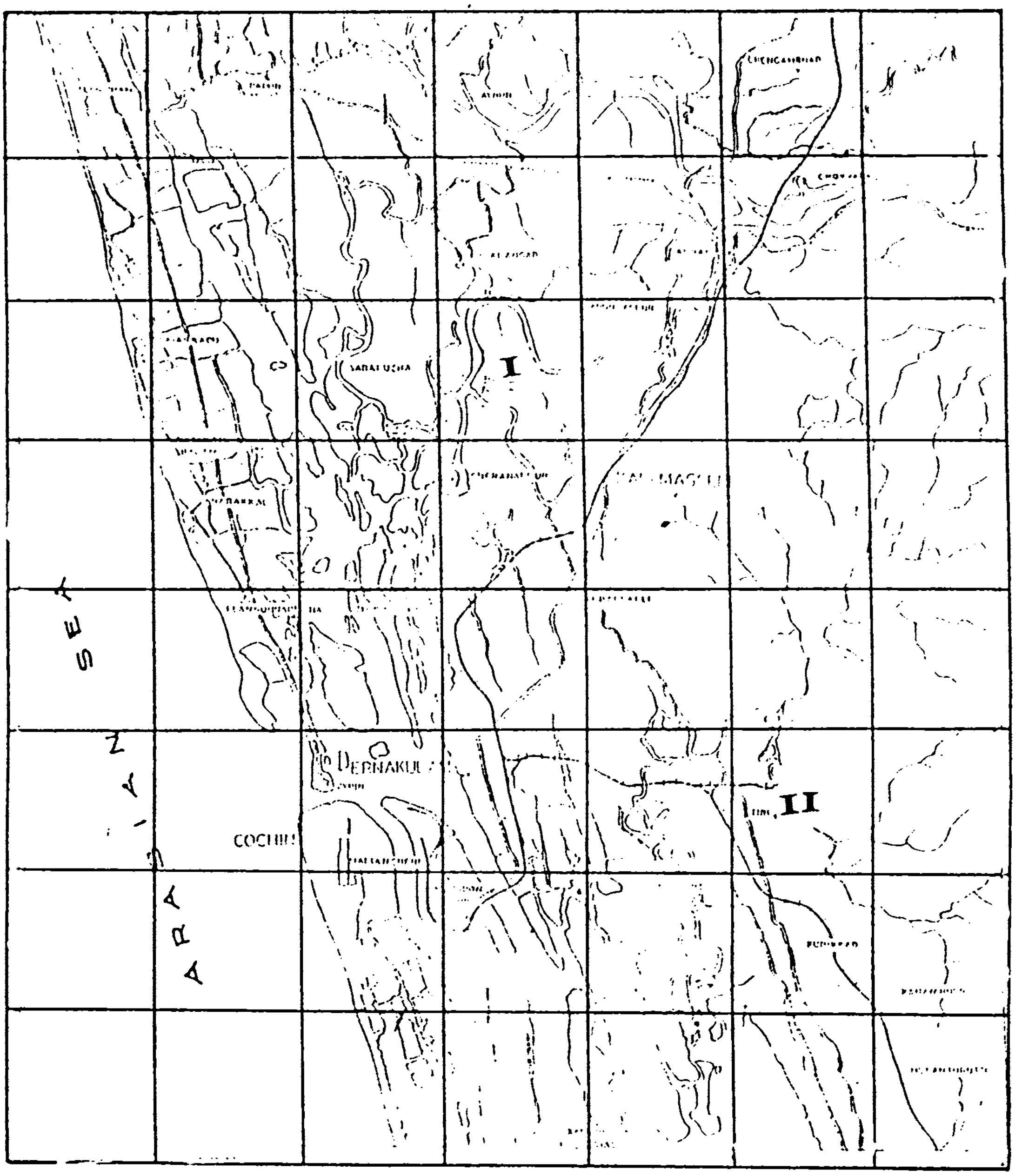


Fig.6.3 4km x 4km grids of Cochin with sources

246601 kg/day of SO_2 and source II have an emission of 26985 kg/day. Emission of source I is more than 9 times that of source II. For the sake of convenience, all the physical stack heights falling in each source are averaged to have one representative stack height, from which the total emission from the corresponding source is assumed to occur. The plume rise is calculated by Slawson and Scandy formula and effective stack height is calculated. For source I it is 128.5 m and for source II it is 249 m. The SO_2 concentration from the two sources identified, is computed for the four representative months, at various distances from the source, depending upon the stability , mixing height and wind direction. In each grid considered, the contribution from the two sources are added and the twenty hour mean values have been worked out. The isolines in μ g/m^3 are drawn and are presented for the four seasons.

Fig. 6.4 shows the spatial distribution of SO_2 concentration for January. As expected the major contribution to SO_2 concentration is due to source I. The maximum values of concentration are observed near the source. There is a sharp fall in concentration as one goes a few kilometers away from the source region in any direction. However, a concentration between 770 $\mu g/m^3$ to 520 $\mu g/m^3$ are recorded about 5 Km^2 are surrounded by the source region. This include areas like Eloor, north of Cheranalloor and Varapuzha region which are located to the North of the central region of the city. A concentration between 500 $\mu g/m^3$ to 120 $\mu g/m^3$ are recorded in the most part of the thickly

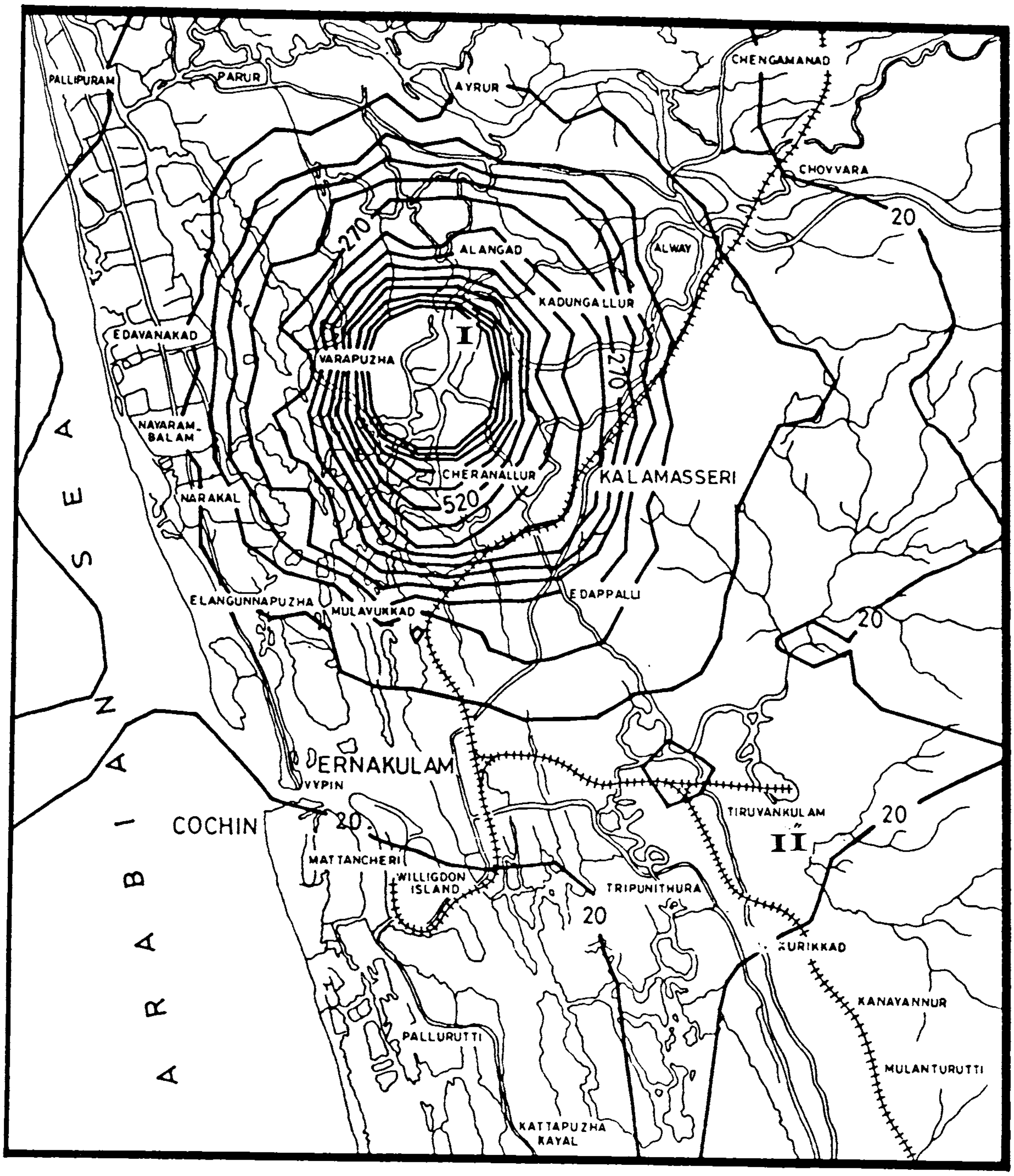


Fig.6.4 Isolines of average SO_2 concentration for January

populated areas of Cochin. In the Southeast sector the extreme portions have shown low values of the order of 20 $\mu g/m^3$. Concentration is slightly above 20 $\mu g/m^3$ near the source II, which is located in the Southeast sector of the city. The northern part of the region also showed lower concentration of the order of 20 $\mu g/m^3$.

Fig. 6.5 shows the spatial distribution of SO_2 concentration in April. The higher concentration is again near the source. Comparatively lower concentration is observed near the central region of the city which lies in the Southwest direction with respect to the major source. This may be due to the effect of sea breeze blowing from west to east, comparatively longer period of the day, in this month. The gas is transported more towards the east of the city. The rate of decrease of SO_2 concentration with distance form the source is more in this month compared to that in January. The central part of the city showed the least concentration compared to other pre seasons. Southern half portion of the region is having a concentration between 270 $\mu g/m^3$. The concentration surrounding 5 to 6 square kilometer from the source II is much higher and it is greater than 800 $\mu g/m^3$. The concentration very nearer to source I is of the order of 1700 $\mu g/m3$. The effect of source II is not felt much during this month also. The extreme southern part and the western part of the city recorded the lowest concentration.

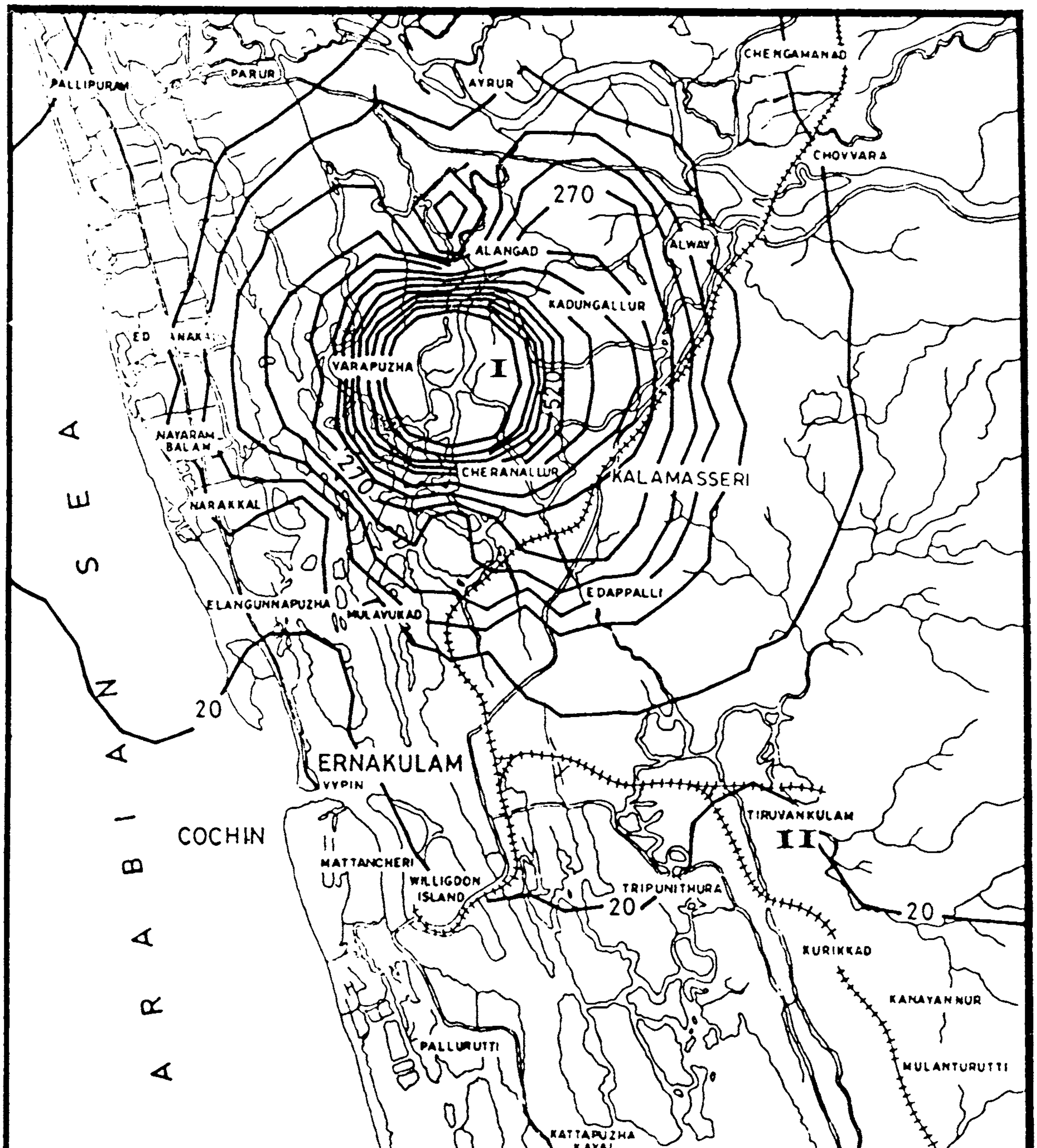


Fig.6.5 Isolines of average SO_2 concentration for April

The sulfur dioxide distribution in July is shown in fig.6.6. The concentration near the source is least compared to the other three seasons. This can be due to the effect of heavy monsoon rainfall during the season. Continuous rainfall causes for the cleaning of the atmosphere to a certain extent by the washout and rainout processes. A concentration between 50 µg/m3 to 500 µg/m3 has been observed in most of the thickly populated region of the city. The distribution is slightly towards the eastern part of the region. Generally the concentration in different places are lower in this season compared to the other three seasons. This also may be due to the effect of monsoon rainfall.

Fig. 6.7 shows So_2 distribution in October. Distribution is some what similar to that of January with slightly lesser concentration near source I. Near source II concentration is comparatively more. A slight spreading is shown towards south and southeast direction. The concentration decreases at a faster rate towards the western part of the city . A concentration 50 ug/m3 to 500 µg/m3 has been noticed in most of the thickly populated areas. Within five to six square kilometers surrounded by the source region the concentration is above 500 µg/m3. In general, it is observed that the maximum is always recorded near the source region with their magnitude differing from season to season. The concentration near the source region is maximum in January, which is the representative month of winter season. The concentration near the source is minimum in the month of July

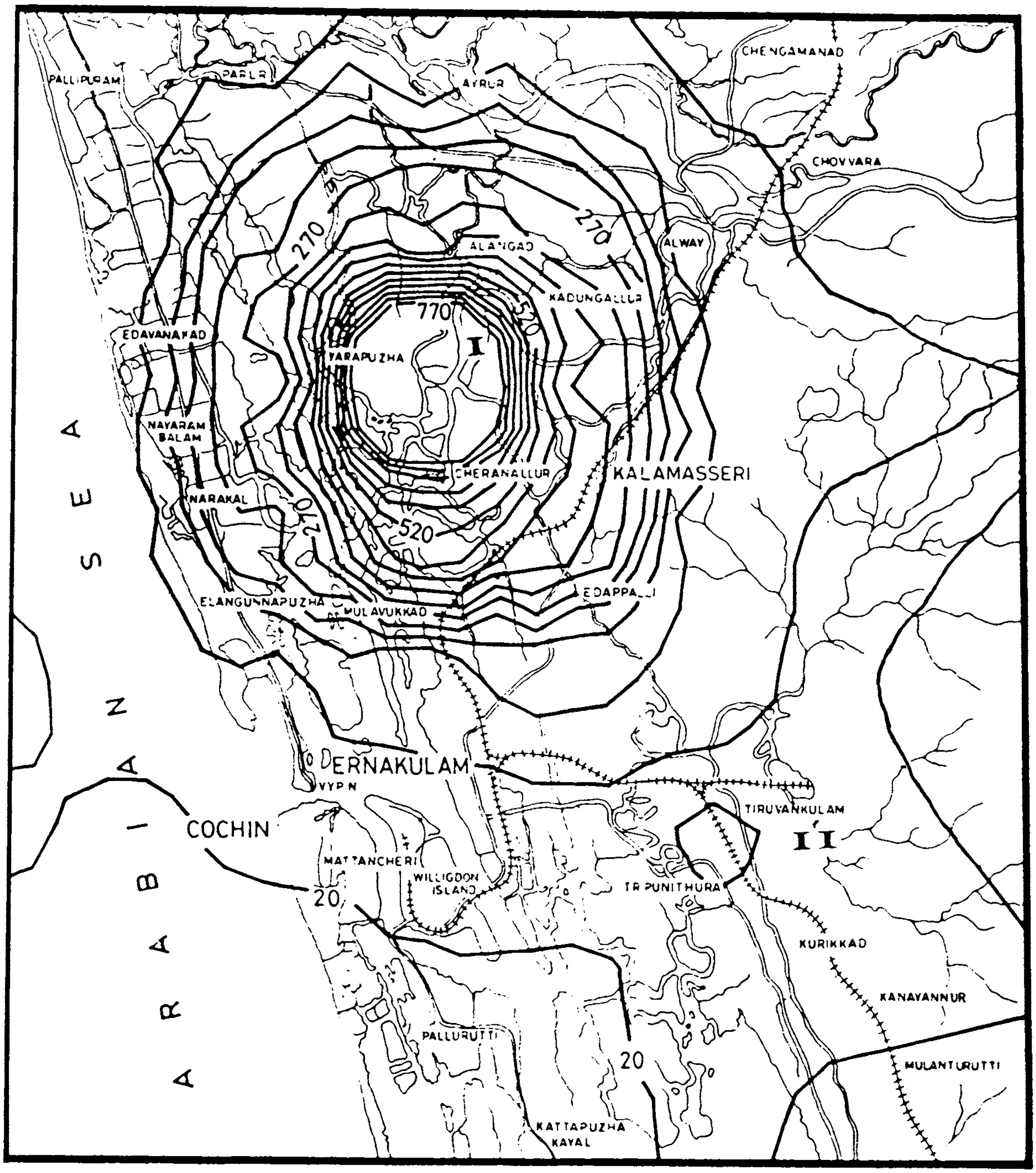


Fig.6.6 Isolines of average SO_2 concentration for July

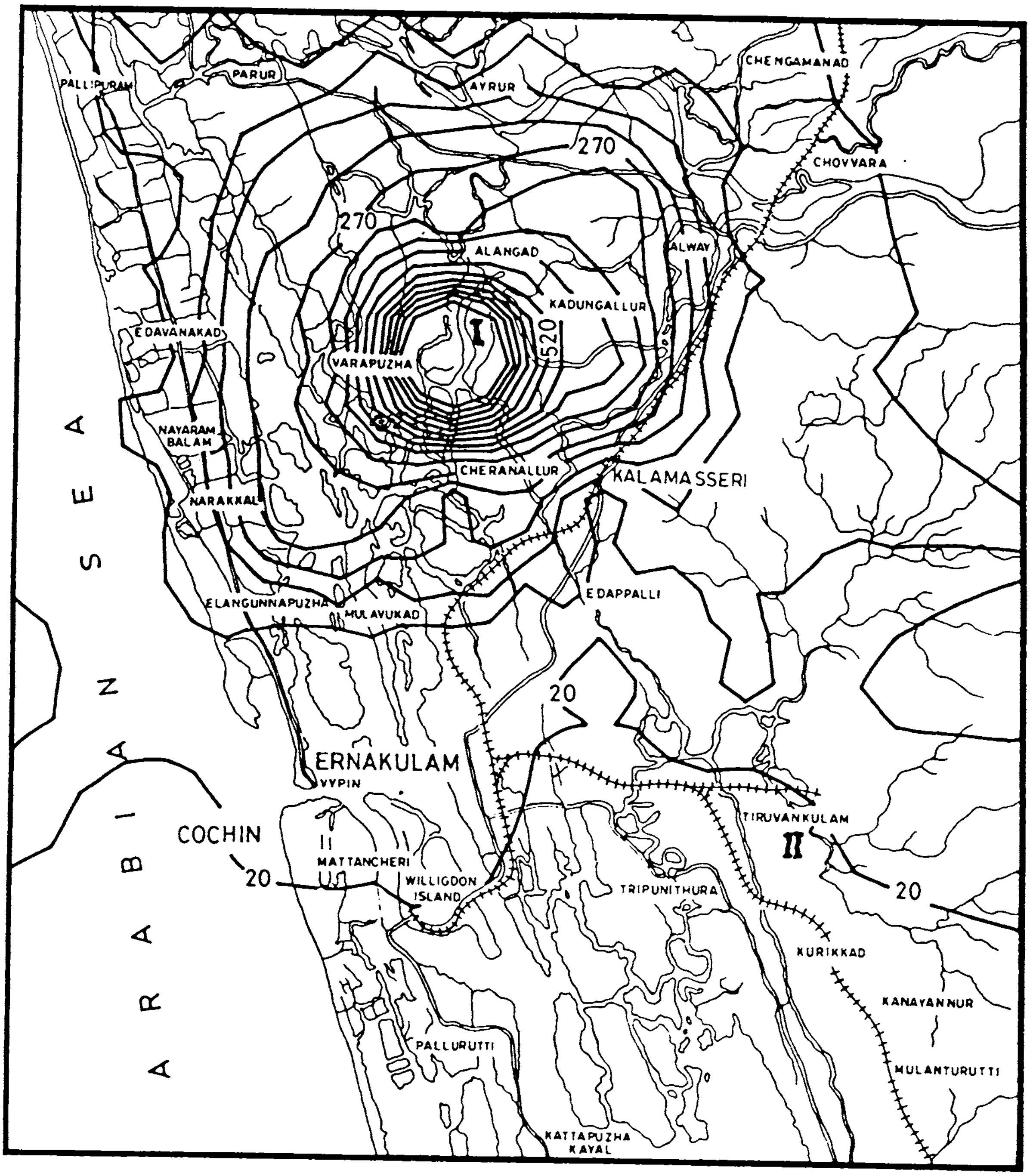


Fig.6.7 Isolines of average SO_2 concentration for October

which is the representative month of south west monsoon season. The concentration near the source is comparable during April and October, which are representative months of premonsoon and postmonsoon seasons respectively.

The variations in mixing height doesn't seem to be contributing more to the difference in concentration in various seasons. On the otherhand wind speed appears to have more control in determining the spatial concentration and the direction of spreading.

There is no single direction in all the seasons, in which the spread is very prominent. It should be noted here that the concentrations are 24 hour values and hence the effect of reversal of wind direction from day time to night time or vice versa is not felt much. However the day time wind speed being more, there is a possibility of a slight domination of the wind directions during day time.

However one notable feature of the distribution is the spread towards south and a sudden fall from the center of maximum towards north. This is mainly due to the effect of prevailing wind direction. During day time, Cochin is experiencing sea breeze most of the time from west-northwest direction and also from west direction. During night time winds are generally weak and is from north or northeast direction. In both the cases these directions modified by the urban structure of the city cause for the spreading of pollutants towards either south or southeast.

Another interesting feature is the effect of variation of the magnitude of the concentration at the source is not felt much in the suburban region of the city. This is also true in the case of central parts of the city which is located southsouthwest of the major source. The concentration is mostly around 100 µg/m3 in the built up areas of the city. In the case of increased concentration at the source region, the values in the thickly populated areas have not shown a proportionate increase, though there is a marginal difference. The observation is very interesting in view of the fact that even if the source strength goes up in the present source identified, the increase of concentration will not be proportionate in many built up areas of Cochin, but it causes concern only in a region about 20 square kilometers surrounded by the major source.

The maximum concentration interestingly is well below 1 ppm in all the cases. But if one compares the standards of environmental protection agency, USA the values exceeded the limit of 365 µg/m3 in most of the places in Cochin. The concentrations show in the present study appears to be more representative compared to the computations made by Anilkumar (1986) for Cochin. The concentration obtained by him were very high due to the very small wind velocity taken for the calm conditions. In addition the stack height used in some of the cases were very low.

It is in the interest of community that the level of SO_2 concentration should be reduced considerably. The stack heights in different cases can be raised instead of altering the structure and capacity of the sources. Even though the emission from source II , that considered in the present study is actually high , its contribution to SO_2 concentration is not predominant. One of the reasons why the source II does not contribute much to the concentration is because of comparatively higher stack heights there. The effect of effective stack height, as is seen in this case is very important and hence it is suggested that the average physical stack height in source I could go up by at least five times the present heights. It should be noted that it is on an average only. For further bringing down the values of concentration one can also suggest devices to control at the source itself. Apart from these two the plume temperature can also be made to be slightly higher to have further rise of the plume due to buoyancy or some device should be installed that pump out the smoke through the stack exit, so as to have considerable vertical velocity of the plume. Eventhough comparatively lower concentration are recorded in the month of July, the monsoon period should be viewed with caution. This is because of a good percentage of pollution in the atmosphere can be brought to the ground by washout or rainout due to the heavy precipitation occurring in this period. This can also cause for the occuranc of acid rain fall. Also one should not forget the low mixing heights in this period, which cannot dilute the pollutants in the vertical.

6.3 Summary

The spatial distribution of the 24 hour SO_2 concentration for different seasons for a ten year period has been studied in this chapter. In general the maximum concentration is always recorded near the source I region with their magnitude differing moderately from season to season. The emission from source I is more than 9 times that of source II and the effective stack height for source one is only half of that of source II . Hence the contribution due to source II is very less. Towards the north the effect of source II is not at all significant.

There is no single direction in which the spread is very prominent. However a slight spread towards south or southeast is noticed. A sudden fall in concentration from the center of maximum is noted in all the seasons.

The variation in mixing height does not seem to be contributing more to the difference in concentration. On the other hand, wind appears to have more control in determining the spatial concentration.

The concentration observed south of the central parts of the city are comparatively low. But the values are found increasing as we go to the northern parts of the city center. Between Ayrur and Edapplly in the northsouth and between NAD and Tattapallir in the eastwest the observed values are often very high. It is often greater than the permissible limit suggested by the Indian standard. Therefore the present trend of the expansion of the city mostly towards the northern direction must be considered very seriously.

As for the locations of the existing industries are concerned , the ideal place would have been the extreme southeast portions of the city so that the city interior and all the densely populated areas would be relatively free from pollution. In such a case most of the spread of the pollutants is over the ocean. However it is not worthwhile to think of a change for the existing industries. In the present situation any newly coming industries can be located towards the far south of the city or far east of the city. This helps the interior of the city for no further increase in the concentration levels.

CHAPTER VII

ENVIRONMENTAL ASPECTS

This chapter deals with some aspects of rainfall characteristics, spatial variation of air temperature and relative humidity, incidence of fog and comfort index studies. As was pointed out in chapter 4 some aspects of surface winds are also discussed in this chapter In order to cover all the major surface parameters in the present study.

7.1 RAINFALL

There have been already some studies carried out on the rainfall pattern of Cochin (Ananthakrishnan et al (1979), Ramesh Kumar and Ananthakrishnan (1986) ,Rajan et al (1981) and Rajan (1988a)). Some of the results due to Ramesh Kumar and Ananthakrishnan have been mentioned in the introduction chapter. The yearly, monthly and diurnal variations of rainfall of Cochin is studied by Rajan. The variations in rainfall intensities from minute to minute for various rainspells occurring at different season has also been studied for Cochin. Studies on intensity of rainspells at Cochin and effect of lunar cycle on rainfall over Kerala have been studied by Bindu (1991). These studies are presented as Annexure A and Annexure B. Studies carried out to find out the chemical composition of rainwater of this city and the relationship between surface temperature and rainfall quantity are discussed below.

7.1. Chemical composition of rainfall

Due to increase in urbanization and indsustrialisation, the atmospheric pollution is on increase and for the quantification of pollution status of a city measurement of various parameters have been suggested from time to time. Variety of pollution which are emitted into the atmosphere by human activity enter the natural cycles and rainfall returns this pollution to earth where they can affect biological processes in aquatic and terrestrial ecosystem. The concentration in rain water of any contaminant is generally known to vary inversely with the amount of rain fall and a similar relationship is also obtained in individual rainfall between the concentration and precipitation rate.

Various natural and anthropogenic activities like a) release of gaseous and particulate matter by volcanic activity b) reduction of sulphur,nitrogen and other constituents in stagnant water bodies c) mining activities. d) release of gaseous and particulate matter by smelters, blast furnaces, e) Incineration of garbage f) emission from cement industries, chemical industries etc., g) burning of fossil fuel and h) aerial spraying of insecticides effect the chemical composition of atmospheric constituents. Numerous factors like wind velocity, direction, height of emitter, topographical conditions, aerodynamic properties of the particulate matter emitted etc., affect the transport of the aerosols to long distances. Although eventually all particulate matter is deposited on the surface of the earth as dry fall-out or in rain, the composition of rainfall shows considerable variation from region to region.

Study of chemical composition of rain water can help in understanding the geochemical cycle of various elements and also in assessing the pollution status of different regions. Since rain water can contribute significantly to the nutrient requirements of plants, studies regarding the deposition of various chemical constituents is of importance from agricultural point of view also.

Krishna Nand (1984) had shown that over India, lowering of pH to acidic values might be restricted close to highly industrialized cities only. Based on the study of pH data collected from ten BAPMoN stations he had pointed out that the phenomenon of acid rain may not be regional scale. The pH data of rainwater obtained from different parts of India are studied by Krishna Nand and the values given by him are given in Table 7.1.1.

It is felt that acid rainfall studies must be carried out for this city also, since, the air pollution level of this city has now become comparable with other major cities in the country. National Environmental Engineering Research Institute's Cochin zonal laboratory has also started some attempt on this aspect. In the present work rain water samples during the south west monsoon

Table 7.1.1 Mean pH at different stations (Other than BAPMoN stations)

Sl.No.	STATION	pH
1	AMRITSAR	7.00
2	BAY OF BENGAL	6.75
3	BHOPAL	6-7.2
4	BIKANER	7.8
5	BOMBAY	6-7,4.5
6	CALCUTTA	6-7
7	DELHI	7-8.4
8	JAISALMER	7.20
9	LUCKNOW	7.45
10	PALSANA	7.80

Source : Krishna Nand (1986).

period of 1985 are collected and analysed for pH, electrical conductivity, sulphate and chloride. A brief discussion on these components of rainwater is given below.

The pH of precipitation is defined as the negative logarithm of hydrogen ion concentration. It is widely used to study the pollution status of different regions in the world. Co2 plays a very important role since it dissolves in water and forms carbonic acid (H_2CO_3) which is a weak acid. At normal concentrations and presence of CO_2 in the atmosphere, the equilibrium value of pH of rainwater would be 5.65 at 20^0C. Measurement of pH of rain water of western countries shows very low values pH but measurement in India indicates much higher values. If ammonia in even trace quantity is present in the atmosphere , the pH of rain water would be 7. Absorption of ammonia is not the only way in which value can be raised. Soil particles which are usually slightly basic when swept to the atmosphere by wind get dissolved in rain water and release into solutions. This also cause for a rise in pH value. In addition to this another important physical reason for higher PH value of tropical rain water is the high temperature dependence of solubility of CO_2 in rain water. pH of rain water depends directly on the amount of CO_2 which actually get dissolved in water. Since solubility of CO_2 decreases rapidly with increase in temperature, lower the ambient temperature greater the rate of dissolution and lower the pH value. The higher dissolution rate and solubility would lower pH values measured at a fixed temperature. This would mean tropical rain water should show higher pH than of extra tropical one. It can be concluded Ph values of monsoon rain water over India should be close to 7 which is the neutral value of pure distilled water. The higher atmospheric temperature in tropics lower solubility and dissolution rate of Co2 added with rapid process of cloud formations and precipitation results in higher pH.

Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valance and relative concentration and on the temperature of measurement. Solutions of most inorganic acid, bases and salts are relatively good conductors. Conversely, molecules of organic compound that do not dissociate in aqueous solution conduct a current very poorly, if at all present. Conductivity meter is used to determine the electrical conductivity of a sample.

Sulphur is an impurity in coal and fuel oil. Burning of coal will release considerable quantities of H_2S in to the atmosphere, which on oxidation would form SO_2, SO_3 and eventually H_2SO_4. The amount sulphur oxides emitted into the atmosphere annually from different countries is given by Wilfrid Bach (1972). On an average 80 million tonnes of sulphur oxides are emitted annually into the atmosphere in the whole world. If this amount is equally distributed over the globe it would increase the world SO_2 concentration by about 0.006ppm. However, Jaunge and Werby (1958) pointed out that precipitation removes all acids and sulphates within a period of about 43 days. There are many industries in and around Cochin which release considerable quantities of SO_2. In addition to local factors, sulphate in rain water may be originated from sea salt nuclei also. The apparatus used to measure sulphate concentration is Nephelometer.

The major source of chloride ion in rain water is likely to be the sea. During the monsoon the sea surface is churned by strong wind resulting in the formation of minute droplets or the sea salt nuclei, some of which may be carried upwards by winds. Although some of these return to the sea either mechanically or through rain fall, others are carried inland and act as condensation nuclei. It is seen from the analytical data that early part of monsoon or at the first shower, the chloride concentration is higher and gradually diminishes with showers due to washing out of major part of dust particles from the atmosphere. Although the results may vary considerably in day to day showers. It is also to be mentioned here that in addition to the successive showers some other factors such as wind velocity, intensity of rain fall , topography of the area are also contributing factors affecting the total mineralisation of rain water of a particular area. Non marine origin such as combustion of fuel also play an important role for the presence of chloride in rain water.

7.1.1. Data and methodology

Rainwater samples are collected from six different locations in and around Cochin using identical glass bottles fitted with large glass funnels. The locations selected are 1. Vypeen, representing island, 2. Kalamassery and Eloor, representing industrial areas, 3. Eranakulam South representing commercial area, 4. palluruthy and Pachalam representing residential areas. Samples are collected from rainfalls occurred before and after the onset of south west monsoon 1995. On an average 10 samples are collected from each station. Precipitation collected on each day is kept in dark and cool place. pH is measured with the help of a standard pH meter as soon as possible after cessation of rainfall. Apart from pH each sample is analysed for sulphate, chloride and electrical conductivity. The mean values and the weighted mean values of ions obtained from the total samples collected are calculated and presented. The weighted mean concentration is obtained by multiplying concentration of ion by the amount of rainfall collected and dividing by the total rainfall of the day.

7.1.1.2 Results and discussions

The results of the chemical analysis of water samples from different localities are given in Table 7.1.2. The mean values and the maximum and minimum values are given in table.

The pH values of the six stations shows a variation from 6.3 in the commercial area (Ernakulam south) to 7 in the island

Table 7.1.2 Results of Chemical analysis of rain water

STATION	CHLORIDE				SULPHATE			
	Max.	Mini.	average concen-tration (mg)	weighted Mean (mg)	Max.	Mini.	average concen-tration (mg)	weighted Mean (mg)
Vypeen	9.99	6.25	8.54	7.58	0.50	0.05	0.200	0.120
Kalamassery	6.25	4.69	5.99	6.25	0.15	0.08	0.116	0.115
Eloor	12.49	3.12	7.42	9.61	0.20	0.0	0.088	0.065
Ernakulam (South)	12.49	3.12	5.77	6.35	0.20	0.0	0.113	0.085
Palluruthy	9.37	6.25	10.93	6.95	0.25	0.15	0.242	0.347
Pachalam	12.49	3.12	6.25	7.49	0.25	0.0	0.136	0.157

	PH			CONDUCTIVITY		CORRELATION BETWEEN CHLORIDE AND SULPHATE	
	Mean	Max.	Mini.	average concen-tration (mg)	weighted Mean (mg)	Correlation Coefficient	Degree of freedom
Vypeen	6.98	7.95	6.06	30.2	25.75	0.330	5
Kalamassery	6.60	7.05	5.07	20.5	22.17	0.260	6
Eloor	6.42	6.60	6.20	75.25	32.36	0.260	6
Ernakulam (South)	6.32	6.66	6.00	36.85	20.59	0.088	11
Palluruthy	6.32	7.23	6.32	93.25	78.38	0.250	5
Pachalam	6.49	6.90	6.30	74.75	34.84	0.088	5

area (Vypine). In the case of Vypine the samples collected on different days shows pH values ranging between 6.06 to 7.95 with a mean value of 6.98. Kalamassery, representing industrial area shows variation from 5.07 to 7.05 on different days with a mean value of 6.6(slightly acidic). Eloor, which also represents industrial area shows lesser variation from 6.2 to 6.6 with a mean value of 6.42 . South, commercial area shows variation from 6 to 6.6 with a mean value of 6.32. Palluruthy shows variations from 6.32 to 7.23 with a mean value of 6.9. Pachalam, a residential area, shows variation from 6.3 to 6.9 with a mean value of 6.49, slightly acidic. The observed mean pH values indicate presence soluble atmospheric gases like CO_2 and SO_2.

Conductivity gives the total concentration of ions. It is showing very high values for rainfall less than 1 mm for certain cases. The mean value of the stations shows variations from 20 micromhos (Kalamassery) to 93 micromhos (Palluruthy). Vypeen, the Inland station shows less concentration of ions . The mean value of conductivity over the region is 55.13 micromhos. The weighted mean value is less than the average value for most of the stations which shows the inverse relationship between rainfall and conductivity.

The values of SO_4 vary from 0.09 to 0.6 mg/l . The mean value for each station doesn't vary much except for Vypeen. The average value over Cochin is 0.15 mg/l. The weighted mean concentration is less than the mean concentration for most of the stations which indicate the concentration is inversely proportional to rainfall amount. The concentration of sulphate is much lesser compared to that of chloride. A close examination the concentration and rainfall shows a scattered distribution of concentration for lower rainfall amounts. The lowest concentration for Eloor, the industrial area , indicates that contribution of SO_4 coming down through washout near industrial areas need not be high.

The concentration of chloride ion for rainfall amounts less than 1 mm shows much higher values while for large amount of rain fall the values are scattered. Mean value for each station shows variations from 5.77 (south) to 10.93 (Palluruthy). The average value of Cl over Cochin is 7.48 mg/l.

The contribution from washout and droplet evaporation to the specific rain water concentration will not explain the observed inverse relationship in the present case. Rain water concentration seems to be influenced only by the concentration in the cloud droplets. Also the inverse relationship cannot be explained by rainfall rates, since even lαw rainfall amount were quite often the results of passing showers with high rainfall rates. The spacing between rainfall periods, ie., length of dry period in between two collection and fairly equal rainfall duration do not correlate with increased concentration in small amount samples which again indicate the effect of washout is not significant. So the observed inverse relationship can be only due to the element concentration in cloud water, the absolute humidity of the entraining air and the efficiency of water removal.

The chemical data obtained so far from the analysis of rain water reveals that the observed pH values are only in the expected range for tropical regions. The concentration doesn't show much difference with showers which indicates washout doesn't have much influence. It is also to be mentioned here that , in addition to the successive showers some other factors such as wind velocity, intensity of rain fall, topography of the area are also contributing factors affecting the total mineralisation of rain water of a particular area.

7.1.2 Correlation between temperature and rainfall

The purpose of this study is to examine the relation between monthly precipitation and monthly mean air temperature over Cochin, both simultaneous with lag and lead. They would document useful background material to understand the physics of the relation between atmospheric circulation (which produces precipitation), surface hydrology and surface air temperature.

The physical reasoning behind finding relationship between precipitation and temperature is that precipitation affects soil moisture which in tern affects current and future surface temperature by controlling the partitioning between the sensible and latent heat fluxes. Further feed back makes through changed cloudiness, heat capacity, relative humidity, surface albedo and roughness. It is perhaps surprising that the correlation between current precipitation and future temperature has until recently not been studied. The reason is, almost complete absence of any persistence in precipitation anomaly, which makes it an unlikely predictor.

7.1.2.1 Results and discussion

The simultaneous correlation between mean monthly air temperature and monthly precipitation over Cochin in the twelve calendar months for ten year have been studied (Table 7.1.3). There is generally a negative correlation between mean monthly air temperature and monthly precipitation in all seasons. Clouds explain negative correlation. When it is cloudy it is cooler than normal and also rainier than normal. Soil moisture would also explain the negative correlation . Numerical experiments show that surface air temperature and precipitation are sensitive to prescribed soil moisture. The negative simultaneous correlation between mean monthly air temperature and monthly precipitation is probably further enhanced by a feed back between hydrology and atmospheric circulation. Reduced evaporation from dry soil increases the surface temperature which leads to strengthen upper level anti cyclonic flow that will further decrease precipitation and soil moisture.

The lagged correlation between mean monthly air temperature and monthly precipitation of next month showed negative

Table 7.1.3 Correlation of rainfall with temperature

Lag months	Correlation Coefficient	$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$	table	significance
Temperature-Rain				
0	-0.58	7.72	1.98	
1	-0.12	1.31	1.98	Not significant
2	0.20	2.22	1.98	
3	0.36	4.19	1.98	
4	0.38	4.46	1.98	
Rain-Temperature				
0	-0.58	7.72	1.98	
1	-0.68	10.02	1.98	
2	-0.54	5.87	1.98	
3	-0.32	3.67	1.98	
4	-0.04	0.44	1.98	not significant

No. of observations - 120
Degrees of freedom - 118

correlation which proved to be statistically insignificant. The influence of current precipitation on future temperature has also been studied. It showed strong negative correlation which indicate that a dry / wet july tends to be followed by warm / cold August.

Taking different lags as two months, three months, and four months for temperature of the month and rainfall, positive correlation is found which is strong for four months ie., influence of temperature of a month is maximum on the rainfall after four months.

Influence of monthly rainfall on monthly mean temperature was also studied and it showed negative correlation. It is strong for one month lag ie., monthly rainfall of a month influence the mean monthly temperature of next month. For four months lag it proved to be statistically insignificant.

Precipitation - temperature relationships (P-T) found in the above studies suggest that precipitation is an important factor affecting temperature on a local scale. However the existence of a lagged P-T correlation doesn't necessarily mean that precipitation time profitably be used as an additional predictor for future temperature. Because the simultaneous mean monthly air temperature and monthly precipitation shows strong negative correlation , monthly precipitation predictive variance may be accounted by using temperature persistent. The negative P_T correlation is caused primarily by short term climatic anomalies.

The observed P-T correlation, with monthly precipitation leading mean monthly air temperature by a month is much larger than temperature- precipitation (T-P) correlation. This rules out the possibility that monthly precipitation and mean monthly air temperature are correlated only because each of them is correlated to some common slowly varying cause. The precipitation appears to be leading the temperature and the correlations are negative.

7.2 Spatial distribution of temperature and relative humidity

The study of urban temperature distribution is of much interest because of its practical important in the proper design of buildings and cities to secure maximum comfort as well as optimum socio-economic performance and in pollution dispersion studies. Urbanization causes changes in the atmosphere immediately adjacent to them. Almost all meteorological parameters like temperature, humidity, wind, rainfall etc., are affected. It also affects low level lapse rates, turbulence resulting in updraft. A detailed study of temperature field over cities and rural environments is necessary for a better understanding of the imbalances in their dispersive capacities of atmospheric pollutants.

The effect of urbanization on temperature field has been studied in great detail by various workers. The meteorological data have been collected by conducting mobile surveys. Though the mobile survey give quick results, they have their own limitations. As such it is desirable to collect meteorological data from different locations in a city continuously for a longer period for detailed study of the effect of urbanization on temperature field.

Pattern of humidities in cities are closely related to that of the temperature distribution which in turn depends upon the distribution of urban building densities. Humidity island play a key role in determining the residence times of pollutants, their rate of deposition and chemical action on the exposed objects.

7.2.1 Data and methodology

Temperature and relative humidity data are collected for the winter months during the period 1992 - 1994 from different localities in and around Cochin using thermohygrographs. The stations are selected in such a way that they cover most of the thickly populated area of the city. The stations are Eloor, Kalamassery, Ambalamughal, representing industrial area, Kaloor, Palluruthy representing residential areas and Ernakulam South ,Tripunithura, representing commercial areas. A number of temperature and RH observations using whirling Psychrometers are also taken during early morning hours of this period. The values obtained are used to plot the isolines of temperature and RH in order to study their spatial variations and to find out the existence of any heat islands within the city.

7.2.2 Results and discussion

The isolines of temperature and RH for four selected timings namely 0530, 1130,1730 and 2330 hrs. are drawn on the map of Cochin and are presented in fig 7.2.1 and fig 7.2.2 respectively. These maps provide the mean picture of temperature and Relative Humidity distribution during the winter season for Cochin.

The temperature distribution for 0530 hrs and 1130 hrs are shown in figure. The isolines are shown mainly for the major land mass only. The temperature structure in the north western parts does not show much variation because that area is mainly covered by a number of small islands. During this hour at 0530 the temperature in the rest of the region varies between 24^0 C to 26^0 C. The temperature gradient is from west to east. The higher temperatures are observed near the coastal region. This can be attributed to both the effect of coast and a number of high-rise buildings right at the coastal region, which prevent the incursion of cold land breeze. The temperature is found decreasing as one go towards inland region.

At 1130 hrs the temperature values in the region vary between 28^0C and 30^0C. The south east parts of the region showed

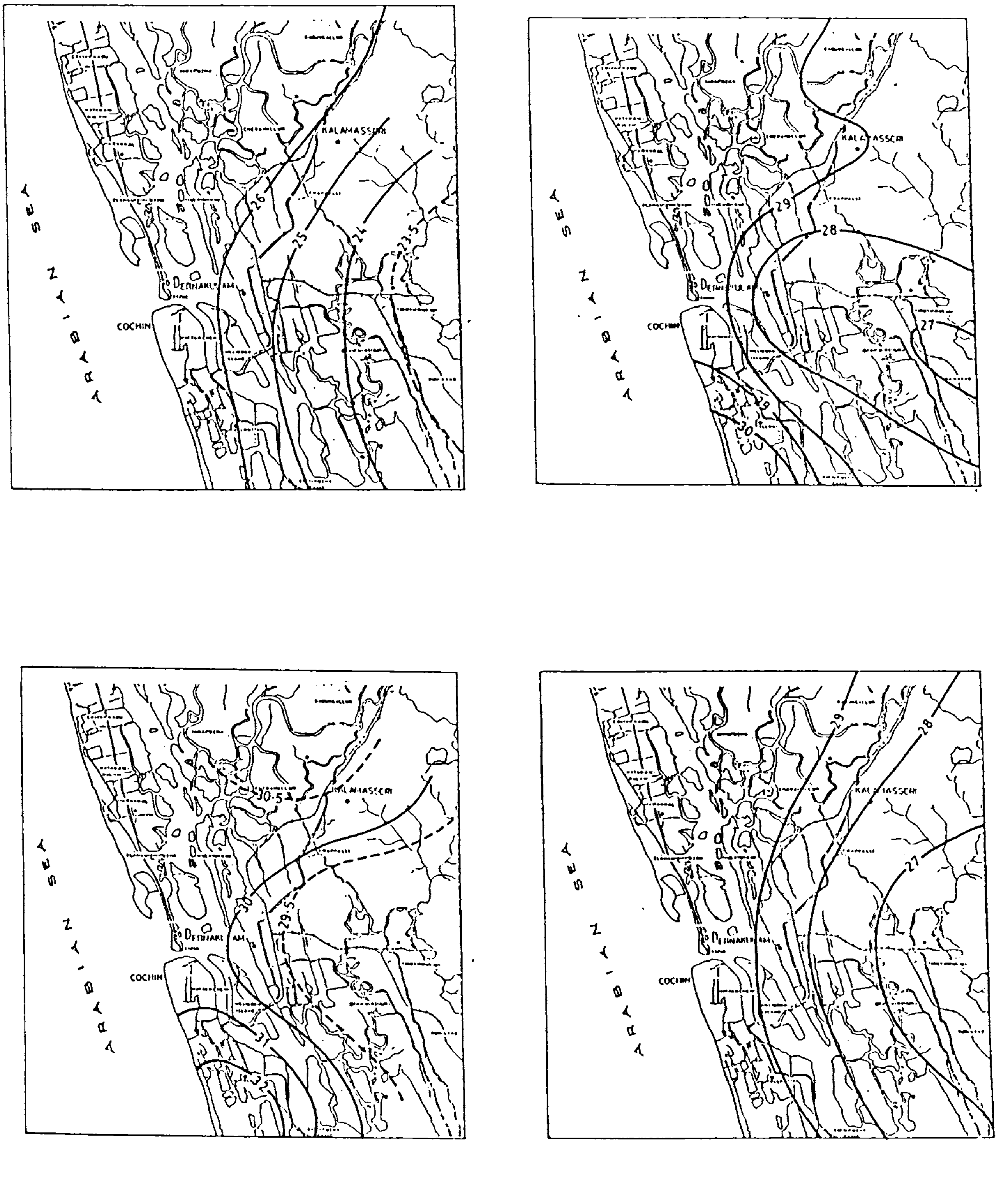


Fig. 7.2.1 Spatial distribution of temperature for six hourly intervals (0530 hrs, 1130 hrs, 1730 hrs, 2330 hrs)

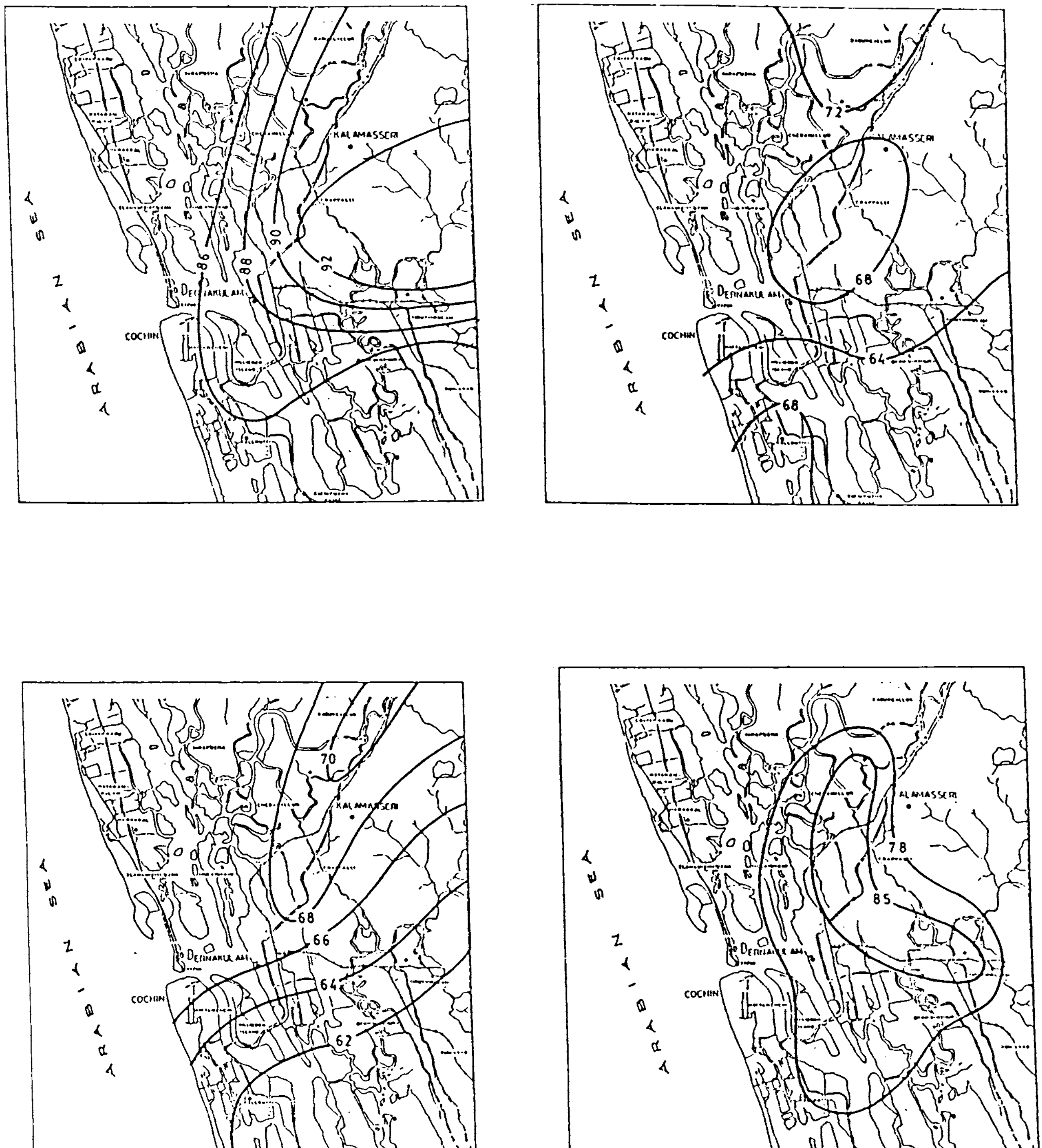


Fig. 7.2.2 Spatial distribution of Relative Humidity for six hourly intervals (0530 hrs, 1130 hrs, 1730 hrs, 2330 hrs)

lower temperature compared to other portions. The south west parts of the region covering Mattanchery island which is comparatively a larger island in the region showed higher temperature during this hour.

Figure shows the temperature distribution at 1730 and 2330 hrs. Higher temperatures near the coastal region and a decrease in temperature towards the inland region is the general feature noticed once again. The temperature values at 1730 hrs are higher than the corresponding values at 1130 hrs in most of the places near the coast. The southwerstern parts and the north eastern parts showed higher temperatures during this hour. The range of temperature at 1730 hrs is between 28^{o}C and 32^{o}C. At 2330 hrs the temperature values ranged between 27^{o}C and 29^{o}C. The isotherm pattern during this period is similar to that of at 0530 hrs.

The south west portions are showing higher temperatures during all the four timings. This region comprises the Mattanchery island which is a very thickly populated old town where houses and buildings are constructed very close to each other. The central parts of the city, even though very nearer to the coast, shows higher temperatures compared to the southern and northern parts of the city. This can be attributed to the large number of tall buildings constructed parallel to the coast which obstruct the flow of sea breeze which prevails during most period of the day.

Figure shows the spatial variation of RH at 0530 hrs and 1130 hrs for winter months. Throughout the region, RH was above 85% at 0530 hrs in this season. RH decreases towards the coast in accordance with the corresponding increase of temperature towards the coast at this hour. The range of RH in most of the thickly populated ares at 0530 hrs is below 86%-92%. The gradient was comparatively less in the centre parts of the city.

The RH range at 1130 hrs is between 64%-72%. The northern portions or the region shows the comparatively higher RH.

The spatial variation of RH at 1730 and 2330 hrs is shown in figure(7.22)At 1730 hrs, RH shows an increase from the south western parts towards the north eastern parts. The minimum value of RH in the south western parts is 62% where as the maximum in the north eastern parts is 70%. A mean value of about 65% is found in most parts of the city during this season at 1730 hrs. The RH values at 2330 hrs ranged between 78% and 86%. Near the coastal region the value is nearly 80%. The values first show an increase towards the interior of the city and then show a decrease far away from the city. Most of the central portions here show an average value of 83% during this hour.

7.3 Surface Wind

For a proper environmental and urban planning the information of wind speed and directions and their variations both seasonal and diurnal is very much essential. Designing the buildings, location of industrial and residential sectors are dependent primarily on the climatology of wind. All atmospheric dispersion models require a complete and thorough knowledge of wind climatology for any given locality. Preliminary studies in the wind climatology of Cochin have been studied by Anil Kumar (1986). He has presented three hourly wind roses making use of surface wind data for Cochin during the period 1973 to 1982. In the present work the zonal and meridional components of the winds during the period 1983 to 1992 are worked out and is subjected to harmonic analysis. The vector mean of three hourly winds during this period is computed and making use of this, the temporal variation is also studied.

7.3.1 Data and methodology

Using three hourly wind speed and direction, vector winds are plotted for all months to get the temporal variation. The temporal variation of vector winds is presented. Three hourly winds are also resolved into zonal and meridianal components,

$u = -V\sin\theta$ ---- zonal component

$v = -V\cos\theta$ ---- meridional component

Three hourly wind components are then subjected to harmonic analysis.

7.3.2 Results and Discussion

Figure 7.3.1 shows mean wind vectors of three hourly surface observations. The characteristic changes in the surface

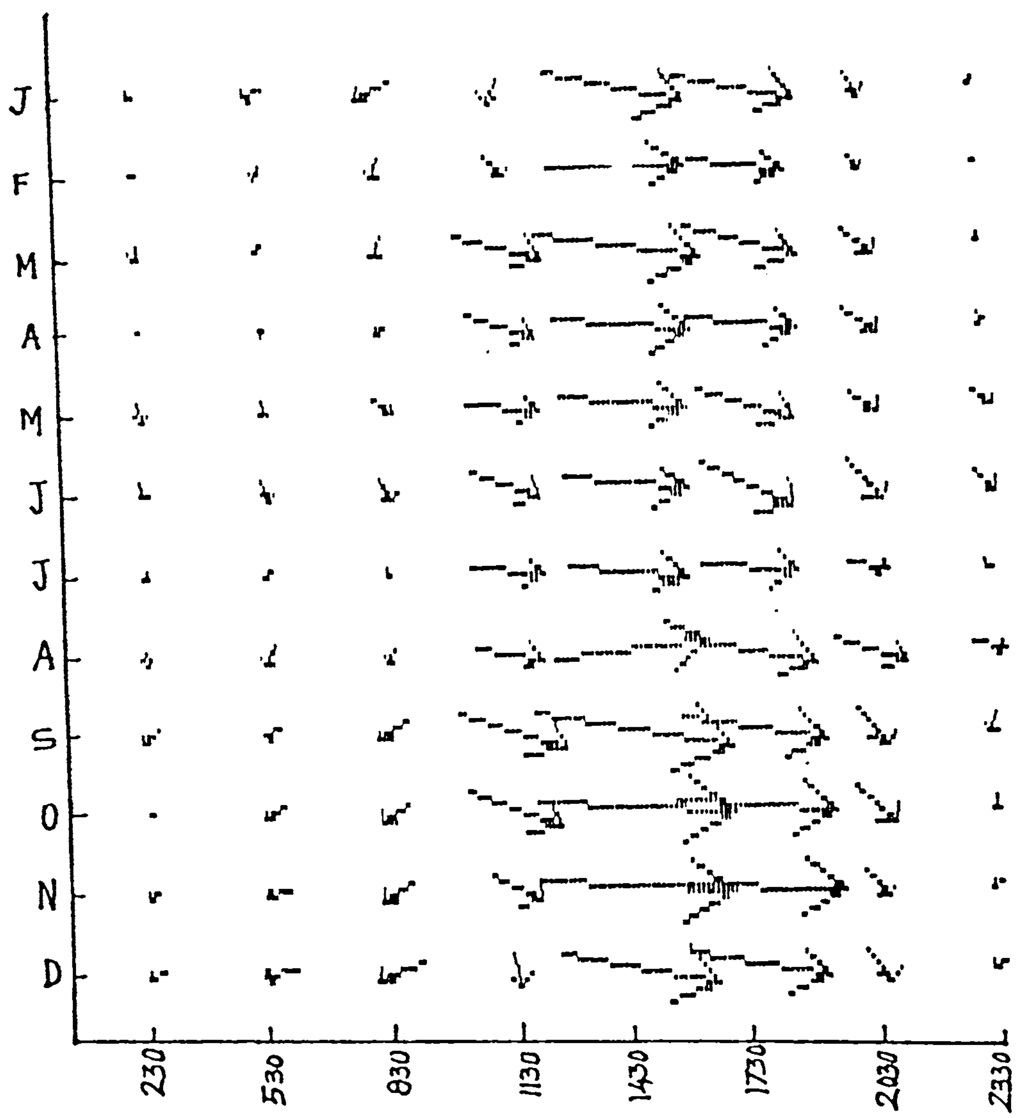


Fig. 7.3.1 Mean monthly vector winds of three hourly surface observations

winds from morning to evening due to the setting in of sea breeze and land breeze may be noted. Cochin which is in the west cost is having sea breeze from west. Seasonal variation of winds are interlinked with the seasonal variation of pressure which in turn is coupled with seasonal variation of temperature. Sea breeze intensify after the pressure tendency has occurred its maximum value around 1430 hrs. It is also the time of maximum temperature.

From the figure one can see that winds are strong in the afternoon hours. Winds are mostly northwesterlies around 1130 hrs. Wind gets intensified and becomes westerlies in the afternoon hours. However, in the evening hours winds are northwesterlies during most of the months. The northwesterly winds in the evening hours get weakened to northerlies or northnortheasterlies in the night hours and early morning hours. The winds again intensify gradually to become westnorthwesterlies.

Generally the winds are very weak during night hours and early morning hours. Land and sea breezes are the most striking feature of diurnal variations of wind. This arise from the differential heating and cooling of land and sea during day and night. Harmonic analysis of the meridianal component does not show any seasonal or diurnal cycles. In the case of zonal wind component, there are certain oscillations which are dominating in the seasonal and diurnal cycles.

Zonal component has its maximum strength during March around 1430 hrs. It is strong during 1430 hrs for all the months when temperature and pressure tendency are maximum. It is also conspicuous during 1130 and 1730 hrs. Westerly components prevail during monsoon months for all the time. For the other months it is dominant at 1130 hrs to 2030 hrs , which is the time of occurrence of sea breeze. It is very weak during 2030 hrs and after that land breeze sets in which is also very weak.

Meridional component which is weaker is having its maximum intensity during July around 1730 hrs, which is the monsoon month. It is comparatively stronger between 1130 hrs and 2030 hrs when the westerly wind component is also having its maximum strength.

In the seasonal cycle annual oscillation is found to be the most dominating oscillation. Amplitude is maximum at 1130 hrs and least at 0230 hrs. The amplitude of annual oscillation varies between 0.4 to 1.4 mph for different hours. Semi-annual oscillations are present in the day time. But in early morning and late night hours short period oscillations dominate which may be due to local effects.

Harmonic analysis also shows that the diurnal oscillation is dominating in the diurnal cycle. This is due to the effect of land and sea breezes dominating over the seasonal influences. Diurnal and semi-diurnal oscillations are found to be important.

Table 7.3.1 Results of harmonic analysis of seasonal cycle of zonal component of wind

TIME	A1	PHASE1	A2	PHASE2	VAR.	A1 / VAR. (%)	A1+A2 / VAR (%)
0230	0.43	7.45	0.13	0.94	0.26	69.26	83.27
0530	0.65	7.95	0.87	9.69	0.51	84.14	92.36
0830	1.10	7.56	0.07	1.02	1.43	84.58	93.68
1130	1.43	5.94	1.32	9.36	4.25	47.78	92.89
1430	1.23	2.38	0.98	9.31	2.63	57.65	94.18
1730	1.31	2.44	0.62	2.83	2.29	75.00	95.84
2030	0.68	5.43	0.19	10.38	0.87	53.56	74.10
2330	0.73	6.72	0.10	11.67	0.82	65.00	68.10

Table 7.3.2 Results of harmonic analysis of diurnal cycle of zonal component of wind

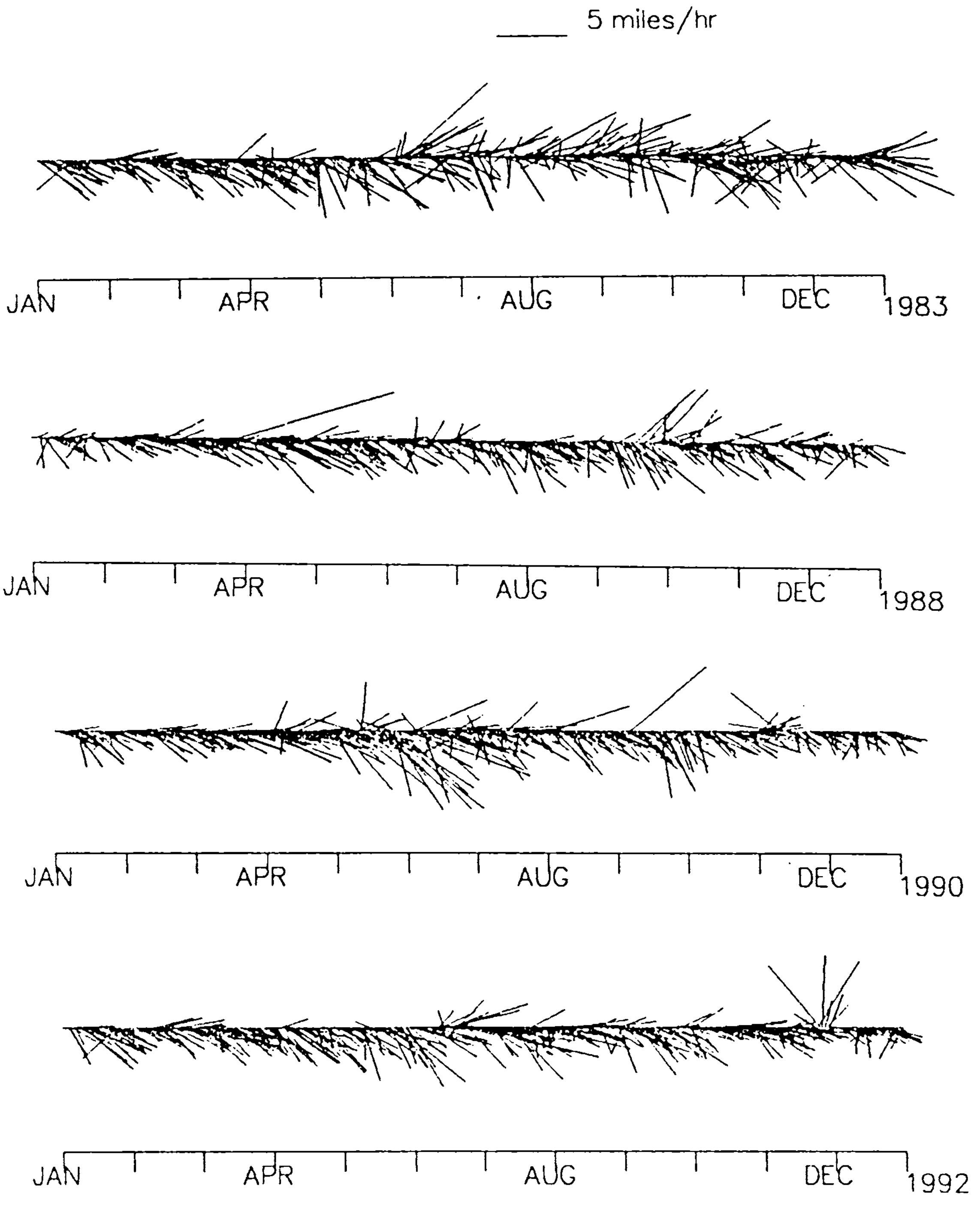
MONTH	A1	PHASE1	A2	PHASE2	VAR.	A1 / VAR. (%)	A1+A2 / VAR (%)
JANUARY	3.76	5.66	2.05	1.38	18.59	76.01	98.5
FEBRUARY	4.33	5.49	2.30	1.35	24.20	77.36	99.2
MARCH	4.31	5.40	1.90	1.16	22.20	83.47	99.7
APRIL	4.34	5.29	1.86	1.09	22.70	83.01	98.3
MAY	3.31	5.68	0.96	1.12	11.97	91.54	99.3
JUNE	2.53	5.35	0.79	1.03	7.04	90.6	99.5
JULY	2.26	5.28	0.78	1.07	5.80	87.8	98.4
AUGUST	2.33	5.21	0.87	0.99	6.27	86.46	98.5
SEPTEMBER	2.84	5.37	1.26	1.21	9.77	82.7	99.1
OCTOBER	3.32	5.24	1.44	1.09	13.15	83.5	99.4
NOVEMBER	2.55	5.37	1.52	1.33	9.30	69.98	94.9
DECEMBER	2.96	5.72	2.02	1.43	13.57	64.65	94.7

They contribute more than 94% of the total variance. The variance is maximum in February and minimum in July. The phase of diurnal oscillation is around 1530 hrs and that of semi-diurnal oscillation is around 0330 hrs and 1530 hrs. The maximum amplitude of first harmonic and one of second harmonic coincides. The amplitude of diurnal oscillation is maximum during early morning hours and minimum during peak winds hours.(Tables. 7.3.1 & 2).

Time series of daily mean wind vectors (fig 7.3.2) for typical years presented indicate contrasting features in the surface wind pattern. In the pre-monsoon month (May) winds are generally weak northwesterlies (< 3 mph - 4 mph). With the onset of monsoon (May-June) the winds strengthen to over 10 mph - 15 mph maintaining same direction as the pre-monsoon months. Around the onset date a spurt in the wind speed is observed for all the years which is all the more significant for 1990. A typical drought monsoon year (1983) is characterized by a highly variable wind (both magnitude and direction) during the active phases of monsoon (June - August) compared to other years. Post-monsoon period is also characterized by northwesterly winds (about 5 mph).

7.4 Comfort indices

The sensations caused in the human body by the atmospheric environment can be characterized by a number of discrete physical parameters or their combinations. These parameters are usually represented by the common meteorological elements;



(In figure the wind direction is actual wind plus 180°)

Fig./.3.2 Wind stick plots

temperature, intensity of radiation, wind speed and moisture measure such as vapor pressure, due point, wet bulb temperature or relative humidity.

Meteorologists in the normal service deal with a population rather than individuals. He is not in a position to evaluate all the variables that should enter equations describing the strain caused by the environment. Although prominently concerned with indoor conditions they devised over thirty years ago a measure which is essentially based on reactions of normal persons to the environment characterized by temperature, humidity and wind conditions. This index was labeled effective temperature and has been widely used as a corollary measure in physiological investigations. Comfort and discomfort are felt before temperature changes in skin and body have taken place. Differences of opinion on comfort are quiet inevitable, depending on clothing and state of activity. High metabolic rate because of heavy work and clothing shift the effective temperature boundaries to lower values.

Human biometeorology concerns relationships between natural and artificial geophysical factors and human psychological, pathological and behavioral responses. Human dependence on two conditions in the atmospheric environment is absolute. Oxygen for respiration and suitable thermal surroundings are required.

Thermal comfort of humans is the result of the synergistic effect of several components of the immediate environment. To the extent that these components - generally weather elements - are quantifiable, indexes can be constructed for various combinations of them. The particular combination used depends on the use intendent for the index, how significant a component is and the ease with which it is measured and its representativeness. Thus we may wish to predict reaction of people in general in a large metropolitan area.

There are different biometeorological indices. Effective temperature (ET) and the THI (Temperature,humidity index, formerly called the discomfort index) has been widely used, to characterize the degree of uncomfortableness expected in large populations. The THI can be calculated from temperature and wet bulb temperature, or from any other moisture indicator. Another way of combining temperature and humidity is represented by Humiture. Some of the discomfort indices used are

1) Thom (1959) and US weather Bureau (1959) have given a simplified relationship between temperature and humidity to determine a parameter which is called a discomfort index (DI).

   $DI = Td - 0.55\ (1-RH)(Td-58)$

   where Td is dry bulb temperature in degree fahrenheit and RH is relative humidity expressed as a fraction.

2) Temperature humidity index suggested by Thom.

THI = 0.4 (t+tw) + 4.8

3) The formula for effective temperature given by Missenard.

ET = T - 0.4 (T-10) (1-RH) /100 where R is the relative humidity.

4) Strain index developed by Lee measures relative strain imposed by the atmospheric environment on man.

G = A [M - W - 5.55 (34-ta) /

Ia + Ic - 0.000033v (46-p]/(c-p)/ra+rc

A number of bioclimatic study regarding human comfort are now available for India. A glance through these articles clearly indicate a preference for the use of bioclimatic indices. Strain indices are used to signify different categories of comfort or discomfort under varying climatic conditions. Two points need to be in mind when using these indices.

1) Physiological reactions of the body are largely subjective while strain indices are used for analyzing data regarding atmospheric variables which are objectively recorded by instruments.

2) Physiological reactions to climate result from the influence of total ambient atmosphere, acclimatization to a particular type of climate and one's economic conditions. On the other hand bioclimatic indices are based on a few selected atmospheric variables.

Air conditioning engineers require the information on effective temperature at different places for installation of air conditioners. Effective temperature is used to indicate the degree of thermal comfort or to predict the sensation of warm and physiological strain imposed by the atmosphere on human beings.

In order to calculate the effective temperature the instantaneous values of wind speed, humidity and temperature values are required. However these elements are not available for the same height. From different studies it was concluded that the effective temperature and the discomfort index are one and the same thing when one is indoor or when there are light winds.

7.4.1 Data and Methodology

In the present work Thoms 1959 DI has been worked out for Cochin. The DI values for all the months are computed for every three hour intervals using ten years surface temperature and RH values. Using the values the isolines showing the distribution with respect to month and time are drawn.

The study of DI during the winter months has also been made for seven stations spread over Cochin, each representing different localities such as residential, industrial, commercial, island and coastal. The temperature and RH values during the winter months of 1992 and 1993 only is used for this. The DI values at each stations for each three hour interval has been worked out. The average of these three hourly values for each station are plotted to get the spatial variation.

7.4.2 Results and discussions

The scope for developing an index for the purpose of bioclimatic studies with regard to comfort conditions in India is immense. However it is not only necessary keep in mind our climatic characteristic but also that our cultural environment which includes food, clothing and shelter is quiet distinct from the mid-latitude. Suitable modifications are made for Indian condition. Malhothra (1967) has conducted experiment and given different comfort zones based upon effective temperature.

$$ET = t - 0.4(t-10)\ (1-4/100)$$

Using the data of Malhothra's comfort zones and discomfort indices, Parthasarathy and Rakhecha (1972) worked out deferent scales of discomfort. Table 7.4.1 shows this different scales of comforts. According to this the comfort index for different times and months over Cochin are studied. From the figure 7.4.1 the most comfortable periods are early morning hours of December and January. Noon time is uncomfortable period for all the months especially during summer months. The DI values during the noon hours of summer months are much higher. For all other months and all other timings poor comfort exists. Uncomfortable period starts by 1000 hrs. However, in summer months it starts much earlier and is by 0700 hrs. In the after noon it comes to poor comfort only after 1930 hrs. For summer months it is only after 0300 hrs in the morning that it comes to poor comfort. So the period of poor comfort is lesser during summer months, It is

Table 7.4.1 Types of Comfort Zones and their respective DI Values

Sl. No.	Type of comfort zone.	DI Value	Effect on population
1.	Uncomfortable period	less than 50	Everybody feels unpleasant due to very low temperature and humidity.
2.	Slight or poor comfort.	50 to 60	50% of the population feel unpleasant due to low temperature.
3.	Most comfortable period.	60 to 75	Only 10% of the population feel unpleasant.
4.	Slight or poor comfort	75 to 80	50% of the population feel unpleasant due to high temperature.
5.	Uncomfortable period.	80 to 85	Everybody feels unpleasant due to high temperature.
6.	Most uncomfortable period.	more than 85	Sun strokes/heat strokes are common.

Source : Parthasarathy and Rakecha (1972)

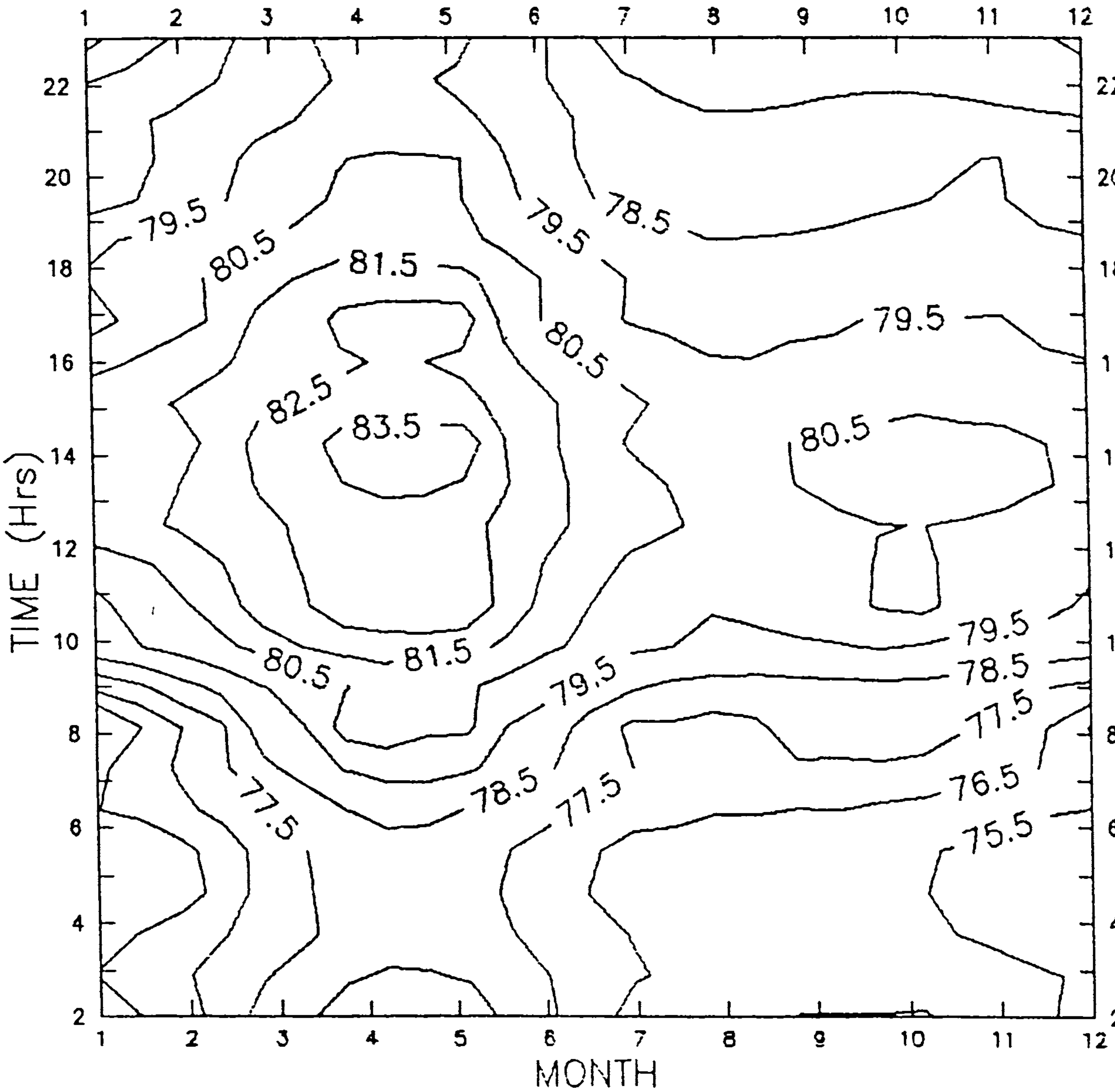


Fig. 7.4.1 Isolines of Discomfort Index for different time and months over Cochin

between 0300 hrs and 0700 hrs. For the rest of the time it is uncomfortable. The other months also shows some what similar pattern.

Discomfort index for different stations are calculated and the isolines are drawn. The method is adequate in studying climatic comfort at individual stations and for the purpose of comparison between stations. For this numerical scores can be given to the sensation of comfort or discomfort signifying the degree of it. Spatial variation of comfort conditions can be studied by drawing isolines using these indexes for a number of stations.

Fig. 7.4.2 shows the isolines of discomfort indices of Eloor, Kalamassery, Kaloor, South, Ambalamughal, Thripoonithura and Palluruthy during winter months. The magnitude of isolines vary from 74.5 to 80.5. Poor comfort exist up to 1000 hrs for the station Eloor and the rest of the time it is uncomfortable. This is a highly polluted industrial area and major sources of pollution are located in this area. Kalamassery, a nearby station, shows most comfortable period between 0600 hrs and 0800 hrs . Poor comfort prevails before 0600hrs during noon time it is uncomfortable and lasts up to 2000 hrs. Poor comfort prevails after 2000 hrs . In Kaloor, a residential cum commercial area, poor comfort exists for most of the time. It becomes uncomfortable by about 1230 hrs and lasts till 2000 hrs. The station Ernakulam south shows poor comfort for most of the time.

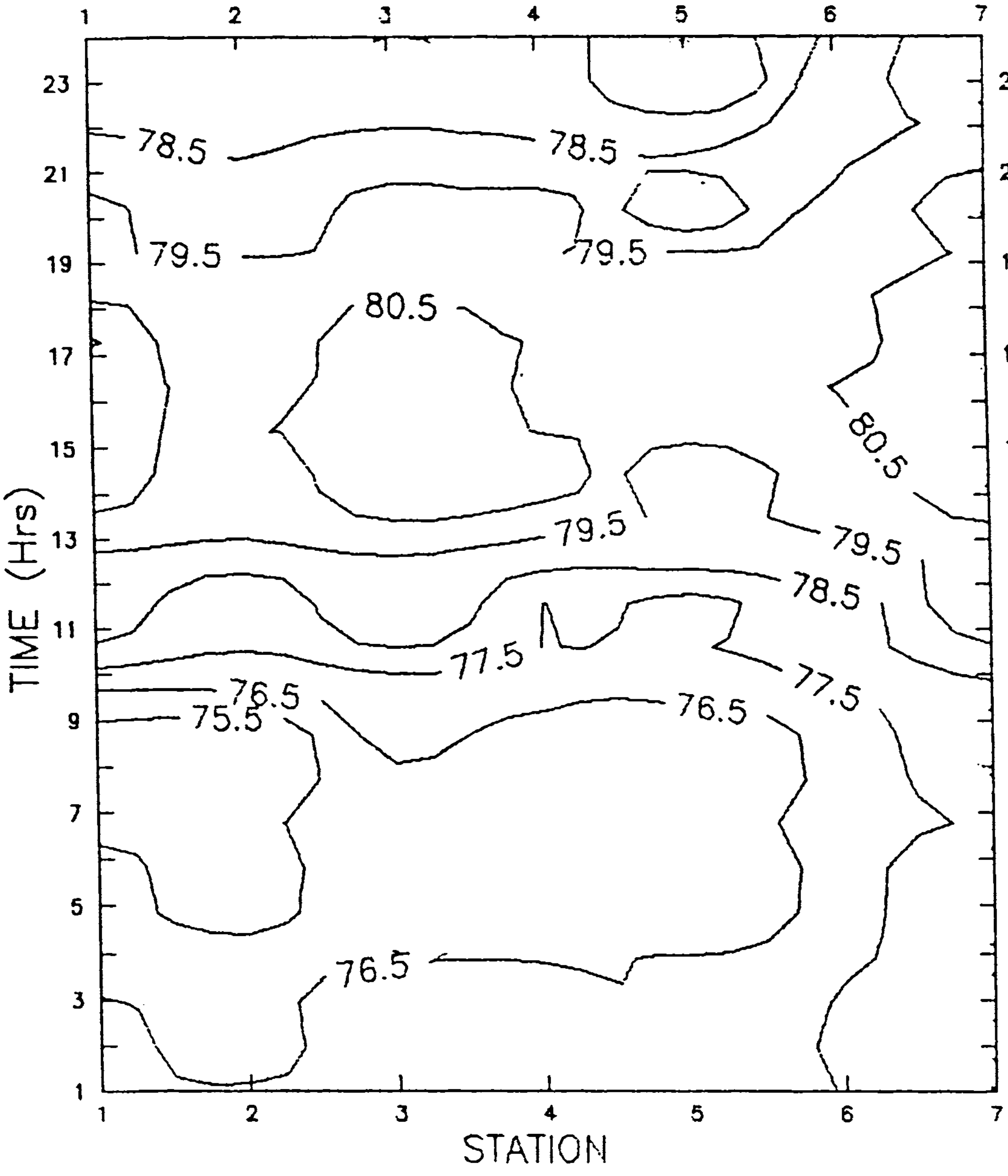


Fig. 7.4.2 Isolines of discomfort index for different stations in and around Cochin

1. ELOOR 2. KALAMASSERY 3. KALOOR
4. ERNAKULAM (SOUTH) 5. AMBALAMUGHAL
6. TRIPUNITHURA 7. PALLURUTHY

It becomes uncomfortable by about 1300 hrs and remains uncomfortable till 2000 hrs. ernakulam south is actually the centre part of the city. Ambalamughal area which is an industrial area is most comfortable from 2200 hrs till around 0800 hrs . It becomes an area of poor comfort during the rest of the day. In the case of Tripunithura, poor comfort exists for most of the time.

7.5 Incidence of Fog

Fog is essentially a cloud that forms at and close to the ground. It can be defined as the cloud that envelops the observer on the ground and is sufficiently tends to reduce the horizontal visibility to 1 km or less. If in similar circumstances , the visibility exceeds 1 Km it is called mist.

The presence of adequate moisture and condensation particles in the atmospheric layers close to the ground and cooling of the air are the basic requirements for the occurrence of fog. The cooling of air often occurs from contact with the surface of the earth. Typical of this is what is known as radiation fog. When wind is nearly calm and the sky is clear at night , the ground cools by radiation and this cooling is transmitted to the adjacent air layers. If there is enough moisture in the surface air fog may set in close to the ground and progressively extent upwards. Under such conditions there is often what is known as an "inversion" in the lower atmosphere.

The inversion acts as a lid which prevents vertical air motion and effectively trap the aerosols in the lower layers. In the highly polluted industrial areas such a situation gives rise to what is known as "smog " (a mixture of smoke and fog) which can produce serious respiratory ailments.

Fog can also occur when cold air streams over a warm water surface. This is known as steam fog. It occurs close to the water surface gradually extending upwards under favourable conditions. Sometimes one can notice for when light rain is falling. In this case the raindrops are slightly warmer than the air and the water vapour evaporated from the raindrop begins to condense on the nuclei present in the lower layers. This is known as rainfog. Another situation in which fog occurs is when warm air from the sea close over cold land surface. This is known as advection fog. Often two or more causes operate simultaneously in the fog formation.

At Cochin one can notice under favourable conditions most of the above types of fog. The land and sea breezes have a role in the occurrences of fog at Cochin . The sea breeze from the west brings in clear moist air in the afternoons and evenings. The land breeze which set as a feeble current around midnight is from the east or northeast, where many of the industries are located. Hence in general the aerosol contents of the lower atmosphere will be more in the early mornings which is a condition favourable for the occurrence of fog. The increasing air pollution associated with growing industrialization and urbanization is an important factor for fog formation.

To understand the fog formation it is important to know the vertical variation of temperature. Normally air temperature decreases with the height in the lower level of atmosphere. The situation when temperature increases with height is known as inversion. The base of inversion , the intensity of inversion and the thickness of inversion layer are of much important in determining the vertical mixing of surface air. Several study have been carried out on the frequency of occurrence of inversion for different region by various workers. Padmanabha Murthy and Mandal (1980) have studied the frequency of inversions for Delhi and Visakhapatanam. Viswanatham (1980) has studied the frequency of ground based and elevated inversions for the four metropolitan cities in India for a five year period on a seasonal basis. The percent frequency of ground based and elevated inversion and isothermals for each month are studied for the period between 1973 to 1982 for Cochin by Anilkumar (1986).

An attempt has made in the present study to find out the reasons for the occurrance of fog over Cochin. The data recorded about fog is collected from airport meteorological observatory at Cochin. This include the hourly surface temperature and dew point temperature, the temperature at different levels. Number of occurrences of fog in each month for a period of five years is also collected.

The frequency of occurrence of fog in each month and in each year is shown in Table 7.5.1 The frequency of occurrence of fog vary from year to year. The lowest frequency was observed in the year 1990 (6) and the highest in the 1991 (13) . The distribution of fog in various months shows that the month November has invariably recorded the occurrence of fog. On the other hand the months July and August has not reported fog during the five years considered. The frequency of occurrence is maximum in November followed by October and January - February. The frequency of occurrence is minimum in July and August followed by April and May . Altogether 45 days reported fog during the period.

A study of surface winds on days with fog and without fog is carried out. It is found that the surface winds during the previous day evening hours of fogy days are mostly from west or westnorthwest directions. On the other hand, during non-fogy days, the directions of winds in the evening are mostly from northnorthwest or north directions. When the winds are from the west or westnorthwest directions, the moisture incursion over the land will be higher. This is because air reaching the land is travelling more time over ocean and therefore the moisture content will be higher. If these winds continues to blow for more time in the evening hours it causes for the decrease in night

Table 7.5.1 Frequency of occurance of fog

Month/year	1989	1990	1991	1992	1993	total
January	4		1			5
February		1		4		5
March				4		4
April			1			1
May	1					1
June	1		3			4
July						0
August						0
September			2		2	4
October	1	1		1	3	6
November	2	3	4	1	1	11
December		1	2		1	4
Total	9	6	13	10	7	45

temperature and makes the atmosphere more stable. This in turn causes for low mixing height which can favour for the formation of fog by condensation of water vapour on the dust particles. Which are plenty at ground level in this fast developing city. When the wind directions are north or northnorthwest, the winds reaching land travel comparatively lesser time over sea, therefore the moisture incursion is not very high.

A comparative study of mixing heights during days with fog and without fog have showed that mixing height alone have not much to play with the occurrence of fog. Days with fog always showed very low or nearly zero mixing height values during previous night hours, on the other hand all nights with very small mixing heights do not cause for fog in the succeeding mornings.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The overall quality of urban environment has deteriorated over the years with larger cities reaching saturation points and unable to cope with the increasing pressure on their infrastructure. In built-up areas, the effect of complex geometry of the surface, shape and orientation of individual buildings, their particular thermal and hydrological properties, roads and other urban factors, the heat from metabolism and various combustion processes taking place in the cities, the pollutants released into air, water, and land all combined, create a climate which is quite distinct from that of rural or suburban areas. The present thesis deals with a detailed study of the meteorological aspects of urban environment of Cochin, a fast developing industrial city.

The objectives of the present study include an appraisal of the meteorological features over the city to provide the basic climatological information for practical applications. The investigation also envisages an analysis of meteorological aspects of air pollution through the use of a appropriate Gaussian model. Through this approach, the spatial distribution of air pollutant concentration is projected. Another aspect which is envisaged in the study is the spatial and temporal variation of human comfort indices. Other important environmental aspects such as the incidents of fog, occurrence of land and sea breezes and chemical analysis of rain water to check for the occurrence of acid rain are other areas under purview of this study.

A review of the literature shows the necessity for the study of both meteorology and environmental aspects together. A detailed analysis of the various surface meteorological parameters shows that April is the hottest month and January is the coldest month. The maximum surface pressure is recorded in January and the minimum pressure in May. In the case of RH, the maximum is observed in July and the minimum is in December. Harmonic analysis of surface parameters shows that in the case of temperature, annual as well as semi-annual oscillations dominate in the seasonal cycle and both diurnal and semi-diurnal oscillations dominate in the diurnal cycle. Annual and semi-annual oscillations also dominate for pressure with maximum amplitude occurring in December - January for annual oscillations and February - March and August - September for semi-annual oscillations. RH shows annual as well as triannual oscillations in the seasonal cycle with maximum amplitude occurring in August for annual oscillation and March, July and November for triannual oscillations. RH shows diurnal as well as semi-diurnal cycle.

The vertical time-sections of temperature and specific humidity during pre-onset, onset, break and withdrawal phases of summer monsoon are studied in order to investigate the relationship with the prevailing weather conditions at the surface. Temperature at different levels in the lower atmosphere is observed maximum during pre-onset month (May). The temperature pattern shows a drastic reduction with the commencement of the monsoon. Another notable feature is the presence of more thermally stable atmospheric boundary layer in May compared to June.

A study of liquid water content at various levels in the atmosphere shows that the transport of moisture is not confined to any particular level in the atmosphere. The maximum moisture level in the atmosphere is not generally reached on the date of onset of monsoon. It is attained prior to the onset. There is no marked build up of precipitable water in the atmosphere with the advance of monsoon. The moisture content of the atmosphere decreases with height. Least moisture content is in January at all levels and maximum in May. The yearly variation of precipitable water content is small.

Atmospheric stability is an important factor which affects the dispersion of air pollutants. The results of the present study shows highly stable conditions during night hours and unstable conditions during day time is the common feature in the four different seasons. The neutral conditions are more frequent in July, which is the peak monsoon season with overcast skies and high wind speeds occasionally. The highly unstable conditions are observed maximum during the noon hours in the winter season followed by summer, northeast monsoon and monsoon seasons. The highly stable conditions do not allow air pollutants to get dispersed their by resulting in higher concentrations.

The spatial distribution of the twenty four hour SO_2 concentration for different seasons shows that the maximum concentration is always recorded near the source region. There is no single direction in which the spread is very prominent. However, a slight spread towards south or southeast is noticed. A rapid reduction in concentration from the center of maximum is noted in all the seasons. The variation in mixing height does not seem to be contributing more to the difference in concentration. On the other hand wind appears to have a more control in determining the spatial concentration . The concentration observed south of the central parts of the city are comparatively low. But the values are found increasing towards the northern parts of the city. It is often greater than the permissible limits suggested by the Indian standards. Therefore the present trend of expansion of the city mostly towards the northern direction must be considered very seriously.

As far as the locations of the existing industries are concerned, the ideal place would have been the extreme southeast portions of the city so that the city interior and all the densely populated areas would be relatively free from pollution. In such a case most of the spread of the pollutants is over the ocean. In the present situation any newly coming industries can be located towards the far south of the city or far east of the city. This helps the interior of the city for no further increase in the concentration levels.

Frequent occurrence of fog, formerly an unseen phenomena, in Cochin clearly shows the increasing levels of atmospheric pollution. It is time care is taken to purify emission from factories, automobiles and even curbing industrial emission at night hours.

It is expected that the various results mentioned above would be of help to the planners entrusted with the overall development of this city. Only with scientific approach, especially in his understanding of climatic theory, man will have the increasing possibility of controlling his environment. Only then will he be able to use, the atmosphere for the good of all mankind.

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ANNEXURE

Monthly mean values of surface meteorological parameters for Cochin
Source IMD 1931-1960

Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pressure (mb)	0830 hrs	1012.9	1012.4	1011.5	1010.3	1008.8	1009.2	1009.7	1009.9	1010.7	1011.1	1011.6	1012.5	1010.9
	1730 hrs	1008.9	1006.3	1007.5	1006.3	1006.0	1007.0	1007.6	1007.4	1007.7	1007.9	1008.4	1008.9	1007.7
Temperature (° C)	Max.	30.6	30.7	31.3	31.4	30.9	29.0	28.1	28.1	28.3	29.2	29.8	30.3	29.8
	Min.	23.2	24.3	25.8	26.0	25.7	24.1	23.7	24.0	24.2	24.2	24.1	23.5	24.4
Humidity (%)	0830 hrs	66.0	72.0	74.0	75.0	81.0	88.0	89.0	88.0	84.0	83.0	78.0	71.0	79.0
	1730 hrs	64.0	68.0	70.0	74.0	78.0	84.0	87.0	86.0	84.0	80.0	74.0	66.0	76.0
Wind speed (Km.p.h)		8.0	9.3	10.6	10.7	10.9	9.1	9.6	9.9	9.1	7.8	6.7	7.1	9.1
Rainfall (mm)		9.6	30.2	50.0	139.5	364.3	755.9	571.9	385.7	234.8	332.7	183.7	36.8	3099.1

Annexure A.

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NOTES AND NEWS

NATURE OF THE RAIN SPECTRUM AT A LOW LATITUDE COASTAL STATION

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The internal structure of rain falls in terms of rain rate during various instances of time can be determined by measuring rain amounts received during very short intervals of time. A system that can record the intensity of rain fall at every minute has been used for this study.

The rain gauge used for this study consists of a sensor, an electronic system, and a recorder. It directly records minute to minute intensity of rainfall in mm/hr. It also provides separate marks for every millimeter of rainfall. This is achieved by converting the rain water received at the collector into drops of exactly equal size and counting them with optical electronics. The total number of drops received at any interval of time gives the intensity of rainfall during that duration. The counts are then converted into voltages and recorded (Venugopal and Radhakrishnan, 1976).

In principle, rain water falling into the funnel of the drop-forming unit displaces the same amount of water from the cylindrical vessel and emerges through nozzle in the form of drops. The diameter of the nozzle determines the size of the drop and, this in turn, determines the number of drops for every millimeter of rainfall received. As each drop falls, a current pulse is produced that is fed into an electronic counter. The instrument is designed to give intensity. The counter is reset every minute by the controlled pulse. In addition to intensity, total rainfall during any interval of time is registered by counting the pulses. Every 120 drops correspond to 1 mm of rainfall.

The station at Cochin, India (8°59'N, 76°E) experiences a comparatively high intensities of rainfall (Rajan, 1988). Thus, for study purposes, the maximum recordable intensity range used was 120 mm/hr.

The rain spectra at the stations were analyzed for four years by observing the intensity per minute of the rainfall. A total of 16,000 minutes of rainfall were analyzed. Of these, 13,900 minutes correspond to the south-west monsoon season, 870 minutes to the post-monsoon season, 180 minutes to the summer months (March, April), and 150 minutes to the winter months (December, January).

Of the total rain recorded during the south-west monsoon season 38% of the samples were during August, 32% during July, 16% during June and 14% during September. In the summer months, 64% during March and the remaining during April. In the post-monsoon months, 52% were during October and the remaining during November.

The minute intensity rainfall measurements were grouped into categories, for example, <2 mm/hr, 2-5 mm/hr, 5-10 mm/hr, 45-50 mm/hr, 50-60 mm/hr and up to >120 mm/hr. Using these data, frequency table was prepared (Table I).

Table I: Average frequencies of rainfall intensities at Cochin, Indian for four years.

Frequency (mm/hr)	Month									
	Mar.	Apr.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
<2	6	8	227	1044	1176	398	142	43	-	-
02-5	11	10	433	925	1072	376	92	47	2	3
05-10	32	13	505	848	1058	375	74	100	1	18
10-15	12	14	252	473	685	315	41	58	-	11
15-20	9	8	252	307	360	94	24	34	-	7
20-25	17	8	120	218	227	85	19	25	-	10
25-30	10	2	157	179	174	66	26	16	-	9
30-35	5	1	62	103	101	70	7	27	-	-
35-40	3	-	66	69	106	39	4	18	-	10
40-45	8	-	29	60	52	45	6	8	1	10
45-50	1	1	37	58	49	27	3	9	1	20
50-60	-	-	57	46	73	19	6	18	-	11
60-70	-	-	33	33	47	20	3	9	3	29
70-80	-	-	19	27	34	9	7	5	-	-
80-90	-	-	9	15	16	4	-	-	-	-
90-100	-	-	4	2	8	4	1	-	-	-
100-120	-	-	8	8	5	1	-	-	-	-
>120	-	-	9	8	6	-	-	-	-	-

Of the samples during the south-west monsoon season, 21% had an intensity of < 2 mm/hr; July had the highest frequency of 24% while June had the lowest of 10%. The seasonal frequency was 12% with intensity values between 10 and 15 mm/hr. September recorded the highest frequency (16%) and July the lowest (11%). With high intensity rainfall, the frequency was found to be 1% for rain intensities of 50 to 60 mm/hr. This range of intensity was highest for June (3%) and lowest for September (<1%). Occasionally, there were rain intensities >120 mm/hr during June, July and August.

During the summer there was no high intensity rainfall, only 35 mm/hr was observed. The post-monsson months were similar, with high intensity rainfall. For intensities of <2 mm/hr, the frequency was 21%. November had the highest frequency rate (31%). High intensity rain spells, up to 880 mm/hr, were also recorded during these months.

The study has shown that, in general, rainfall is low intensities. But, during the south-west monsoon season, rainfall having an intensity of <2 mm/hr constitutes nearly 2% of the total rainfall in that season. Most of the rains at that time have intensities between 5 and 10 mm/hr and 10-15 mm/hr, 12% each. During the south-west monsoon, August provides 35% of the total rainfall with 14% occurring in the range of 10-15 mm/hr. In other seasons, a similar distribution can be seen, but it is more consistent in the south-west monsoon time. High intensity rainfall is present during the monsoon months. These results provide an overall idea of how intense the rainfall is in each season and in each month. Detailed analyses will help in land use planning provided the run-off values, are known.

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Annexure - B.

551.590.22 : 551.577.37

Effect of lunar cycle on rainfall

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सार — केरल के तीन पश्चिमी तटीय केंद्रों के दक्षिण-पश्चिम मानसून अवधि की वर्षा के 1931 के आगे के 50 साल के आंकड़ों का विश्लेषण किया गया। उक्त अवधि को दो भागों में बांटा गया है। पहले भाग में अपेक्षाकृत अधिक वर्षा अर्थात् जून-जुलाई में हुई वर्षा के आंकड़े हैं और दूसरे भाग में अपेक्षाकृत कम वर्षा अर्थात् अगस्त-सितम्बर में हुई वर्षा के आंकड़े हैं। इस अध्ययन के लिए केवल >6.25 सें० मी० प्रति दिन की वर्षा मात्रा वाले वर्षा दिवसों का उपयोग किया गया है। चंद्र चक्र में 29.53 दिन हैं और उसे दस अवस्थाओं में बांटा गया है। प्रत्येक अवस्था में लगभग तीन दिन हैं। सौर सक्रियता के प्रभाव पर विचार करने के लिए अवधि को सक्रिय और निश्चेष्ट सूर्य प्रक्रिया में विभाजित किया गया है। अवधि का यह विभाजन उन वर्षों के निर्धारण से किया गया जिनमें क्रमशः सूर्य धब्बों की संख्या उच्च चतुर्थक से अधिक रही और जिनमें सूर्यधब्बों की संख्या निम्न चतुर्थक से कम रही। आंकड़ों का विश्लेषण χ^2 परीक्षण के उपयोग से किया गया। इससे सिद्धांत और वास्तविक प्रेक्षण के बीच असंगता की मात्रा का पता चलता है।

विश्लेषण से ज्ञात हुआ कि भारी वर्षा और चंद्र चक्र के बीच कुछ सार्थक सांख्यिकीय संबंध है। सक्रिय सूर्य प्रक्रिया अवधि में प्रभाव अधिक सार्थक होता है जिससे सौर सक्रियता के प्रभाव का भी पता चलता है।

ABSTRACT. Rainfall data for a period of 50 years from 1931 onwards have been analysed for three west coast stations in Kerala for the southwest monsoon period. The period is divided into two halves, the first half, *i.e.*, June-July, providing comparatively more rainfall and the second half, *i.e.*, August-September, providing comparatively lesser rainfall. Rainy days, having rain amounts >6.25 cm/day, have only been utilised for this study. The lunar cycle, which is having 29.53 days, is divided into ten phases, each phase constituting of around three days. To consider the effect of solar activity, the period is divided into active and quiet sun by considering those years with sunspot number greater than the upper quartile and those with sunspot number less than the lower quartile respectively. The data were analysed using χ^2 test. It describes the magnitude of the discrepancy between theory and observation.

Analysis has shown that there is some statistical significance between heavy rainfall and lunar cycle. The effect is more significant in active sun period which shows the effect of solar activity also.

Key words — Lunar cycle, Sunspot number, Rainfall, Quiet sun, Active sun.

1. Introduction

In recent years some workers have carried out studies on rainfall in relation to lunar activities. Manchly (1954) found a significant tendency for a reduction in rainfall on approximately 2 to 3 days prior to new moon. Adderley and Bowen (1962) and Bradley *et al.* (1962) found a marked tendency for extreme precipitation to occur near the middle of the first and third week of synodic month, especially on the third to fifth days after the new and full moon. Visagre (1966), from studies of the winter rain in South Africa, inferred that the winter rain is modulated by the moon. He found a reduced solar influence and increased lunar influence in the winter rains which is not of a convective nature. He also found that only the first and third harmonics of the lunar daily variation in rainfall at South African stations were significant. Berson and Deacon (1965), while analysing the effect of lunar cycle in rainfall, found that the effect is only during the months of heavy rainfall and that only when the sunspot number is below the median value. Only tentative conclusions could be drawn from their studies. The controversial nature of the results of studies has led to the present work.

Here, three coastal stations, namely, Thiruvananthapuram, Cochin and Calicut having heavy rainfall during southwest monsoon season were selected for the present study. These stations are along the west coast of Kerala. Rainfall data of these stations were collected for a period of 50 years.

2. Data and analysis

The daily rainfall data of Thiruvananthapuram, Cochin and Calicut were collected from Indian Daily Weather Report (IDWR) for 50 years from 1931-50 and 1961-89. Useful indications might

TABLE 1

Frequencies of rainy days with rainfall exceeding 6.25 cm/day in ten divisions of lunar synodic period (1931-1950, 1961-1989) for Kerala

	Phase in lunar synodic decimals												
od	1	2	3	4	5	6	7	8	9	10	Total	χ^2	P
							Jun-Jul						
ct sun	19	15	17	23	16	17	7	11	13	13	157	14.78	0.098
ive sun	14	12	9	9	10	11	9	11	7	6	98	5.06	0.826
years	33	27	26	32	33	27	16	22	20	19	255	13.12	0.164
							Aug-Sep						
ct sun	13	8	7	3	2	3	2	6	5	7	56	18.64	0.031
ive sun	—	—	3	2	—	8	5	3	3	7	31	23.52	0.007
years	13	8	10	5	2	11	7	9	8	14	87	13.34	0.16

TABLE 2

Values of rainfall exceeding 6.25 cm/day for active (A) and quiet (Q) sun period for Cochin

	Q						A		
hases	31	32	33	34	43	44	47	48	49
1	108.8	58.4	—	116.45	69.4	—	90.7	67.8	—
2	—	—	—	—	62.0	90.2	—	67.1	—
3	81.8	—	124.0	111.8	78.5	—	—	66.8	68.8
4	100.3	—	100.5	—	322.5	—	75.7	154.9	78.2
5	67.55	—	—	70.1	113.2	103.9	—	75.7	—
6	—	80.5	—	—	64.3	—	—	63.8	—
7	70.4	—	—	—	—	—	—	—	79.25
8	69.2	—	—	—	—	—	81.48	66.8	—
9	82.6	—	—	71.9	—	—	62.7	108.7	65.0
10	—	87.6	87.1	117.1	—	—	128.5	—	—

nerge only if the rainfall of these stations are high. uthwest monsoon season has been selected as it ovides more than 80% of the annual rainfall.

This season has also been divided into two alves; first half providing more rainfall, *i.e.*, June-ily and the second half providing comparatively ss rainfall, *i.e.*, August-September. Only rainfall amounts greater than or equal to 6.25 cm are considered. To find the effect of lunar cycle on rainfall, the lunar cycle which is having 29.53 days is divided into ten phases, each constituting of around three days. The full moon comes between phases 5 and 6 and the new moon between 10 and 1. Ananthakrishnan and Parthasarathy (1984) have found that there is some association between sunspot cycle and

TABLE 3

Percentage deviation of heavy rainfall from mean

Phases	Mean Q	Mean A	% deviation from mean	
			Q	A
1	88.26	79.25	−3.33	−3.03
2	76.1	67.1	−16.65	−17.9
3	99.03	67.8	−8.47	−17.04
4	174.4	102.93	91.1	25.94
5	88.69	75.7	−2.86	−7.38
6	72.4	63.8	−20.7	−21.94
7	70.4	79.25	−22.89	−3.03
8	69.2	74.14	−24.21	−9.29
9	77.25	78.8	−15.39	−3.59
10	97.27	128.5	6.54	57.23

Indian rainfall. To incorporate this idea also, the effect of solar activity in the strength of lunar cycle variations was taken into account. For this we separated the study period into years of greatest and least solar activity. In the present study the data were divided into two parts. One part (denoted active sun) was for years of sunspot relative number greater than the upper quartile and the second part (denoted quiet sun) was for years of sunspot relative number less than the lower quartile.

3. Results and discussion

To gain some idea of the statistical significance of the variations of heavy rainfall in the lunar cycle, the frequencies of occurrence were studied. For this, number of rainy days with rainfall amount greater than or equal to 6.25 cm have been tabulated against each phase of lunar cycle for Kerala coast in Table 1. Values of rainfall exceeding 6.25 cm/day for active (A) and quiet (Q) sun period for Cochin are given in Table 2.

In Table 3, percentage deviation of heavy rainfall from mean is calculated separately for active and quiet sun period. It showed two maxima both in active and quiet sun period, one before the full moon and another in the new moon phase. With a well-marked one in the new moon phase in active sun period and two phases before the full moon in quiet sun period.

From the frequencies given in Table 1 the values of χ^2 for departure from uniformity were calculated. It is one of the simplest and most widely used non-parametric tests in statistical work. It describes the magnitude of discrepancy between theory and observation. The values of significance level P for each value of χ^2 is found out from standard tables. These are appropriate if effects of persistence may be neglected.

For June-July, under quiet sun only, the hypothesis of random distribution of heavy rainfall over the different phases of the moon is contradicted at 10% level, suggesting some influence of the lunar cycle on rainfall. For August-September, under quiet sun, the hypothesis of random distribution of heavy rainfall over the different phases of the moon is contradicted at 5% level, indicating influence of the lunar cycle on rainfall. However, for August-September under active sun, reliable inference cannot be drawn from the computed Chi-square value in view of the small cell frequency (3.1) on the basis of the hypothesis of random distribution.

4. Conclusions

On the basis of the data of a few coastal stations in Kerala, it becomes possible to conclude tentatively that there is some effect of lunar cycle on rainfall over coastal Kerala under quiet sun conditions.

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