ANALYSIS OF HYDROMETEOROLOGICAL DATA

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree of

MASTER OF HYDROLOGY

By

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Candidate's Declaration

I, hereby certify that the work, which is being presented in this dissertation entitled "Analysis of Hydrometeorological Data", in partial fulfilment of the requirement for award of the Degree of Master of Hydrology, is an authentic record of work carried out during the period from July 10, 1996 to June 20, 1997 under the supervision of Dr. N.K. Goel, Associate Professor, Department of Hydrology, University of Roorkee, Roorkee and Sri Hemant Chaudhary, Scientist, 'C', National Institute of Hydrology, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Dated: 24, JUNE, 1997

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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A C K N O W L E D G E M E N T

I, Ashok Kumar Dwivedi, Trainee Officer (P/T) at Department of Hydrology, University of Roorkee, Roorkee, permitted as part time candidate from National Institute of Hydrology, Jalvigyan Bhawan Roorkee, Roorkee, find myself highly indebted to the Institute and the Department of Hydrology. I express my sincere gratitude to Dr. N.K. Goel, Associate Professor, Department of Hydrology, University of Roorkee and Sri Hemant Chaudhary, Scientist 'C' for their continued guidance, cooperation, and encouragement to enable me to successfully produce this meaningful culmination as a part of the assignment for award of degree 'Master of Hydrology'.

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SYNOPSIS

The topic 'Analysis of Hydrometeorological Data', is very wide topic, covers lot of concepts, theories, limits of applicability and approaches. General introduction of traditional and modern data collection methods and equipments, merits and demerits, pre-processing, processing, storage and retrieval etc. are outlined in the thesis. As the data for the present study was obtained from one of the many sensors of Automated Hydrologic Station (AHS), installed at National Institute of Hydrology, Roorkee, a brief introduction of the station and its associated sensors has been provided. Various steps of processing of AHS data have been described along with few sample sheets as output.

Analysis of air temperature data has been attempted with statistical summaries, probabilistic modelling, tests of randomness and ARIMA modelling etc. An interactive software, has been developed in **FORTRAN** as part of the present assignment. This has been used of medelling short interval hourly air temperature data. For this purpose hourly data of temperature for the month of January (1990) was used.

The listing of the programme is provided in **Annexure-I**. Various tables containing data, analysis and modelling results and also the figures containing histogram, scatter plot, autocorrelogram, partial autocorrelogram and spectral density are provided in **Annexure-II**. Similar exercises may be tried for other months or other hydrometeorological data sets with little modification in the software as per needs.

C O N T E N T S

CHAPTER-3 AUTOMATED HYDROLOGIC STATION

CHAPTER-4 PROCESSING AND PRELIMINARY ANALYSIS OF AHS DATA

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CHAPTER - 1

INTRODUCTION

1.0 GENERAL

Hydrometeorology concerns with exchange processes of hydrologic cycle particularly with precipitation, evaporation and evapotranspiration, its time and space dependent historical events are recognized as important inputs for various hydrological studies. The planning, design and operation of water resources systems depend heavily on the inventory of the accurate and relevant data. This is very often time dependent and hence historical records are essential for any project study. As such, this envisage collection, processing and storage of data in order to obtain a long term picture of events (WMO,1971).

The analysis of hydrometeorlogical time series data is performed for any one or a combination of one or more of the following objectives:

- to separate a discrete time series(of time series less than a year) into periodic and stochastic components.

- to investigate whether the various parameters of time series are periodic or non periodic.

- to determine number of significant harmonics(amplitudes are significantly greater than for non periodic series) in periodic parameters.

- to analyze whether stochastic components are dependent or independent.

- for fitting of adequate mathematical dependence models and computing independent stochastic variables from dependent stochastic components.

- fitting probability distribution functions to independent stochastic components and selecting the function of best fit.

- for derivation of the structure as a final mathematical model of time series.

- to provide description of various biases in time series that influence both the structural analysis and the final models.

- selection of structural inference technique for an objective but practical structural analysis of time series.

- for eventual physical explanation of various structural properties of time series.

- for separation of mathematical models into deterministic and stochastic parts, with the parameters of deterministic components subject to sampling errors.

- for computation of explained variables of time series by various components and simulate enquiries.

1.1 OBJECTIVES

The present assignment has been undertaken with the following objectives:

- to process the recorded half hourly data of Automated Hydrologic Station (AHS) for each of the variables and to prepare statistical summaries on daily, monthly basis by developing necessary software in FORTRAN language.

- to study the characteristic features and relative deviations of daily mean temperature as calculated by considering 24 discrete hourly data and other by taking the standard conventional way of averaging the corresponding daily maximum and minimum values.

- to model time series of hourly temperature data through developing general interactive type of software in FORTRAN equipped with necessary graphic capabilities.

1.2 DATA USED

In the present work, the data of air temperature collected through Automated Hydrologic Station(AHS) of National Institute of Hydrology(NIH), Roorkee has been used.

1.3 ORGANISATION OF STUDY

Since analysis of any data proceeds with its collection and processing stage, these aspects are briefly dealt with in Chapter-2. For analysis, the data obtained from Automated Hydrologic Station has been used. Brief description of the AHS, its associated sensors and capabilities are described in Chapter-3. Processing and preliminary analysis of AHS data is given in Chapter-4. Time series modelling of short interval air temperature data is presented vide Chapter-5. This describes various statistical parameters and result of various models fitted and their relative competence in terms of AIC criteria.

Regression analysis of average ((Maximum+ minimum)/2.0) of hourly air temperature as independent variable was performed on average obtained from 24 discrete values as dependent variable. The result shows different deviations for different months of the year as evident from the tables and graphs. General purpose software for ARIMA modelling of time series is presented vide **Annexure-I**. Parameters of modelling and results of analysis are presented in the form of tables and graphs vide **Annexure-II**.

CHAPTER - 2

COLLECTION PROCESSING AND STORAGE OF DATA

2.0 INTRODUCTION

Water is precious resource for human life and culture. Though, the total amount of water on earth is generally assumed to have remained virtually constant in the recorded history, the useful water is becoming a scare resource due to rapid growth of population, together with extension of irrigated agriculture and industrial development. Various uses and demands are stressing the quantity and quality aspects of natural systems. As a result problems are increasing. The problem is not of global shortage of total water, but the challenge is to overcome the uneven distribution of water in space and time on land areas and to supply adequate quality to meet local needs. As a consequence, people have begun to realise that they can no longer follow the philosophy of 'use and discard', either for water or any other natural resource. Therefore the optimum planning and efficient management has become a necessary concern.

Water as a natural resource has been the limiting factor in the development of agriculture and most industries. A thorough understanding of availability and movement of water was realized as necessity for various rational developments and management strategies. A number of International agencies viz. World Weather Watch(**WWW**), World Meteorological Organization(**WMO**), United Nations Educational Scientific and Cultural Organization(**UNESCO**), Food and Agriculture Organization(**FAO**), realized the importance of assessment and management of this natural resource on global scale and launched various programs to expand the domain of information and studies. Data collection on various variables started as a routine practice. The objective of International Hydrology Programme (IHP) of UNESCO in 1977, also expanded not only to cover the hydrological processes and their interrelationship with the environment and human activities, but also the scientific aspects of multipurpose utilization and conversion of water resources to meet the needs of economic and social development. The requirement placed on technology is to supply, at an affordable cost, a dependable supply and quality of water, where and when it is needed. The approach to assessment, planning and management of water shifted perceptibly in multi-disciplinary side. But the report of **WMO/UNESCO (1991)** on Water Resources Assessment, indicated decline in the number of observing networks in some developing countries does not appear a healthy trend.

In water resources planning and management, it is important to know how much water is available and how best to use it. The hydrologic studies are based on modelling exercise and modelling is based on reasonable and representative data. Planning and management of resources need easily accessible, reliable data of comparatively sufficient length on various elements of the hydrological cycle and related factors **WMO (1974)**. The collection, processing and storage of such data is essential in order to obtain a long term picture of events **WMO (1971)**.

The Hydrometeorology is mainly concerned with exchange process in the hydrologic cycle, particularly with precipitation, evaporation and evapotranspiration. All three are measured inadequately by conventional methods for most present applications ranging from global scale to meso and even micro-scales (**UNESCO-1984**).

The advent of more detailed and varied investigations have led to the demand for frequent records of a wide range of variables.

These include hydrometeorological estimates on solar radiation, temperature, humidity and wind direction and speed and rates of evaporation and evapotranspiration for hydrological modelling and water resources studies. A total list, however, of hydrometeorological measurements for hydrological purposes would be large and is limited only by the need to know relevant information and the imagination of users to develop new methods of measurement. A survey of literatures viz. **Linsley et al. (1949), Wisler and Brater(1969), Brown(1975)**, and **Viessman et al.(1977), UNESCO (1984)** provide comprehensive list of common measurements for hydrological use. **Goyal(1996)** has stressed the need for intelligent data loggers and the use of artificial intelligence(**AI**) and expert system techniques to data acquisition systems and reduce data processing burden.

Appropriate techniques of acquisition(collection) and processing of data are more dependent upon the physical phenomenon and the desired engineering goals. In a wider sense, however, the required operation may be broadly divided into data collection and data processing. The details of which are given in the following sections.

2.1 DATA COLLECTION

Data are collected from several types of instruments in a variety of ways ranging from manual readings to recording on charts, tapes, disks, magnetic memories etc. Various methods- traditional as well as modern methods of collection of data, employing manual to sophisticated electronic, are in use. They collect all forms of analog, digital and image data from ground based observation platforms, balloons, aircraft, remotely piloted vehicles, rockets and satellites by making use of improved sensors, scanners, spectrometers and radars.

The point measurements are considered as representative of a large part of area. In a majority of cases, the point source measurements are sufficient. But, when areal estimates of variables are needed, a dense network of instruments and data manipulation is required.

2.1.1 Plan of Data Collection

Work of collection, if aimed on tentative terms of reference, must be completed within reasonable time. This depends on the nature of the processes and the phenomenon under investigation. In case the phenomenon is such that the conditions are changing quickly and frequently, the duration of the observations must be narrowed to such an extent that there is no possibility of a change affecting the data.

The plan of data collection should include the following:

i) Scope of desirable measurement parameter in relation to space and time and a number of variables. The collection may either be performed by taking into account the basis of the political and administrative divisions e.g. country, state, district, city, municipality, ward, circle or blocks OR economic divisions e.g. agriculture, animal husbandry, mining, manufacturing, trade, transport, communications, banking, professional, etc. OR the natural boundaries e.g. plains, mountains, plateaus, forests and coasts etc.

ii) Determination of unit also is very important. For correct statistical analysis of any problem, it is not enough that the facts are collected with maximum accuracy, but, it is also essential that the unit employed is appropriate. The mistake in selection of unit is more harmful than the mistakes in collection of data. If wrong units are taken either for collection or interpretation, the results are bound to be incorrect or misleading. The unit becomes more significant as number of analyst using the statistical tool are more than engaged in compiling the data.

2.1.2 Data Acquisition Techniques and Systems

The data acquisition and processing systems use various techniques, which make use of analog, hybrid or digital equipment. There are a number of options available. Analog equipments perform desired calculations by direct operation on electrical signals representing continuous time history records. General purpose analog can be programmed to solve differential equations using operational amplifiers, whereas special purpose analogue instruments can perform only limited types of operations e.g. a voltmeter or crystal filter wave analyzer. Digital equipments can perform desired calculations by numerical operations on discrete values representing either continuous or discrete time history records. Hybrid equipments include those devices, which employ both analog and digital operations in an effort to combine the more desired feature of both. The simplest form of data collection system consists of three blocks viz.

- a transducer or sensor
- signal conditioner
- data logger

Transducer converts the differential parameters such as air temperature, atmospheric pressure, humidity, wind speed and level of evaporimeter into electrical quantity such as voltage, current, resistance, inductance, frequency etc.

The Signal conditioner performs necessary amplification, attenuation, modulation, analog to digital conversion of the signal received from the transducer or sensor.

The data loggers perform necessary function of data collection and storage including those of primary data checks and some times conversion into necessary engineering units. Intelligent data loggers make use of their logic to perform preprogrammed and predetermined functions.

Data acquisition systems are equipped with output devices of varied type. Basically the devices can be divided into two types viz. analog and digital. Again the output devices can be of indicating type or recording type. The analog type include panel meter, oscilloscope etc., whereas the analog recording type devices are strip chart recorder, UV recorder, analog magnetic type recorder and laser recording type etc. The indicating type of digital output devices include the digital panel meters, electromagnetic counter etc. The digital output devices include printer, paper tape punch, magnetic tape recorder, cassette recorder, floppies, disks, compact disks etc.

2.1.3 Traditional Way of Data Collection

For a long time in past, the data is collected from manually-read stations. These are visited once, or sometimes twice a day at standard times. The observations are taken through a variety of instruments different in make, standard, accuracy, precision, frequency and methods of measurement. The units are managed in isolation and serve only limited objectives. Mostly, the observations are in the form of tables or charts, acquired from mechanical, standalone type recording or non-recording instruments. There are several merits and demerits associated with traditional way of collection of data.

MERITS

- the traditional instrumentation have been found worth for many operational projects. They do not require power, therefore, they are cost effective. Operation is simple and require a small training. Replacement of defective parts is easy and manageable from local markets. Malfunctioning of the equipments can be traced quickly.

- only a few measurements are taken, so simple and convenient to handle on long term basis.

- Records are available in hard copy form, which can be inspected and any kind of tempering deletion is easily identifiable.

- they provide basis for checking, verification, and quality control of data collected from modern equipments.

DEMERITS

- installation and maintenance is difficult and requires mechanical skill. They require frequent visits.

- precision, accuracy and frequency of measurement with these equipments is inadequate and therefore, the estimates are poor.

- the data suffers with systematic errors, which is difficult to differentiate from observation errors.

- collection is time consuming and sometimes become impossible especially from inaccessible, remote and difficult places; the cost of conversion, copying, up-gradation are difficult, and cumbersome and most of the instruments are designed to take measurements on single parameter only. Old instruments suffer with growing loss of sensitivity resulting with passage of time, extreme short lived events are missed due to poor response function of the conventional instruments. Some times the collection is in the form of charts, which are to be decoded before subjected to further use.

- any change either in units, form or formats required heavy input in terms of time and labour. Retrieval is difficult and could not be obtained at the time of need. Special requirement needs fresh exercise of data manipulation.

- calculations for interpolation is difficult and completed manually on the basis of experience of the person handling the data.

2.1.4 Modern Way of Data Collection

Developments in communication technology and computers have provided solid, cost effective and dependable hardware and software solutions to many conventional problems of data collection. They have enabled multiplicity of goals and alternatives in various disciplines of research and study. More precise, accurate, frequent and reliable data are now acquired through modern microprocessor Integrated Control and Logic Circuits with Solid State Memory chip based equipments. Modern developments have not only provided the means to collect information quickly, but provide easier and faster ways of processing and upkeep of these information in various forms, easy to retrieve for quick applications.

The modern way of data collection is done either by a single active or a single passive or combination of both type of sensors, physically or remotely connected with sophisticated electronic gadgets, named as data loggers or data acquisition systems. These instruments need power either through mains or battery. The power consumption is low and possess many qualities e.g. high reliability and tolerance towards a wide range of environmental conditions. There is less human interference and can perform pre-required and preset functions unattended for a long time. These are suitable for installation in difficult and remote areas. They are compatible to be connected through telephone lines with Data Collection Platforms(DCP) and via telemetry links to Satellites and other places of interest. They enable high rate of data transfer. In addition their use in data collection instruments and data transmission, they are amenable to on-site data processing and analysis **WMO(1986)**. Many modern data acquisition systems are in use for climatological, synoptic, hydrological and meteorological uses. World Weather Watch(WWW)has a global network of stations linked via Satellites and make useful data available on real time basis and issues real time forecasts for hazard warnings. This enables to interact, interdependent components in forefront of forecasting.

Modern data collection is performed through modern data loggers and data acquisition systems. The use of new logging devices means frequent observations. In particular, the automated weather stations(**AWS**) and automated hydrologic stations(**AHS**) provide records of the measurement variables at a frequency of even 5 minutes, thus making it possible to calculate improved estimates of evaporation and evapotranspiration than was possible using data collected only from manually-read stations. The modern data acquisition systems are designed to accept multiple data input signals, to process the data according to user defined functions, and to store and/ or output the data in a meaningful form to such devices such as memory-modules, printers, recorders or to other systems etc. They are efficient to be controlled, checked and operated for multitasking environments including those of graphical display in terms of histogram, tables or graphs with variable choices of axes. These systems comprise of three components- sensors, data collection (with quality control, data conversion, processing and storage media etc.), and data output including those of data transmission, if required.

These advances made the users possible to keep such records at number of locations for multiple uses of the same records in various forms including paper, cassette cartridge tapes or various kinds of other magnetic storage media like floppies, magnetic disks, integrated volatile and non volatile magnetic memories. Thus, it has become possible through networking to provide the data or information environment with multi-user, multimedia, multitasking facility. The modern data acquisition systems mainly consist of digital data logging equipments and, therefore, have several advantage over conventional analog type. The digital data logging equipment is preferred because of the following

MERITS

- no human error or no parallax error
- more reliability
- no loss or distortion of signals during their transmission from one location to other OR from one medium to other.
- compatibility of the output media with the computer

- availability of the compact storage media

- enable sharing of expensive peripherals

- enable automatic collection

- flexibility and programmability as per requirements

- help to display data on line, and provides tests of qualification of data and analysis

- interactive in duplex mode with online help

- backup with hardware diagnostic checks

DEMERITS

- manual observations are still needed into the network concepts, which may be utilized by the system to perform periodical quality checks

- the chances of data loss is high due to logger, battery or sensor failure. Periodic frequent visits are needed to check and change the sensors and faulty items.

- any part, sensor, clock or logic may go wrong any time and the data would suffer with systematic bias. The system will not be able to differentiate from its logic provided. Periodic calibration become the ultimate solution to tackle such problems.

- operation, maintenance and vast data handling need high order of professional excellence.

- new technologies are not available to developing countries at affordable prices. Lack of high level skills, necessary spares and equipment make more difficult to sustain them.

- main draw back of such systems are that any omission and mistakes, however small, they are prone to be multiplied and enhanced.

- it needs attention to ensure against possible losses or corruption due to spurious signals.

2.1.5 Indian Scenario

In India, still traditional means of collection of data is prevalent. These are collected by a number of organizations viz. State Govt. and Semi Govt. agencies and Autonomous bodies like irrigation, revenue, Academic Institutions etc., Central Govt. organizations like Central Water Commission(**CWC**), Central Ground Water Board(**CGWB**), India Meteorological Department(**IMD**), Soil Water Conservation Division(**SWCD**) of Ministry of Agriculture, Railway, Defence, Aviation, Undertakings etc. and other research and project bodies. Essential instruments for normal observatories are given in detail in **WMO(1983)**. Existing observational network of IMD is provided by **Lal et al.(1993)**. There are as many as 15,972 hydrographic stations and 558 surface water, 35 radiosonde, 34 Radio wind, 62 pilot balloon as upper airborne, in addition to upper air temperature, pressure wind and humidity are being managed by various Indian agencies like CWC, CGWB and IMD. A total of nearly 223 Agromet stations measuring soil temperature, dew, radiation, evaporation and grass minimum temperature, 35 evapotranspiration and 52 soil temperature measurement stations are being managed by the agriculture department. There are nearly 600

Hydromet, 76 aeronautical 57 seismological, 45 radiation and 15 x-band radar, 3 cm wave length radar and 105 other band radars are operational for warning and hazard operation. Satellite data are collected from 7 different stations. There is one data utilisation centre also operating at IMD. There are altogether 100 DCP centres and 221 maritime and various Portmet stations collecting data on hydrometeorological parameters. **Goyal(1996)** has mentioned about the study specific and site specific data collection is additionally done by a number of other organisations e.g. Brahmaputra Board, Water and Power Consultant Organisations(**WAPCOS**), National Water Development Agency(**NWDA**), Narmada Control Authority(**NCA**), Snow and Avalanche study Establishment of Defence (**SASE**) etc.

2.2 DATA PROCESSING

Data processing constitute an important component of any analysis. The problem in designing a data processing system or routine is the variety of instrumentation used. Some instruments e.g. rain gauge etc. record one single variable while others e.g. weather stations record several different variables, some record on a set time basis while others are read manually at variable time intervals. Some instruments such as neutron probes, record several values of the same variable at the same location. In some cases, instruments that measure the same variable that record on different media, and different preprocessing routines are required to bring the data on common format.

Data processing means transformation of the raw data into such forms that enable users ready manipulation and efficient storage. Data typically enter the system via key punching of manuscript records, by mechanical conversion of analogue records, or in a digital form. Raw data are commonly compressed or reformatted into their most usable forms, and they should be subjected to a variety of quality checks at appropriate stages. Regardless of the type of data being processed or the path its processing takes, basic requirement is to maintain standard of operation that will not degrade the quality of the data **WMO(1994)**. Various references may be cited contributing towards quality control methodology for the data that are needed for hydrologic application e.g. **Allen(1972) outlining the quality control procedures**, measurement errors and various errors are described in **WMO(1968)**, and the checks of the series by Autocorrelation is given in **WMO(1970)**, **Creutin and Obled(1982)** have given orthogonal polynomial procedures, **Collier(1980)** indicated the use of radar for checking of the precipitation data. **Swedish Meteorological Office(1980)** used a simple statistical formula for checking doubtful values of the precipitation. **Bissell(1981)** has described detail screening techniques for telemetered data qualification checks.

The essential features of processing of any data include data preparation, data entry, validation, primary processing database updating, secondary processing, retrieval and output, the details of which is given below:

Processing may be manual or computerized. The main objectives being i) to evaluate the data for its accuracy and ii) to prepare the data in a form appropriate for subsequent analysis. Manual processing is prone to various limitations and errors, whereas computerized processing is fast and has several advantages over the manual processing.

Measurement variable has to be converted into more commonly used forms and formats before it can be used in hydrological investigations. As more and more data are collected from a variety of instruments, methods, form and formats, where a large number of manipulations are required and each data type needs separate and specific quality treatment to minimize instrumental and observer errors, it becomes essential to quickly modify, standardize, store and transfer them to permanent files for their future use. Most of the quality control and conversion routines require standard values, derived for each individual instrument. These values must be readily accessible on the computer in order that those routines may be carried out. The steps involved to bring the data in convenient useful form are associated with collection, processing and storage and become an integral part of data analysis.

2.2.1 Data Preparation

Data preparation of raw data is essential before analysis. The raw data is usually supplied on the tape recorder or strip chart recorder in the form of voltage time history. A number of operation are required after its collection to make time history suitable for analysis. This part includes preparation of data file through data punching of the transcription, field records, entries, non standard data formats including coding, reduction and standardization. In Analog data processing, the data preparation usually includes only conversion into engineering units and perhaps the formation of the type loops to permit the data to be recirculated for continuous display to an analog analyzer. In case of Digital Data Processing, a number of additional steps are required in data preparation phase. These digital data preparation procedure may be classified as digitizing procedures and processing procedures. Digitisation is a procedure of further codings. This consists of two separate and distinct operations

- sampling and
- quantification,

where sampling is the process of finding the instantaneous points at which the data are to be observed, while quantisation is the conversion of data values at the sampling points into numerical form.

2.2.2 Data Entry

This part means data keying directly through **VDU's** (Visual Display) etc. or imputing charts and maps into raster form through digitizer, or accessing through tapes discs, solid state memory devices, optical readers and through communication lines. Some times the data recorded in the analog form is to be converted into digital form. This comes under the sampling procedures. This for digital data analysis is usually performed at equally spaced intervals. The problem then is to determine an appropriate sampling interval. On one hand, sampling at points which are too close together will yield correlated and highly redundant data, and thus unnecessarily increase the labour and cost of calculations. On the other hand, sampling at point, which are too far apart lead to confusion between the low and high frequency components in the original data. This later problem is called Aliasing. It constitutes a potential source of error inherent in all digital processing which is preceded by an analog to digital conversion.

The Errors in Data Entry: In practice, the quantising error is usually less important relation to other sources of errors in the data acquisition and processing procedures. However, care must be exercised otherwise the resolution will be poor and the quantising error would become significant. Besides, the sampling and quantisation errors, other analog to digital converter errors, the operation error and non linearities should be considered into account.

2.2.3 Validation

This part includes range checks, sum checks and consistency checks in between various station data. The data already converted to the digital form are required to be converted to physical engineering units. In this pre-qualification of data would be necessary. This involves the detection and removal of isolated outlier, level shifts, trends and other types of errors, which may have occurred. Most of the digitizing procedures produce information in units that are proportional to the true physical units. A common technique is to store reference or calibration signals, which enable conversion to engineering units directly is through validation procedures. It is then possible to determine the relationship between digitized and physical units directly.

2.2.4 Primary Processing

It is essential before the data is put to further use. Faster methods of processing through the use of computers have been evolved. Need of faster methods of processing become necessary when data record length is large. There must be some means of specifying not only the type of instrument, but also the recorder type, its recording frequency and the type of variable that a system measures.

Through primary processing, many errors observational or instrumental, occurring at various stages of recording and entering or transfer of data from manuscript to computer files are identified, flagged and removed. Detailed quality control of large volumes of data by visual inspection is quite impracticable. However, the use of digital computers has made the task simpler and all the data can be subjected to desired quality control checks.

Primary processing differs from validation procedures, which make comparisons of test values against input data. This is viewed as a procedure necessary to manipulate and transform the input data for output and storage. From operational hydrology point of view, both are parts of main database updating procedures executed on a monthly basis. Both updating and some stages of primary processing are conditional upon the successful validation of data. The main components of primary processing are:

The first operation is the data editing. It refers to pre-analysis procedures designed to detect and eliminate spurious and/or de- regard data signals which might have resulted from collection and recording problems e.g. excessive noise, signal dropout, loss of signal or data due to sensor malfunctions etc. The editing can often be accomplished through visual inspection of data time history signals. In more sophisticated data acquisition and processing systems, a specific instrument for quick look evaluation might be employed. Real time spectrum analyzers are popular for this application. It should be noted that the time date editing step is more critical for the case of digital processing than for analog processing. This is true because once the data have been converted to digital format, it is often difficult to detect even the most obvious errors in the original data. This includes standardization of units, calculation of derived parameters, further coding of input to reduce storage requirements, and arranging data in database. The main components of data processing are:

2.2.4.1 Data Adjustment for Known Errors

In this, data received after first stage of quality control performed manually by the observer are corrected before subjected to validation. The adjustments are needed to correct datum errors, differences between time and date of records, gradual drift of the clocks, sensor device or recording mechanism or discrete events caused due to sudden snags in the mechanical, electronic or electrical components (e.g. clock jams, or pen/paper jams etc.). The essential feature of the correction procedures, performed manually or by the use of computers, is that all modified data values must be flagged to indicate all adjustments that have been made during data adjustments.

2.2.4.2 Aggregation and Interpolation of data

Means summing of discrete values over a defined time interval. All dynamic nature data are sampled at small intervals and used as averages or totals over a long period of time. In most of the application, for most of the hydrologic applications, daily values serve the purpose, but, sampled more frequently to obtain reliable daily estimates (e.g. air temperature and wind speed and direction). The same becomes true in case of water level and river flow data. If data sampling has been adopted at constant frequency of observation, the aggregation is straightforward, but with frequent changes in sampling frequency, a two stage interpolation/or aggregation is recommended.

2.2.4.3 Assessment of Derived Variables

In hydrology, the most frequent derived hydrological parameter is the run-off and as hydrometeorological variable is the evapotranspiration. These data need not be stored and may be derived at the time of need. But decision may be taken on the basis of the following:

- i) How often is the use?
- ii) How complex is the computations ?
- iii) What is the objective of the data bank, whether to keep fundamental variables or the derived also.?

2.2.4.4 Output of Statistical Summaries

These may be brought out as routine outputs, usually on a monthly and annual basis, of data processed during the database updating cycle. These are considered as basic data retrieved outputs and in many places reduces the efforts of software developments.

2.2.4.5 Conversion to Database Storage Formats

If the primary data format differs from the main database file format, necessary changes are incorporated including its format through validation and quality control procedures through primary processing before subjected to main database file to update it. The modern view is that there is no need, and it is generally inadvisable, to use common formats. Data-input formats should be designed to suit the characteristics of the data collection and data-entry systems. Data storage formats should be designed to suit the storage media and the data-access requirements. Merging of data from several input forms into a single record and vice-versa, are outlined in **(WMO/FAO, 1985)**.

2.2.5 Database Updating

New sets of data are added up and errors are reported. WMO and FAO publications deal directly with many of the procedures, which may be consulted for background theoretical formulation techniques information and may be adopted as an extension of the available tools. The details of processing of the climatological data are given in **WMO(1983)** and for Hydrological data vide **WMO(1974) & WMO(1994)**.

Data base updating is carried out during periods of 'bad' data for those variables which show a marked trend. It is only used when a smooth, slowly changing trend is expected. Although, great efforts are made to reduce the amount of manual editing to a minimum by use of automatic correction procedures and the careful selection of acceptable limits in the quality control stage, it is inevitable that some manual intervention will be necessary. After the data is deemed to be correct, they are converted into their final processed form, written to the relevant file and any temporary files that have been created to hold the data during the quality control stage is automatically deleted and thus, the data base is updated.

2.2.6 Secondary Processing

In this part, processing is performed for routine statistical summaries, filling of missing data values and interpolation, aggregation or disaggrigation etc. This is required when the data used are not those recorded. For modelling purpose such as stream flow, is generally measured as a river level, but it is the river flow which is of interest. The meteorological variables are recorded so that the estimates of evaporation can be made. Secondary processing therefore becomes essential to convert the measured variables into normally used variables. Conversion factors and tables are necessary to carry out these procedures; the factors are generally accessed through well organized site directories. Quite often the recorded data frequency is greater than the required storage frequency. The average and sums depending on the variable, over the required frequency must be calculated. On completion of this stage, summary print outs are produced.

The amount and nature of data stored on the direct access processed files depends on the type of the instrument. In view of the cost of the permanent storage computer discs, it is highly desirable to limit the data stored to a minimum. This is generally achieved by storing only those data which can not be generated by other stored variables. In theory, only the measured values need be stored. However, in some cases, such as calculation of evaporation rates, it is observed that calculating the derived values from the measured variables is so time consuming and therefore expensive that it is not economical to store only the measured variables.

In secondary processing, the consideration must be given to the user's requirements and, wherever possible, it is the variable normally used for studies are stored. In some cases, when the requirement is from a point source, in other several areal estimates are required; these must be calculated and stored.

2.2.7 Storage and Retrieval of Data

The final data values are stored in direct access files with quality indices flagged to them. This should provide means of identification of files in the site directory. For those data recorded at sub-daily intervals, the direct access files may consist of 366 records, each record may represent one day (midnight to midnight) of the year. The size of each record depends on the type of site/instrument and the quantity of data on daily basis need to be stored. For those data, recorded manually at variable time intervals, the situation is rather more complicated, because the number of data occurrences per year and the time and the date of recording is variable. In these cases, variable length direct access file may be used and the records may be created at the time of their actual use.

Data stored in the direct access files are convenient to handle and any data of any particular day may be retrieved without the necessity to read through the data from preceding days. The dedicated software for data processing and analysis e.g. HYMOS etc. are other added advantages in the field of data collection, processing and management. This part is done for taking out data from a set of data with parameter type, parameter value, location, period of record, time interval of record with option to select output devices. The use of INTERNET and other developments in communication systems have recently added new dimensions to this aspect. Information exchange technology through 'Information High Way', World Wide Wave (WWW) etc. have replaced many of the conventional techniques and concepts. E-mail and V-SAT also are contributing towards faster exchange of data to pre selected multiple destinations.

2.2.8 Output

This is one of the very important part of processing which provides tools to view the data and arranges to keep the records in the desired form and formats by making use of Printers, Plotters, VDU's. The display of processed data may be done by the help of standard routines on the terminals or on paper. This needs display in a wide variety of ways and the same may be accomplished by the users.

2.3 REMARKS

Data collection programmes and practices are increasing day by day. But, the aim to achieve basin wise information is still a concern. There is an urgent need to set up standards for the instruments, methods, techniques etc. and earmark the Institutes to select best available to meet the national demands. Data collection concept should be changed from individual project to national network concept. The available technology of communication with ground based VHF, radio, satellites communication may be introduced. There is also a need to view modern costly and efficient technology to make changes suitable for inaccessible areas. In satellite, the problem is that the equipments can not be interrogated directly from the remote sites by this link, since communication is one way only. A viable solution will have to be thought and worked out to make it more useful to make the uplinking and downlinking simultaneously. There are other communication system as meteor burst and land line transmission. These have not been touched here, though they have potential advantages.

CHAPTER - 3

AUTOMATED HYDROLOGIC STATION

3.0 GENERAL

The Automated Hydrologic Station(AHS) is a microprocessor based automated, self diagnostic and control system, fabricated for study of hydrometeorlogic and hydrologic components of Hydrologic Cycle. It has three components - the Sensors, the Data Acquisition System(DAS) and Output Devices; the main being the DAS, which has microprocessor as its heart. Sensors of AHS are connected with DAS through a system of cables. Most of the system work on 220V/50Hz mains supply. Now a days some advance and intelligent data loggers are available which on suitable modification may be utilised to work as either a Weather Station or the 'AHS'. Both of them are provided with built-in backup battery to ensure their unattended and uninterrupted smooth operation. The systems are so designed that they can be interrupted also by the operators at any time by sending necessary commands through front panel operator's switch board.

The Automated Hydrologic Stations are an integrated measuring system comprising of a large number of sensors for measuring various hydrometeorological/hydrological parameters simultaneously on a preset interval. The parameters of measurement are evapotranspiration, measured by measuring changes in the weight of a lysimeter, percolation through measuring flow, runoff through measuring level; soil moisture by measuring electrical conductivity through conductivity blocks; sky and ground radiation including albedo by measuring long and short wave radiations through global and net radiation; air temperature and ground temperature through thermistors;

wind direction and speed through measuring digital counts; relative humidity by measuring air moisture through humidity sensor, sunshine duration by measuring sunshine time of a day in minutes through heliometer, atmospheric pressure by measuring pressure through pressure transducer and rainfall by measuring pulses corresponding to a definite volume of water through tipping bucket sensor.

The microprocessor of DAS is so preprogrammed that it can perform various functions - periodic scanning of sensors, monitoring health and state of its various peripherals like printer, cassette recorder, memory chips etc. DAS interrogates periodically each sensor connected to it with appropriate interface (analog or digital, depending on the kind of available output signal and acquisition cycle, as per standard fixed for hydrological studies. The periodicity of the acquisition is the function of the kind of the parameters.

3.1 THE AUTOMATED HYDROLOGIC STATION OF NIH

An Automated Hydrologic Station (AHS) was procured by NIH in 1986 by UNDP assisted project with the objectives of developing understanding about the system operation/ maintenance and to study various problems and characteristics of short interval data. The system became fully operational by March, 1990. The system was not provided with any software support either for transfer or for processing of data in standard formats. The data on various hydrometeorological and hydrological parameters was received on cassette tapes on a regular interval. The data was received in the interval of 30 minutes for physical parameters with slow evolution speed viz. temperature, humidity, atmospheric pressure etc. and 4 seconds for physical parameters with fast evolution speed like wind, rain, sunshine etc.

For some of the sensors, present value (not the threshold) is considered for simplicity in operation and handling. For some sensor parameters cumulative values for a total of 24 hours beginning from (0h00) hours (midnight). The values are cleared/reset daily at midnight (0h00) hours IST. Recording is preset at half hour interval which enables acquisition and preparation of output message format at every half an hour interval. Total sensor and acquisition parameters may be classified as consisting of hydrologic part and the meteorologic part. The hydrologic part includes lysimeter- a container of mild steel with all necessary accessories like sensor, load cell, precision electronics, digital readout and processor for converting and processing the electrical voltage into kg. This measures total change in water available in the soil monolith. There are three pairs of temperature and the same for ground conductivity sensors, measuring ground temperature and electrical conductivity/ or soil moisture at three different depths- 30, 50 and 80 cm inside and outside the lysimeter respectively. Measurement of runoff and rate of percolation of water through lysimeter column is done by other two sensors. Meteorological part, however, includes rest of the sensors- air temperature, wind direction and speed, humidity, sunshine, global radiation, balanced radiation, atmospheric pressure, precipitation or tipping bucket, water level and the sensor for monitoring battery status.

Table-3.1 provides list of sensors. **Table-3.2** provides format of data output, which is in **ASCII** (American Standard Code for Information Interchange) code, indexed by date, time and Station Identifier, if it is a new day. The time interval to produce such message is in relation with the acquisition cycles and the message is generated after execution of a complete cycle. It is first stored into station memory, sent to the printer and recorded to the tape also, if the tape recorder is ready. A cassette can record a maximum of 400

Table 3.1 LIST OF SENSORS OF THE AUTOMATED HYDROLOGIC STATION(AHS)

SL NO.	PARTICULARS	CAPACITY	INSTALLED
i)	Air temperature	Two	One
ii)	Relative Humidity	Two	One
iii)	Wind Direction & Speed (jointly)	Two	One
iv)	Global radiation	Two	One
v)	Sun-shine duration	One	One
vi)	Atmospheric pressure	One	One
vii)	Rainfall	Three	Two
viii)	Balanced radiation	One	One
ix)	Ground Temperature	Six	Six
x)	Electrical ground Conductivity	Six	Six
xi)	Weight	One	One
xii)	Water Flow	One	One
xiii)	Water level	Three	One

Table 3.2 FORMAT OF OUTPUT MESSAGE AS PREPARED BY TELEDAT-2000 OF AUTOMATED HYDROLOGIC STATION

251085 NIH-01

0430

1T1	23.4	1T2	23.7	1T3	15.3	1T4	15.2	1T5	14.6	1T6	14.1
1T7	14.2	1T8	14.2	3W1	5.6	19.5	25.0	3W2	5.6	19.6	25.0
1H1	67.1	1H2	68.1	1S1	122.	1R1	4.3	1R2	4.1	1R3	4.3
1P1	972.6	1K1	205.6	1C1	232.	1C2	120.	1C3	220.	1C4	20.
1C5	35.	1C6	70.	1B1	-2.0	1G1	10.	1G2	210.	1F1	12.4
1L1	5.65	1L2	2.01	1L3	10.56	1BA	1113.9	06345			

* First line of message format is for Date and Station identifier - NIH 01

* Second line is for time of the message recorded

messages on one side of one tape/cassette and a maximum of 20 messages (i.e. for 10 hours only) can be stored in the buffer (temporary) memory of DAS-2000/Teledat-2000 in case the output media- tape drive or the printer is not ready and not responding properly with the commands of the DAS-20000. When the tape becomes ready to accept the messages, all the stored messages of its buffer are transferred from its buffer to the tape and the memory thus occupied is released. Each message is a set or sometimes called as a block of message that contains information of the last or the proceeding half hour interval. The operator, however can also interact with the system and may dispose a number of commands to supervise the TELEDAT functions. The information relating to sensor symbol and their description is given in **Table-3.3**, whereas the statement of message content, interval of acquisition and the status of messages etc. are provided in **Table-3.4**. A block diagram of AHS is presented vide **Fig 3.1.**

3.2 BRIEF DESCRIPTION OF SENSORS

3.2.1 Air Temperature Sensor

Thermilinear Thermister sensor(YSI 701), a composite device consisting of resisters and precise thermistors, whose output voltage is linear to the variations in temperature, manufactured by M/s Thermister Yellow Springs Instrument, USA, is used for sensing air temperature. The sensor as whole is protected from the environmental hazards and the leads are electronically isolated from the outer probe surfaces, may be used for medical and bio-medical applications. It is shielded with relative humidity sensor and sensing is done from a height of 2m above the ground. In the data set it is identified by term 1T1 and gives fairly good resolution of 0.1°C.

TABLE 3.3 SENSOR SYMBOLS AND THEIR DESCRIPTIONS

ID.	TYPE	VALUE	UNITS
1T1-1T2	ATMOSPHERIC AIR TEMPERATURE	XX.X	°C
1T3-1T8	GROUND TEMPERATURE	XX.X	°C
3W1-3W2	WIND EAST comp NORTH comp	XX.X	m/s
1H1-1H2	RELATIVE HUMIDITY	XXX.X	%
1S1	SUNSHINE DURATION	XXXX.	mn/24h
1R1-1R3	RAIN	XXX.X	mm/24h
1P1	ATMOSPHERIC PRESSURE	XXXX.X	mb(milibar)
1K1	WEIGHT	XXXX.X	Kg
1C1-1C6	GROUND ELECTRICAL CONDUCTIVITY	XXXX.	micro Siemens
1B1	BALANCED RADIATION	XXXXX.	W.h/(m** 2)
1G1-1G2	GLOBAL RADIATION	XXXXX.	W.h/(m** 2)
1F1	WATER FLOW	XXX.X	cc(ml or dm**3)
1L1-1L3	WATER LEVEL	XX.X	meter (m)
1BA	BATTERY	SSXX.X	Status power & Voltage

Table 3.4 STATEMENT OF MESSAGE CONTENT, INTERVAL OF ACQUISITION AND THE STATUS OF MESSAGES

ID	SENSOR	INTERVAL	STATUS
K1	WEIGHT	30mn	Present Value
F1	WATER FLOW	4s	Present State of the amount
C1-C6	CONDUCTIVITY	30mn	Present value
T3-T8	TEMPERATURE gnd	30mn	Present value
W1-W2	WIND DIRECTION (degree from NORTH)	4s	-------------
	wind speed	4s	East Morth component
		30mn	average max. speed during last 30 mn.
H1-H2	HUMIDITY	30mn	Present value
S1	SUN DURATION	4s	Present state of the amount
G1-G2	GLOBAL RADIATION	4s	Present value
B1	BALANCED RADIATION	4s	Present value
P1	AIR PRESSURE	30mn	Present value
R1-R3	RAIN	4s	Presentstate of amount
L1-L3	WATER LEVEL	30mn	Present value every 5mn

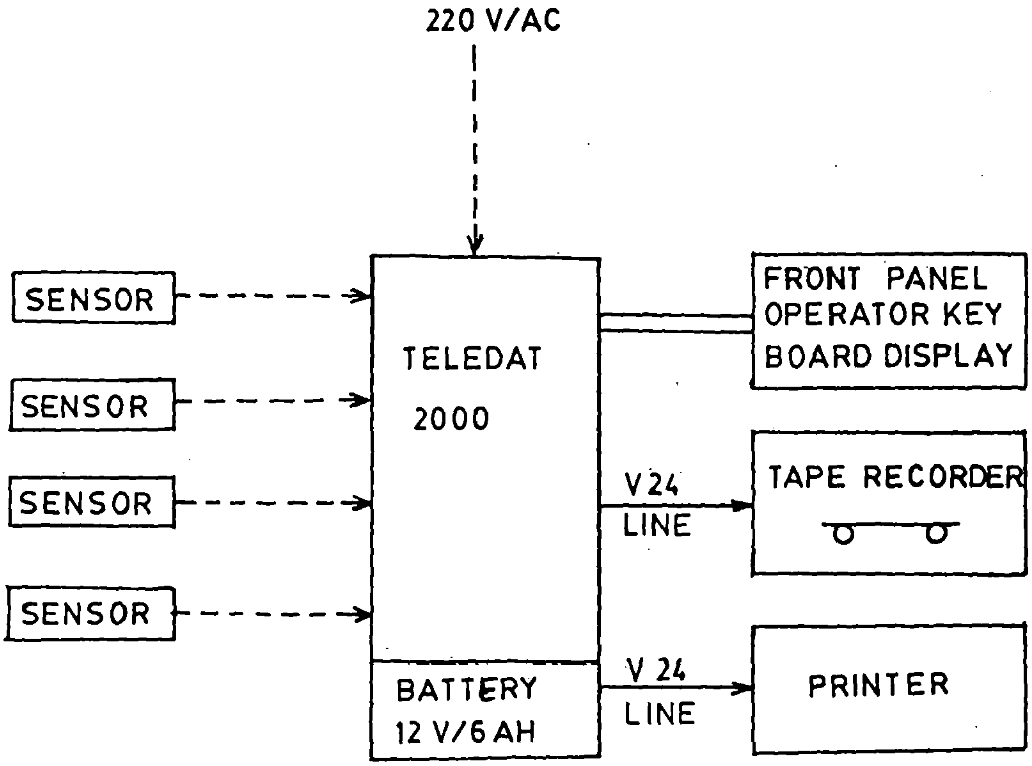

FIG. 3.1. BLOCK DIAGRAM OF AUTOMATED HYDROLOGIC STATION.

3.2.2 Relative Humidity Sensor

The sensor is capable of measuring relative humidity directly in terms of percentage (%). Its measurement is essential to know and to monitor evaporation from the open water surfaces and evapotranspiration from plants etc. The sensor is manufactured by M/s Wilh Lambrecht Kg, 34 Gottingen, Germany. It can work efficiently within a temperature range of -60 to 70 °C and between 5% to 100% humidity conditions. The sensor element is human hair, treated mechanically with pernix. The human hair is very sensitive to changes in relative humidity. Any change in the length of the hair is converted into proportional changes in the resistance values and then to proportional voltage values compatible to DAS-2000. In data set it is identified as 1H1.

3.2.3 Global Radiation Sensor

The sensor CM-6 measures short wave radiations between 305 to 2800nm wavelength, coming from the sun and the sky and incident on half of the globe of the sensor (180°). It is supplied by M/s Kipp & Zonen, Delft Holland, Mercuriusweg 1, PO Box 507. Moll thermopile consisting of 14 elements of constantan- manganin, is used. The outer part is covered with two glass domes, one is provided as protection against atmospheric influences. Linearity is better than 1.5% over the whole range of 0-1000 (Watt hour/ Meter). This also is kept at a height of 2m above ground. In data set it is identified as 1G1.

3.2.4 Net Radiation Sensor

The portion of the total radiation of all wavelengths, transformed into other forms of energy, is termed as 'net radiation' or 'balanced radiation'. It is the difference of incoming to ground and outgoing energy from the ground. Sensor for this type was supplied by M/s Kipps and Zonen, weighing 6 kg. This sensor is capable of measuring short wave, long wave radiations and also the albedo. Two identical pyranometers are used to measure energy from a height of 1 meter above ground. Greater heights produce radiation divergence. This also is kept at a height of 2m above ground. In data set it is identified as 1B1.

3.2.5 Wind Speed and Direction Sensor

It is very light weight anemometer, equipped with three spherical beaded cups mounted on a rotor with 280 nm diameter. The overall height is 300mm and needs very small threshold and little tendency to overrun in gusts. Direction sensing part weighs 13g and 20g respectively with a total including body is only 500gm. Each revolution produces 6 pulses, which are counted and changed to necessary engineering unit. It is kept at a height of 10m above the ground. In the data set it is identified by 1W1, of which first two parts are direction vectors measured from north and the third is the speed component in m/s.

3.4.6. Rainfall Sensor

There are two rainfall sensors connected with DAS-2000 of AHS viz. 1R1 and 1R3. Tipping bucket rain gauge, made up of Lacquered Aluminum, is used to monitor rainfall for every half hour interval with an accuracy of 0.1mm of depth of rainfall. This in terms of volume for a catch area of 200 cm^2 comes out to be m corresponding to each and every tip of bucket. Rainfall with intensity greater than 7.5mm/ minute can not be measured accurately. The sensor weighs 4kg.

3.2.7 Water Level Sensor

It is basically float/pulley mechanism wound over multiple turn (10 turn) potentiometer. The float is dropped into a small plastic casing of height 1m and cross sectional area 100 cm^2 (10cm x10cm square). The sensor is capable of measuring run-off water, excess of the lysimeter catchment, collected in the above plastic casing. Any change in water level causes float to rise, which give rise a proportional voltage and fed to DAS-2000 of AHS. In data set it is identified as 1L1.

3.2.8 Rate Of Percolation Sensor

The percolated water through the soil monolith of the lysimeter is measure by Lambert LY-100/10 type of sensor, powered by 5V DC. The sensor output in the form of digital state 0 and 1. It is basically a tipping bucket type of mechanism. The water as it comes through the soil column of the lysimeter is poured to this mechanism, and the total volume of water is sum over 24 hours cumulative values in terms of CC. This is identified by 1F1.

3.2.9 Sun - Shine Duration Sensor

Measurement of sun-shine duration is done by the help of Solarimeter/(Solar-III type)/sun-shine duration sensor. It is manufactured by M/s Haenni & Cie mbh, D-7000 Stuttgart 50, PO Box 500529, FRG. The sensor consists of a detector and a heating element. There is a Thermister, which is used as temperature feeler. There are two parts: one to regulate the heat with a capacity of 20 Watts. The sensor has sensitivity with in a range of 70 to 280 Watt/ $Meter^2$. It measures in terms of minutes. In data set, it is identified by 1S1.

3.2.10 Soil Temperature Sensor

The sensor, YSI 701 from M/s Yellow Spring, is similar to that described under air temperature. It is powered with 1.471 V reference voltage source. The range of measurement varies between -30 to ± 50 °C. Three sensors are kept in one steel tube at a preset distance of 30, 50 and 80 cm to measure temperature at these three depths below surface. In data set there are six such sensors identified as 1T3, 1T4, 1T5, 1T6, 1T7 and 1T8.

3.2.11 Atmospheric Pressure Sensor

The sensor is Rosemount and powered by +12V DC, signal is 0 to 5V and has range 800 to 1100 mb. It measures instantaneous value of atmospheric pressure in terms of mb. It is identified by 1P1.

3.2.12 Weight Sensor

The sensor is Gisiger GT1 and powered by 24V AC, has range from -5-- to + 1500 kg, sensor signal being -1 to 3V DC. It is identified by 1W1.

3.2.13 Conductivity Sensor

These are zypsum conductivity blocks from M/s Beckman CEL-WED. It is powered by ± 12V AC. The range of measurement being 1 KΩ to 1MΩ. The sensor signal being 0 to 3V DC. In data set there are six such sensors identified as 1C1, 1C2, 1C3, 1C4, 1C5 and 1C6.

CHAPTER - 4

PROCESSING AND PRELIMINARY ANALYSIS OF AHS DATA

4.0 INTRODUCTION

This chapter presents the processing and preliminary analysis of the data. The data of AHS is first processed by the microprocessor at the collection level itself followed by its conversion into desired engineering unit before blocks of message are generated and sent to the output devices - cassette recorder and printer for recording. The data on various variables are obtained in the increasing order of date and time. These blocks of data are recorded on cassette tapes where each of it can record a total of 800 half hourly block of data, 400 blocks on either side.

4.1 PRELIMINARY PROCESSING

The output data of AHS as recorded on the cassette is in ASCII code. Therefore, further processing of the data in tabular form or graphs or statistical summaries is required.

To commence processing for presenting the data in tabular form, the data recorded on these cassettes are first transferred to the hard disk of a Personal Computer **PC-XT** or **PC-AT** with the help of a communication software. The data so transferred are kept in files marked as **RAWDAT10.1** and **RAWDAT10.2** etc. The number '10' indicates cassette number and '1' and '2' are the sides of the cassette- first or second side. Then the data is processed and combined to form sets on monthly basis. The files are marked as AHS01.90, AHS02.90 etc., where '01' and '02' indicate months and the extension '90' indicates year. This exercise was performed through main frame **VAX-11/780** system. This monthly set of data is further subjected to processing, where the data is processed and kept in the tabular forms. These processed data are kept in two different files, marked as **MET01.90** and **HYD01.90** etc., where 01 and 02 are the months and 90, the year. At this stage the data is restored without any loss of generality, even not subjected to any quality checks. The data contained in the MET*.* and HYD*.* are in tabular form, one sheet for each day of MET and HYD series. Sample sheets are presented vide **Table 4.1** and **Table 4.2**. Further, processing was carried out to present the data of individual variables with necessary statistical summaries for each of the periods-half hourly, daily and monthly. This part of analysis and presentation needed great attention for maintaining the quality. The summary was prepared for each month data separately, consisted of half hourly data arranged with increasing number of day with basic statistics viz. maximum, minimum, mean, standard deviation, Coefficient of skewness, Coefficient of Kurtosis and the missing number of data values etc. for each half hour interval at bottom and each day at the right hand side. The bottom right corner consists monthly maximum, minimum, mean and total effective number of half hourly values available in whole month. By making use of Word Perfect DTP software, two months data were presented on a single A-3 size paper sheet, a sample copy of which is provided vide **Table-4.3**

4.2 STUDY OF DAILY AVERAGE TEMPERATURE

By temperature of any place at any given time, we mean that the air temperature measured under standardised conditions and with certain recognised precautions against errors introduced by radiation from the sun or other heated body. There are numerous applications which may be cited in hydrological process modelling viz. snowmelt,

TABLE 4.1 DATAOF AUTOMATED HYDROLOGIC STATION

(METEOROLOGICAL PART)

Dated: 180991

Time hours	Air Temp °C	Atmospheric Pressure (mb)	% Humidity	Rain-I (mm)	Rain-II (mm)	DIRECTION of WIND North	East	Wind speed (m)	Sun-Shine duration (minute)	Balanced. Radiation Wh/m²	Global Radiation Wh/m²
0030	24.8	916.5	91.0	0.0	0.0	0.0	0.0	0.0	0.	-1.	1.
0100	24.8	916.3	91.5	0.0	0.0	0.0	0.0	1.3	0.	-1.	2.
0130	24.3	916.0	91.1	0.0	0.0	0.6	-0.4	2.4	0.	-1.	3.
0200	24.2	915.9	98.1	0.0	0.0	0.4	-0.2	1.5	0.	-1.	5.
0230	23.9	915.4	98.2	0.0	0.0	0.0	0.0	1.0	0.	-1.	5.
0300	24.0	915.3	98.1	0.0	0.0	0.0	0.0	0.0	0.	-1.	5.
0330	23.8	915.0	98.2	0.0	0.0	0.0	0.0	0.0	0.	-1.	1.
0400	23.8	915.0	98.1	0.0	0.0	0.0	0.0	0.0	0.	-1.	9.
0430	24.0	915.3	98.2	0.0	0.0	0.0	0.0	0.0	0.	0.	11.
0500	23.5	915.3	98.2	0.0	0.0	0.1	0.6	2.7	0.	1.	13.
0530	23.1	915.3	98.1	0.0	0.0	0.5	0.3	1.8	0.	2.	13.
0600	23.8	915.6	98.2	0.0	0.0	0.5	0.1	1.1	0.	2.	14.
0630	23.1	915.8	98.1	0.0	0.0	0.1	0.0	1.6	0.	4.	18.
0100	23.8	916.0	98.1	0.0	0.0	0.0	0.0	0.0	0.	13.	30.
0130	24.1	916.4	98.1	0.0	0.0	0.0	0.0	0.0	0.	31.	53.
0800	24.0	916.6	98.2	0.0	0.0	0.0	0.0	0.0	0.	56.	84.
0830	24.2	916.8	98.1	0.0	0.0	0.0	0.0	0.0	0.	89.	125.
0900	24.3	911.0	91.1	0.0	0.0	0.3	0.2	1.8	0.	124.	169.
0930	24.9	911.1	96.2	0.0	0.0	0.6	0.4	2.0	0.	112.	229.
1000	25.2	911.1	93.1	0.0	0.0	0.8	0.5	2.2	0.	231.	311.
1030	21.2	911.0	86.6	0.0	0.0	0.9	-0.3	2.4	5.	313.	481.
1100	29.0	916.6	15.9	0.0	0.0	0.1	-0.1	2.5	11.	658.	839.
1130	31.3	916.3	68.6	0.0	0.0	0.1	-0.1	3.5	11.	951.	1220.
1200	31.1	915.8	60.4	0.0	0.0	2.3	-0.6	5.4	11.	1265.	1608.
1230	31.9	915.3	60.5	0.0	0.0	2.5	-1.0	6.6	11.	1588.	2024.
1300	32.3	914.8	61.0	0.0	0.0	2.4	-0.9	6.8	11.	1863.	2311.
1330	32.2	914.5	56.1	0.0	0.0	3.4	-0.9	6.9	20.	2113.	2182.
1400	32.3	914.1	56.1	0.0	0.0	3.0	-0.6	6.9	43.	2439.	3132.
1430	32.5	913.6	54.1	0.0	0.0	2.4	-0.5	1.1	69.	2100.	3416.
1500	32.9	913.0	54.1	0.0	0.0	1.1	-0.4	5.8	91.	2906.	3151.
1530	32.5	972.1	54.4	0.0	0.0	0.2	0.0	6.2	116.	3088.	3995.
1600	32.9	912.1	56.5	0.0	0.0	0.3	0.0	6.0	142.	3231.	4200.
1630	32.2	912.4	56.8	0.0	0.0	0.0	1.0	2.6	112.	3358.	4368.
1100	31.1	912.3	58.3	0.0	0.0	0.0	0.0	2.6	202.	3441.	4484.
1130	31.1	912.4	62.0	0.0	0.0	0.0	0.0	0.8	218.	3488.	4553.
1800	30.0	912.6	69.0	0.0	0.0	0.0	0.0	0.3	218.	3510.	4583.
1830	29.0	912.8	15.6	0.0	0.0	0.0	0.0	0.6	218.	3514.	4590.
1900	28.3	913.0	81.4	0.0	0.0	0.0	0.0	0.6	218.	3514.	4591.
1930	28.0	913.4	84.4	0.0	0.0	0.0	0.0	0.0	218.	3513.	4591.
2000	21.8	913.4	84.8	0.0	0.0	0.0	0.0	0.1	218.	3512.	4592.
2030	21.9	913.8	83.9	0.0	0.0	0.0	0.0	0.0	218.	3511.	4592.
2100	21.9	913.9	81.9	0.0	0.0	0.0	0.0	0.0	218.	3511.	4592.
2130	28.0	914.1	80.1	0.0	0.0	0.0	0.0	2.4	218.	3511.	4592.
2200	21.4	914.4	82.6	0.0	0.0	0.0	0.0	0.3	218.	3511.	4593.
2230	25.9	914.6	91.9	0.0	0.0	0.0	0.0	0.0	218.	3511.	4593.
2300	25.0	914.5	95.1	0.0	0.0	0.0	0.0	0.0	218.	3510.	4594.
2330	24.3	914.1	96.5	0.0	0.0	0.0	0.0	0.0	218.	3509.	4595.
0000	24.0	914.2	91.5	0.0	0.0	0.0	0.0	0.0	218.	3508.	4595.

TABLE 4.2 DATA OF AUTOMATED HYDROLOGIC STATION

(OTHER PARAMETERS)

Dated: 220491

Time hour	Ly. weight (Kg.)	level (m)	Flow cm^3	G.T.1 °C	G.T.2 °C	G.T.3 °C	G.T.4 °C	G.T.5 °C	G.T.6 °C	Con.1 μ-simen	Con.2 μ-simen	Con.3 μ-simen	Con.4 μ-simen	Con.5 μ-simen	Con.6 μ-simen
0030	-0.50	0.10	71.	28.5	27.2	25.8	29.2	27.4	26.1	498.	128.	227.	0.	-4.	55.
0100	-0.50	0.10	141.	28.4	27.2	25.8	29.2	21.4	26.1	496.	128.	227.	0.	-4.	55.
0130	-0.50	0.10	212.	28.3	27.2	25.8	29.2	27.5	26.0	495.	128.	227.	0.	-4.	56.
0200	-0.50	0.10	280.	28.2	27.2	25.8	29.2	27.5	26.0	495.	128.	227.	0.	-5.	56.
0230	-0.50	0.10	346.	28.0	21.2	25.8	29.1	27.5	26.0	491.	128.	227.	0.	-4.	56.
0300	-0.50	0.10	411.	27.9	27.1	25.8	29.1	27.6	26.1	490.	128.	228.	0.	-4.	56.
0330	-0.50	0.10	474.	27.8	21.1	25.8	29.1	27.6	26.1	488.	127.	227.	0.	-4.	56.
0400	-0.50	0.10	537.	21.1	21.1	25.8	29.0	27.6	26.1	487.	127.	226.	1.	-4.	56.
0430	-0.50	0.10	597.	27.5	27.0	25.8	29.0	27.7	26.1	487.	128.	227.	0.	-4.	56.
0500	-0.50	0.10	655.	27.4	27.0	25.8	28.9	27.7	26.1	484.	129.	227.	1.	-4.	56.
0530	-0.50	0.10	712.	27.3	26.9	25.8	28.9	27.7	26.1	483.	128.	228.	0.	-4.	56.
0600	-0.50	0.10	772.	27.1	26.9	25.8	28.8	27.7	26.1	483.	127.	227.	1.	-4.	57.
0630	-0.50	0.10	835.	27.0	26.9	25.8	28.7	27.7	26.1	480.	125.	221.	-1.	-4.	55.
0700	0.00	0.10	895.	26.9	26.8	25.8	28.7	27.7	26.1	479.	125.	228.	1.	-S.	57.
0730	-0.50	0.10	957.	26.8	26.8	25.8	28.6	27.8	26.2	478.	125.	227.	-1.	-4.	55.
0800	-0.50	0.10	210.	24.9	25.3	24.6	26.8	26.5	-49.3	562.	160.	296.	3.	-2.	88.
0830	0.00	0.10	224.	24.9	25;2	24.6	26.8	26.5	-50.6	558.	159.	296.	3.	-2.	88.
0900	0.00	0.10	237.	24.1	25.2	24.6	26.7	26.5	-50.6	557.	159.	294.	2.	-2.	87.
0930	-0.50	0.10	250.	24.7	25.1	24.6	26.6	26.5	-50.6	555.	159.	294.	3.	-2.	87.
1000	-0.50	0.10	268.	24.1	25.0	24.6	26.5	26.4	-50.6	555.	158.	294.	3.	-2.	87.
1030	-0.50	0.10	286.	24.7	25.0	24.6	26.5	26.4	-50.6	554.	158.	294.	3.	-2.	87.
1100	0.00	0.10	302.	24.9	25.0	24.6	26.4	26.4	-50.6	555.	158.	293.	3.	-2.	87.
1130	-0.50	0.10	323.	25.1	25.0	24.6	26.4	26.4	-50.6	556.	157.	292.	3.	-2.	87.
1200	0.00	0.10	346.	25.2	25.0	24.6	26.3	26.4	-50.6	555.	157.	292.	3.	-2.	86.
1230	-0.50	0.10	370.	25.5	25.0	24.6	26.3	26.3	-50.6	554.	157.	291.	3.	-2.	86.
1300	0.00	0.10	395.	25.7	25.1	24.6	26.3	26.3	-50.6	557.	156.	290.	3.	-2.	85.
1330	-0.50	0.10	421.	26.0	25.2	24.6	26.3	26.3	-50.6	558.	156.	289.	2.	-2.	85.
1400	0.00	0.10	449.	26.3	25.2	24.6	26.3	26.3	-50.6	558.	156.	287.	3.	-2.	84.
1430	-0.50	0.10	478.	26.6	25.3	24.6	26.3	26.3	-50.6	563.	155.	287.	2.	-2.	84.
1500	-0.50	0.10	508.	26.9	25.3	24.7	26.3	26.2	-50.6	564.	155.	286.	2.	-2.	84.
1530	-0.50	0.10	539.	27.2	25.1	24.7	26.4	26.2	-50.6	566.	154.	286.	2.	-2.	83.
1600	-0.50	0.10	571.	27.4	25.5	24.7	26.5	26.2	-50.6	565.	155.	284	4.	-4	85.
1630	0.00	0.10	603.	27.6	25.6	24.8	26.6	26.2	-50.6	568.	154.	284.	3.	-4.	85.
1700	-0.50	0.10	635.	27.8	25.7	24.8	26.7	26.2	-50.6	571.	157.	283.	3.	-3.	84.
1730	-0.50	0.10	667.	28.0	25.7	24.8	26.9	26.2	-50.6	573.	154.	282.	3.	-4.	84.
1800	-0.50	0.10	699.	28.1	25.8	24.8	27.0	26.2	-50.5	573.	154.	282.	3.	-4.	83.
1830	0.00	0.10	731.	28.2	25.9	24.8	27.1	26.2	-50.5	576.	154.	281.	1.	-3.	81.
1900	-0.50	0.10	757.	28.2	26.0	24.9	27.2	26.2	25.5	574.	154.	281.	3.	-4.	83.
1930	-0.50	0.10	783.	28.3	26.0	24.9	27.4	26.2	25.4	574.	156.	279.	2.	-2.	83.
2000	-0.50	0.10	805.	28.3	26.1	24.9	27.5	26.2	15.3	576.	154.	279.	3.	-4.	83.
2030	-0.50	0.10	828.	28.3	26.1	24.9	27.6	26.3	25.4	576.	153.	279.	1.	-3.	82.
2100	-0.50	0.10	851.	28.2	26.2	25.0	27.7	26.3	25.4	515.	154.	219.	3.	-4.	82.
2130	-0.50	0.10	875.	28.2	26.3	24.9	27.8	26.3	25.4	515.	154.	278.	2.	-4.	82.
2200	0.00	0.10	896.	28.1	26.3	25.0	27.9	26.4	25.5	514.	153.	219.	1.	-3.	80.
2230	-0.50	0.10	923.	28.0	26.3	25.0	28.0	26.4	25.5	512.	151.	278.	2.	-3.	81.
2300	0.00	0.10	956.	27.9	26.3	25.0	28.0	26.5	25.5	571.	155.	279.	2.	-3.	81.
2330	-0.50	0.10	1001.	27.8	26.3	25.0	28.0	26.5	25.4	511.	155.	278.	2.	-3.	81.
0000	-0.50	0.10	1053.	27.7	26.3	25.0	28.0	26.5	25.4	567.	155.	261.	2.	-3.	81.

rainfall-evaporation and evapotranspiration etc. in which temperature plays a major role eg. agricultural crop production and Water Quality modelling of effluent pollutants etc. It is an important and easily obtained indicator of the energy available for evaporation and is recognised as the element of chief classification value and its accurate measurement and statement require careful attention. Thus, it is important to understand the methods by which average temperature are determined. Mean daily temperature is calculated from the available records of temperature **Wiesner(1970)**. However, **Black(1991)** has given the following guidelines

i) averaging the reading taken on the current temperature thermometer in the morning and evening

ii) averaging the maximum and minimum readings; or

iii) striking the horizontal line(which will be mean) through the undulating pen trace on the hygrothermograph chart so that the area above and below it between the line and the trace are equal.

The first two will work provided the temperature change during the day is uniform. The third needs to be adjusted for any error deviations of the mechanical/bimetallic instrument from the true temperature as indicated by the maximum and minimum thermometers.

According to **Miller(1957)**, **McAdie (1891)** and **Black(1991)** the average of 24 hours readings taken at one-hour intervals provide a more accurate estimate of the mean daily temperature. **Black (1991)** has however emphasised that the average of 24 hour vale may be employed to calibrate the other less time consuming methods finally used. But, where twenty four hourly observations are not available, the mean daily air temperature is calculated from readings taken at certain times of the day, usually, morning, afternoon and evening **Millar(1957)**. Various combinations are practised e.g.

(7.00 a.m. + 2.00 p.m. + 9.00 p.m.) ÷ 3.00

(7.00 a.m. + 2.00 p.m. + 9.00 p.m. + 9.00 p.m.) ÷ 4.00

(6.00 a.m. + 2.00 p.m. +10.00 p.m.) ÷ 3.00 etc.

It is stated that all of the above formulae give a fairly satisfactory daily mean temperature. In practice, the daily average or daily mean air temperature is calculated by dividing the sum of maximum and minimum temperatures by 2. This is advantageous that it saves a lot of efforts, because in this case, the thermometers are inspected only once a day.

It is to be emphasised that in most of the applications, normally mean daily temperature is desired as an input. This becomes input for calculating weekly, 10 daily, fortnightly, monthly or annual means of temperature for various modelling applications. Therefore, it becomes necessary to exercise care in utilising temperature and other hydrometeorological data in the light of hydrological processes and moisture storage.

In recent years, considerable developments in the field of instrumentation and methods of measurements have enabled accurate and precise observations. Automated instruments can take frequent sampling at any desired preset interval. By these developments, it is now possible to update the traditional scientific concepts, as the daily average or mean air temperature, in terms of actual numerical estimates. In the present study, the daily mean air temperature was calculated by two different approaches on monthly basis and the results of study are presented in the form of tables and graphs. The study was undertaken with the following broad objectives:

i) study the month wise variations in the daily mean values as calculated by

a) by taking the average of the two extremes- daily maximum and minimum i.e. $T_{E(ave)} = \{\frac{Maximum + Minimum}{2.0}\}$

b) by taking the average of hourly air temperature i.e.

$$T_{h(ave)} = \frac{1}{24}\sum_{i=1}^{24} T_{h(i)}$$

where $T_{h(i)}$ is the hourly air temperature.

ii) study the variation in the above on annual basis and to compare the results on the basis of regression analysis.

4.2.1 The Data

The half hourly data of one year recorded by Automated Hydrologic Station of National Institute of Hydrology, Roorkee was considered in the study. The half hourly data was aggregated to hourly values.

4.2.2. Methodology

Daily average air temperatures were calculated by two different ways: i) by taking the average of two extremes temperatures-daily maximum and daily minimum temperature. ii) by taking the average of daily 24 discrete values. These calculations were performed for all the 12 months of a single year 1990. Linear regression for all months were also performed between these means taking the average calculated by (Max+min/2) as independent variable. Graphs were plotted taking abscissa for independent variable and ordinate for dependent variable.

December , 1990

DAY\HR	0030	0100	0130	0200	0230	0300	0330	0400	0430	0500	0530	0600	0630	0700	0730	0800	0830	0900	0930	1000	1030	1100	1130	1200	1230	1300	1330	1400	1430	1500	1530	1600	1630	1700	1'
1	9.2	8.9	9.0	8.7	8.4	8.4	8.1	7.9	7.6	7.6	7.3	7.0	6.8	6.8	7.1	9.0	10.7	13.0	15.5	18.1	20.1	21.8	22.1	22.9	23.7	24.2	24.6	24.5	24.3	24.5	23.7	23.3	22.3	18.5	1
2	10.0	10.1	9.5	9.1	8.7	8.2	7.9	7.4	7.3	7.2	6.8	6.6	6.4	6.5	7.1	8.9	10.6	13.1	15.6	17.3	19.2	20.8	21.0	21.8	23.2	23.6	24.4	25.3	25.3	25.1	24.9	24.8	22.8	18.6	1
3	9.7	9.4	9.2	9.0	8.7	8.7	9.1	9.3	8.6	8.3	7.9	7.8	7.7	7.8	8.1	9.8	11.6	13.6	16.8	17.8	19.6	21.9	23.1	23.5	23.8	24.6	24.6	24.3	24.5	25.2	24.6	24.7	23.1	--	16
4	10.7	10.5	10.2	10.1	10.0	9.7	9.5	9.2	9.2	9.3	9.1	8.8	8.6	8.4	8.8	10.6	13.0	14.5	16.7	18.6	--	20.6	22.3	23.7	24.4	24.1	24.5	25.5	25.8	24.9	24.6	24.5	23.0	19.6	17
5	10.9	10.8	10.5	10.0	9.8	9.9	9.6	9.5	9.4	9.3	8.9	8.6	8.5	8.4	8.8	10.2	12.6	15.0	17.6	18.0	19.1	20.5	22.5	22.8	23.4	24.0	24.2	24.7	23.9	24.0	23.7	23.0	22.1	19.5	17
6	10.1	9.8	9.6	9.2	9.0	9.0	8.8	8.7	8.4	8.0	8.0	7.9	7.8	7.9	7.9	9.3	10.8	12.3	14.9	17.4	18.8	20.7	21.4	22.3	22.9	23.7	23.9	24.4	25.0	24.4	24.3	23.7	22.8	19.4	16
7	10.1	9.9	9.7	9.3	9.4	9.1	9.0	8.9	8.8	8.3	8.2	8.4	8.2	8.0	8.2	9.9	11.7	12.9	15.6	17.5	19.4	20.3	21.9	22.8	22.9	23.7	24.8	25.2	24.7	25.6	25.0	24.1	22.5	19.2	16
8	10.7	10.4	10.3	10.2	10.2	9.8	9.5	9.6	9.5	9.6	9.2	9.2	9.8	9.5	9.6	10.8	12.4	13.9	15.8	19.0	20.4	21.2	22.8	24.5	24.8	24.3	24.1	23.5	23.2	24.4	24.2	23.4	22.0	19.0	16
9	11.9	12.0	12.0	11.6	11.4	11.1	11.0	11.1	11.3	11.1	10.8	10.8	11.0	11.1	11.2	11.5	12.3	13.1	14.7	16.9	17.4	19.4	20.4	20.9	21.6	21.9	22.2	22.4	22.4	22.0	21.3	20.1	19.5	18.1	16
10	9.3	9.1	9.0	9.1	9.0	9.4	9.8	9.4	9.3	8.8	8.5	8.6	8.1	8.2	8.1	9.4	11.7	13.7	16.6	18.7	20.8	21.5	22.2	22.8	23.7	23.4	23.3	24.2	23.3	23.2	23.2	22.7	21.0	18.3	16
11	10.2	9.9	9.6	9.3	9.1	9.1	8.9	8.7	8.6	8.7	8.3	8.0	8.2	8.1	8.7	8.8	9.8	11.8	15.3	17.7	20.6	21.0	22.2	23.0	23.8	24.3	24.6	24.6	24.7	24.6	24.2	23.7	23.0	19.7	17
12	10.1	10.9	10.7	9.9	10.7	10.2	10.0	10.6	10.4	9.7	9.2	9.0	9.5	8.4	7.6	9.7	11.9	14.1	16.0	17.6	18.6	20.1	21.0	22.4	23.3	24.3	24.2	24.4	24.3	23.9	23.4	23.2	22.0	20.9	18
13	11.2	11.4	11.3	11.2	10.6	10.4	10.4	10.2	10.1	9.8	9.6	9.4	9.1	8.7	8.8	9.3	10.3	11.8	13.6	15.0	16.6	18.3	19.8	20.6	21.8	22.4	23.4	23.9	23.2	23.3	22.9	22.9	22.2	19.5	16
14	9.1	8.9	8.4	8.4	8.2	7.8	7.5	7.5	7.3	7.1	7.0	6.9	6.8	6.0	5.7	7.5	9.6	11.5	14.5	15.2	16.0	18.2	18.8	20.3	21.5	21.7	21.8	23.0	23.7	23.6	22.3	21.0	19.1	17.2	15
15	11.1	10.9	10.7	10.2	10.1	9.8	9.9	9.5	9.9	9.9	9.5	9.2	9.0	8.8	8.9	9.8	10.9	12.4	15.3	18.2	19.7	21.1	22.2	23.1	23.5	24.2	24.1	24.7	24.6	25.6	24.5	24.8	22.9	18.9	16
16	12.2	12.2	11.9	11.8	11.8	11.8	11.3	11.4	11.0	10.9	11.0	11.1	10.8	10.5	10.3	11.5	15.1	16.0	18.9	21.7	20.9	21.6	22.1	22.1	23.2	23.6	23.2	23.6	25.0	23.9	23.4	22.0	23.4	19.9	17
17	10.9	10.7	10.4	10.6	10.1	9.9	9.7	9.8	9.8	9.7	9.7	9.2	9.1	8.8	8.6	9.9	11.7	13.8	17.5	19.8	20.3	21.4	23.3	22.4	24.1	24.7	25.5	25.3	25.7	26.3	26.0	25.1	23.0	20.3	16.
18	9.7	9.3	8.7	8.8	8.4	8.6	8.3	8.1	7.7	7.3	7.2	7.5	7.4	7.8	8.4	9.5	11.5	12.6	14.2	16.4	18.1	19.6	20.7	22.4	23.8	24.5	24.1	24.7	25.4	25.0	24.1	23.0	21.9	20.5	17.
19	11.8	11.5	11.2	10.8	10.6	10.4	10.3	9.7	9.3	8.6	8.5	8.6	8.8	8.3	8.5	9.0	9.5	9.9	11.1	13.1	14.6	16.5	18.0	19.4	20.8	21.3	21.6	21.4	21.9	21.6	21.5	21.3	20.5	19.3	17.
20	9.5	10.0	10.1	9.9	9.4	9.8	9.3	8.4	8.1	7.9	7.8	7.4	6.4	7.3	7.0	6.7	7.0	7.6	8.1	9.0	13.4	13.7	16.4	17.4	19.0	20.0	20.2	20.5	20.9	21.2	21.1	20.9	19.9	17.0	14.
21	9.0	9.0	8.9	8.6	9.0	7.9	7.5	6.1	6.2	6.3	6.4	6.1	5.9	5.7	6.4	6.4	7.3	9.4	11.1	12.7	13.1	14.3	15.3	17.3	18.3	19.2	20.3	20.9	21.4	21.7	20.9	20.4	19.4	17.8	15.
22	9.4	9.0	8.4	8.2	8.1	8.1	7.6	7.2	7.0	6.8	6.7	6.5	6.4	6.3	6.4	7.0	8.0	8.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
23	8.2	7.4	6.9	6.7	6.3	5.8	5.7	5.2	5.3	5.1	4.9	4.2	3.9	3.9	3.6	3.8	5.8	7.4	9.1	12.2	14.5	16.8	18.0	18.4	19.4	18.8	20.1	21.3	21.0	20.4	20.8	19.9	18.7	16.8	14.
24	8.0	7.5	7.7	7.6	7.1	6.5	6.2	6.2	6.2	6.2	5.8	6.2	6.6	6.8	6.1	6.6	8.3	10.0	11.9	15.3	18.3	19.8	18.7	19.3	19.7	20.3	21.1	21.4	21.7	21.6	21.5	20.8	19.7	18.5	16.
25	9.3	8.6	8.7	8.7	9.0	8.8	8.5	9.2	9.2	9.0	8.9	8.7	8.2	8.6	8.8	9.0	9.5	10.7	12.0	13.1	13.1	14.6	15.4	16.3	17.3	17.7	18.8	18.7	19.1	19.0	18.8	18.2	17.2	16.0	14.
26	10.7	9.9	9.8	9.3	9.8	9.0	9.0	8.7	8.3	7.8	7.6	7.5	6.9	6.8	6.8	7.6	8.9	9.7	10.6	14.3	16.2	18.0	18.9	19.9	20.0	21.7	20.6	20.6	21.7	21.1	20.2	21.0	21.3	18.7	16.
27	11.0	10.5	10.3	10.1	9.9	9.9	9.8	9.7	9.4	9.4	8.9	8.6	8.4	8.2	8.1	8.6	10.5	12.3	13.2	15.4	17.3	19.6	20.4	22.0	23.0	23.7	23.7	24.6	24.5	24.3	24.2	24.3	23.3	20.4	17.
28	11.5	11.5	11.3	11.1	10.8	10.7	10.5	10.4	10.6	10.4	10.0	9.9	9.6	9.7	9.5	9.8	10.9	12.4	13.8	15.7	17.3	19.4	21.0	21.9	23.4	24.1	23.8	24.0	24.1	22.8	22.6	22.0	21.0	19.8	18.
29	13.8	13.9	14.0	13.5	13.7	14.5	15.4	15.2	15.8	16.3	16.6	16.7	16.6	16.2	15.4	15.4	14.9	14.8	15.4	16.1	16.1	15.9	16.2	15.5	15.4	17.2	15.6	15.1	15.2	15.2	15.9	15.2	15.2	14.9	14.
30	13.3	14.2	14.0	14.8	14.8	14.8	12.5	10.4	10.5	10.4	10.3	10.0	10.1	10.2	10.3	10.6	11.3	13.2	14.8	17.5	17.6	17.2	16.2	15.7	15.5	14.3	14.3	14.0	13.7	14.3	14.3	14.5	10.1	9.7	8.
31	7.6	7.8	7.8	7.8	7.6	7.4	7.5	7.4	7.3	7.5	7.8	7.4	7.2	6.9	6.5	6.6	7.7	9.2	11.4	11.6	11.7	12.0	13.4	13.7	14.3	14.1	14.1	14.1	14.0	14.1	13.6	13.2	12.6	12.1	11.
EFF.	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	30	30	29	30	30	30	30	30	30	30	30	30	30	30	30	29	30
MIN.	7.6	7.4	6.9	6.7	6.3	5.8	5.7	5.2	5.3	5.1	4.9	4.2	3.9	3.9	3.6	3.8	5.8	7.4	8.1	9.0	11.7	12.0	13.4	13.7	14.3	14.1	14.1	14.0	13.7	14.1	13.6	13.2	10.1	9.7	8.
MAX.	13.8	14.2	14.0	14.8	14.8	14.8	15.4	15.2	15.8	16.3	16.6	16.7	16.6	16.2	15.4	15.4	15.1	16.0	18.9	21.7	20.9	21.9	23.3	24.5	24.8	24.7	25.5	25.5	25.8	26.3	26.0	25.1	23.4	20.9	18.
MEAN	10.3	10.2	10.0	9.8	9.7	9.5	9.3	9.1	8.9	8.8	8.6	8.4	8.3	8.2	8.2	9.1	10.6	12.1	14.3	16.2	17.5	18.9	19.9	20.7	21.5	22.0	22.2	22.5	22.6	22.6	22.2	21.7	20.6	18.2	16.
STD.	1.4	1.6	1.6	1.7	1.7	1.9	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.1	2.0	2.1	2.1	2.2	2.6	2.7	2.6	2.7	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.2	3.1	3.1	3.2	2.5	2.
C.V.	13.7	15.7	16.2	16.9	17.8	19.7	19.7	20.5	21.7	22.9	23.9	25.0	26.0	25.5	24.6	22.5	20.2	18.2	18.2	16.8	14.9	14.1	13.6	13.6	13.6	13.7	13.9	14.4	14.4	14.3	13.8	14.1	15.5	13.5	12.
CSKEW	.4	.6	.7	1.1	1.0	1.0	[illegible]	[illegible]	1.2	1.5	1.8	1.8	1.7	1.7	1.1	.2	-.1	-.5	-.6	-.7	-.7	-1.1	-.8	-1.0	-1.2	-1.4	-1.5	-1.6	-1.7	-1.6	-1.6	-1.5	-1.9	-2.1	-2.
CKURT	3.4	3.7	3.8	4.9	5.0	5.3	[illegible]	[illegible]	[illegible]	8.1	9.3	9.6	8.9	8.9	7.3	5.6	3.2	2.7	3.0	3.5	2.6	3.3	2.7	3.0	3.4	4.1	4.6	4.8	5.3	4.8	5.0	4.7	6.5	7.5	8.2

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TABLE:4.3

SENSOR ID: 1T1

STASTICAL SUMMARY AND **DATA SHEET** OF AHS DATA

ATMOSPHERIC AIR TEMPERATURE IN °C

November , 1990

DAY\HR	0030	0100	0130	0200	0230	0300	0330	0400	0430	0500	0530	0600	0630	0700	0730	0800	0830	0900	0930	1000	1030	1100	1130	1200	1230	1300	1330	1400	1430	1500	1530	1600	1630	1700	17:
1	15.2	15.0	14.8	14.4	14.3	14.1	13.9	13.8	13.5	13.6	13.6	13.3	13.3	13.5	14.7	15.3	18.1	20.7	22.5	23.6	24.5	25.7	26.6	27.0	28.6	29.0	29.8	30.6	29.6	30.1	30.1	29.2	27.5	20.6	18
2	15.5	15.0	14.8	14.8	14.6	14.3	14.2	14.3	14.2	13.6	13.2	12.8	13.0	13.3	14.2	15.5	17.8	19.6	20.9	22.7	23.5	25.8	26.2	27.4	28.8	29.2	29.2	28.8	29.2	29.1	30.4	28.8	27.3	25.1	22
3	16.3	16.2	16.3	16.3	15.8	15.1	14.9	14.3	14.2	14.1	14.0	13.9	13.9	14.0	15.3	17.7	21.1	23.4	24.8	26.6	27.3	27.6	29.7	30.2	29.2	30.6	30.8	30.1	30.0	30.7	30.9	30.3	29.6	26.7	23
4	15.9	15.6	15.2	15.1	14.7	14.3	14.2	14.4	14.0	13.7	13.6	13.6	13.6	13.6	15.0	16.9	18.6	21.5	23.6	25.1	26.7	27.8	28.7	29.6	28.7	29.2	30.4	30.4	30.8	30.1	30.1	29.3	28.5	25.6	22
5	15.2	14.9	14.8	14.6	14.3	14.2	13.9	13.6	13.5	13.1	13.0	12.9	12.8	12.9	14.3	16.2	17.6	21.1	22.8	24.2	26.1	27.1	28.1	27.9	28.6	29.3	30.2	30.0	30.0	29.2	30.2	29.1	27.7	25.4	22
6	14.8	14.6	14.2	14.2	13.9	13.5	13.3	13.1	12.9	12.7	12.5	12.4	12.2	12.4	14.3	15.0	17.4	19.7	21.3	23.0	24.5	25.5	27.0	26.9	28.3	29.2	29.8	29.6	29.4	29.2	29.0	28.3	27.5	24.8	21
7	14.8	14.7	14.5	13.9	13.8	13.7	13.4	13.2	12.9	12.7	12.8	12.6	12.3	12.6	14.0	15.9	17.5	20.1	22.5	23.6	24.9	26.4	27.8	26.4	28.0	27.8	27.8	28.2	28.2	28.1	27.7	27.4	26.4	24.4	22
8	15.2	14.9	14.7	14.6	14.9	14.8	14.7	14.3	13.9	14.1	14.1	13.2	12.9	12.9	14.2	16.2	20.0	21.4	22.9	23.7	25.1	25.3	27.3	26.7	28.3	28.0	27.4	28.0	28.1	27.7	28.1	27.8	27.0	24.4	21
9	15.1	15.1	14.8	14.3	13.9	13.4	13.5	13.2	12.9	12.8	12.6	12.2	12.3	12.7	13.7	15.5	16.3	18.7	20.7	22.2	23.4	24.4	26.1	26.9	27.9	28.7	28.4	28.9	28.9	28.9	29.2	28.3	27.2	24.3	21
10	14.6	14.4	14.3	14.2	14.1	13.8	13.7	13.5	13.6	13.1	13.0	13.0	12.7	12.9	14.4	16.5	19.4	20.5	22.1	23.7	25.0	25.9	27.0	27.8	27.9	28.1	28.8	29.4	29.1	28.9	28.5	28.1	27.4	24.8	22
11	14.3	14.0	14.1	14.0	13.4	12.9	12.9	12.7	12.4	12.4	12.3	12.4	12.2	12.6	13.6	15.3	18.3	21.9	23.5	25.3	25.9	27.6	28.1	29.1	30.5	31.2	31.8	31.4	31.9	32.4	32.1	31.7	29.6	25.5	22
12	14.6	14.5	14.1	13.9	13.7	13.5	13.4	12.9	12.9	12.8	12.6	12.5	12.4	12.3	13.7	16.0	19.6	22.1	23.5	25.3	26.9	28.4	29.2	30.9	31.0	30.3	30.8	31.0	30.8	29.9	30.1	29.1	28.6	25.3	21
13	14.0	13.9	13.6	13.2	12.9	13.0	12.6	12.3	12.2	11.7	11.5	11.7	11.7	12.5	13.6	16.3	18.7	21.0	22.7	25.6	27.4	27.7	28.3	28.9	29.6	29.6	30.0	30.0	30.4	30.0	29.8	29.2	27.9	24.3	21
14	13.5	13.4	13.0	13.0	12.4	12.1	12.0	11.9	11.7	11.7	11.4	11.1	10.8	11.0	12.7	15.0	15.9	20.2	21.5	23.8	24.8	27.1	27.9	28.5	28.7	30.2	29.2	29.4	29.6	29.9	29.6	28.6	26.5	24.2	21
15	13.9	13.7	13.4	13.2	13.2	12.9	12.5	12.5	12.2	12.0	12.0	12.6	12.1	12.4	13.3	15.0	17.1	19.4	20.6	22.3	24.4	25.5	26.9	28.6	28.7	28.8	28.6	28.9	29.3	28.9	28.5	27.6	26.6	23.5	20
16	14.1	13.9	13.5	13.5	13.1	12.4	12.3	12.1	12.1	12.1	11.8	12.2	11.4	12.3	13.1	14.4	16.4	18.5	21.5	23.7	25.2	26.4	28.4	27.8	28.3	29.6	29.7	29.9	29.1	29.0	28.2	27.3	26.7	23.4	20
17	13.6	13.4	13.1	12.9	12.7	12.7	12.7	11.9	12.0	12.2	11.9	11.0	10.8	10.7	11.8	13.6	15.5	17.7	21.4	22.1	23.9	25.2	26.5	28.0	27.5	28.4	29.2	29.2	29.4	29.7	30.6	28.5	26.3	22.6	20
18	13.1	12.9	12.7	12.3	12.2	11.6	11.5	11.2	10.7	10.9	10.8	10.5	10.7	10.0	11.4	14.2	15.7	17.8	20.3	21.9	23.4	24.6	26.4	26.6	27.0	27.7	30.0	29.1	29.4	30.0	28.9	28.4	26.3	22.2	19
19	14.5	14.0	14.0	13.6	13.3	12.8	12.3	12.2	11.8	11.6	11.5	11.5	10.8	11.1	12.6	14.5	17.6	21.0	21.7	23.6	24.1	24.8	27.1	26.8	26.5	26.4	27.1	27.5	28.2	26.2	27.0	26.4	24.2	21.1	18
20	13.2	13.3	13.2	12.9	12.7	12.3	11.9	11.7	12.1	11.9	12.0	11.7	11.8	11.9	12.4	13.3	14.9	17.9	20.4	21.8	23.2	24.3	25.3	25.7	26.1	25.7	25.2	26.3	26.3	26.7	25.5	24.6	21.9	20.7	20
21	14.7	14.4	14.4	14.2	14.3	14.1	13.9	13.8	13.9	13.7	13.3	13.1	12.6	12.8	13.8	15.2	16.4	19.1	20.3	21.1	21.7	23.0	24.2	25.2	24.4	26.3	26.4	25.6	26.9	27.3	27.3	26.4	25.7	21.7	19
22	17.0	17.5	16.4	16.1	16.2	16.6	16.3	16.2	15.8	15.6	15.6	15.4	15.5	15.6	16.3	16.5	16.4	17.3	18.1	19.2	21.2	23.7	24.7	25.8	23.9	--	25.7	25.9	25.5	25.2	24.6	23.6	22.7	20.8	19
23	13.7	13.3	13.3	13.2	12.3	12.8	12.1	11.8	12.0	11.8	11.6	11.7	11.2	11.1	12.1	14.9	17.5	20.0	21.2	22.6	23.0	23.6	24.1	25.1	24.2	24.8	25.5	25.3	25.4	25.9	25.1	24.4	23.7	20.6	18
24	12.2	12.2	12.0	11.8	11.7	11.3	11.0	11.0	10.8	10.6	10.3	10.2	10.2	10.2	10.7	12.4	13.8	16.1	18.9	21.2	21.7	23.9	23.1	23.6	23.8	24.9	23.9	24.8	25.0	26.3	25.2	24.2	23.7	20.3	18
25	12.8	12.8	12.5	12.2	12.4	11.9	11.9	11.6	11.3	11.1	10.9	11.0	11.1	10.7	11.2	12.4	13.4	15.0	18.0	19.9	22.1	23.6	24.1	24.9	25.4	26.2	26.6	26.3	26.1	25.5	25.2	24.7	23.6	20.9	18
26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19.3	20.9	21.9	23.3	24.4	24.9	24.6	25.7	25.8	25.7	26.6	26.9	24.2	22.4	20.0	18
27	12.2	12.2	12.0	11.7	11.6	10.5	10.2	10.2	10.0	10.1	10.0	9.7	9.2	9.2	9.9	11.7	13.7	16.0	19.4	20.4	21.0	22.8	23.9	24.8	24.7	25.8	25.7	25.7	25.5	25.8	23.7	25.1	24.0	20.6	18
28	12.2	12.2	11.6	11.6	10.9	12.0	11.9	11.7	11.2	9.9	9.5	9.8	10.6	11.1	11.0	11.7	12.9	13.9	16.3	..	..	..	..	..	..	..	..	..	23.7	23.8	23.5	23.2	22.6	20.8	19
29	12.2	12.2	12.0	11.3	11.0	10.6	10.7	10.4	9.8	9.9	9.6	9.5	9.4	9.4	9.6	10.4	11.2	12.2	14.0	15.4	17.3	18.1	19.8	21.3	22.4	22.7	23.1	23.3	23.9	24.4	23.9	23.7	22.7	19.3	16
30	9.0	8.9	8.8	8.6	8.7	8.4	8.2	8.9	8.1	7.7	7.5	8.1	7.2	7.2	8.3	10.3	12.5	14.8	17.2	18.6	20.4	21.1	22.5	21.2	22.7	23.1	24.3	23.8	23.8	24.1	24.3	23.7	22.3	18.6	16
RPP.	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	29	29	30	30	30	30	30	30	3
MIN.	9.0	8.9	8.8	8.6	8.7	8.4	8.2	8.9	8.1	7.7	7.5	8.1	7.2	7.2	8.3	10.3	11.2	12.2	14.0	15.4	17.3	18.1	19.8	21.2	22.4	22.7	23.1	23.3	23.7	23.8	23.5	23.2	21.9	18.6	16
MAX.	17.0	17.5	16.4	16.3	16.2	16.6	16.3	16.2	15.8	15.6	15.6	15.4	15.5	15.6	16.3	17.7	21.1	23.4	24.8	26.6	27.4	28.4	29.7	30.9	31.0	31.2	31.8	31.4	31.9	32.4	32.1	31.7	29.6	26.7	23
MEAN	14.0	13.9	13.7	13.4	13.2	13.0	12.8	12.6	12.4	12.2	12.0	11.9	11.7	11.9	12.9	14.6	16.6	18.9	20.8	22.5	23.8	25.0	26.1	26.7	27.1	27.7	28.0	28.0	28.0	28.0	27.8	27.0	25.8	22.7	20
STD.	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.7	1.8	1.9	2.4	2.7	2.4	2.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C.V.	11.2	11.3	11.2	11.6	11.8	12.4	12.5	12.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]																																			

Table 4.4 RESULTS OF REGRESSION ANALYSIS OF MEAN DAILY TEMPERATURE(INDEPENDENT VARIABLE $T_{E(ave)} = (T_{MIN}+T_{MAX})/2$)

Months	Equations of Regression lines	Standard error of estimates	Coefficient of Determination (R^2)
January	$T_{h(ave)} = 0.2437 + 0.9165\ T_{E(ave)}$	0.5317	0.9423
February	$T_{h(ave)} = 1.2119 + 0.8756\ T_{E(ave)}$	0.6618	0.9065
March	$T_{h(ave)} = -0.9263 + 1.0199\ T_{E(ave)}$	0.4520	0.9773
April	$T_{h(ave)} = -0.2746 + 1.0073\ T_{E(ave)}$	0.9240	0.9332
May	$T_{h(ave)} = -2.7133 + 1.0765\ T_{E(ave)}$	0.9647	0.8260
June	$T_{h(ave)} = 0.7778 + 0.9700\ T_{E(ave)}$	0.5470	0.9090
July	$T_{h(ave)} = 1.3266 + 0.9384\ T_{E(ave)}$	0.5893	0.9183
August	$T_{h(ave)} = 1.6416 + 0.9201\ T_{E(ave)}$	0.5159	0.8696
September	$T_{h(ave)} = -0.1302 + 0.9775\ T_{E(ave)}$	0.5999	0.7886
October	$T_{h(ave)} = -3.2680 + 1.0843\ T_{E(ave)}$	0.3954	0.9660
November	$T_{h(ave)} = -0.8197 + 0.9649\ T_{E(ave)}$	0.4003	0.9542
December	$T_{h(ave)} = 1.0741 + 0.8302\ T_{E(ave)}$	0.4455	0.9187
All	$T_{h(ave)} = -1.5466 + 1.0339\ T_{E(ave)}$	**0.7334**	**0.9890**

the average values of dependent variable are always less than the average obtained from 24 hourly values. The corrected equation may be given as

$$T_{h(ave)} = -1.5466 + 1.0339\,T_{E(ave)}$$

where $T_{E(ave)}$ is the average calculated from the daily extreme values (Max and Min) and $T_{h(ave)}$ is the average value calculated from the 24 discrete hourly values. In some months the departure is as high as 3°C, which can not be ignored. The graphs **Fig. 4.1** shows regression lines for each months, whereas the regression between $T_{h(ave)}$ and $T_{E(ave)}$ on annual basis is shown in **Fig.4.2.**

4.2.4 Conclusion and Remarks

It is concluded that the traditionally calculated average air temperature are not representative of true daily averages for all the months. A correction factor is to be developed for all observing stations in respect of each month and the data be corrected before using them to other models as inputs.

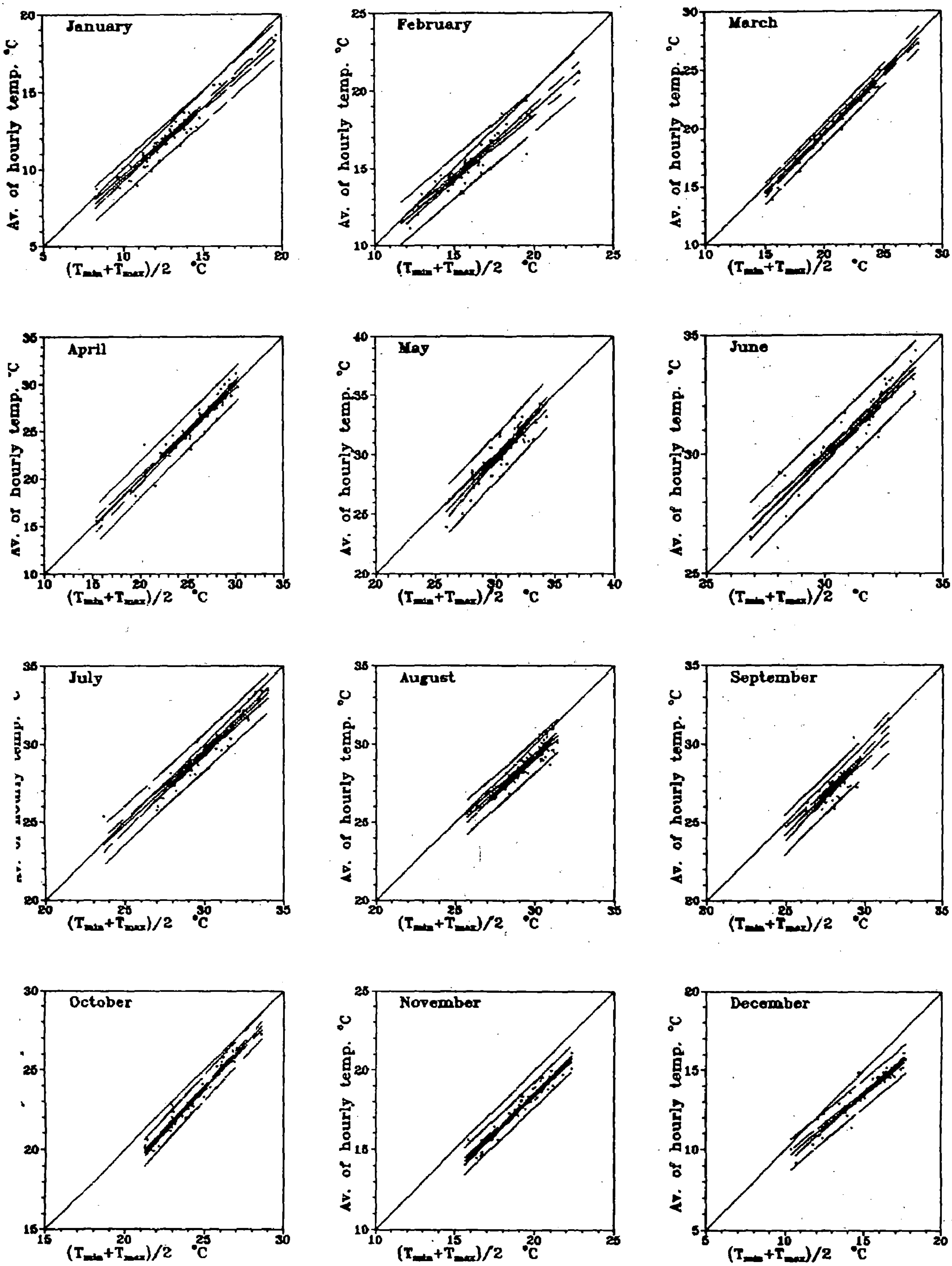


FIG. 4.1 REGRESSION LINE PLOTS OF DAILY MEAN OF HOURLY AND EXTREME AIR TEMPERATURE FOR DIFFERENT MONTHS OF THE YEAR-1990.

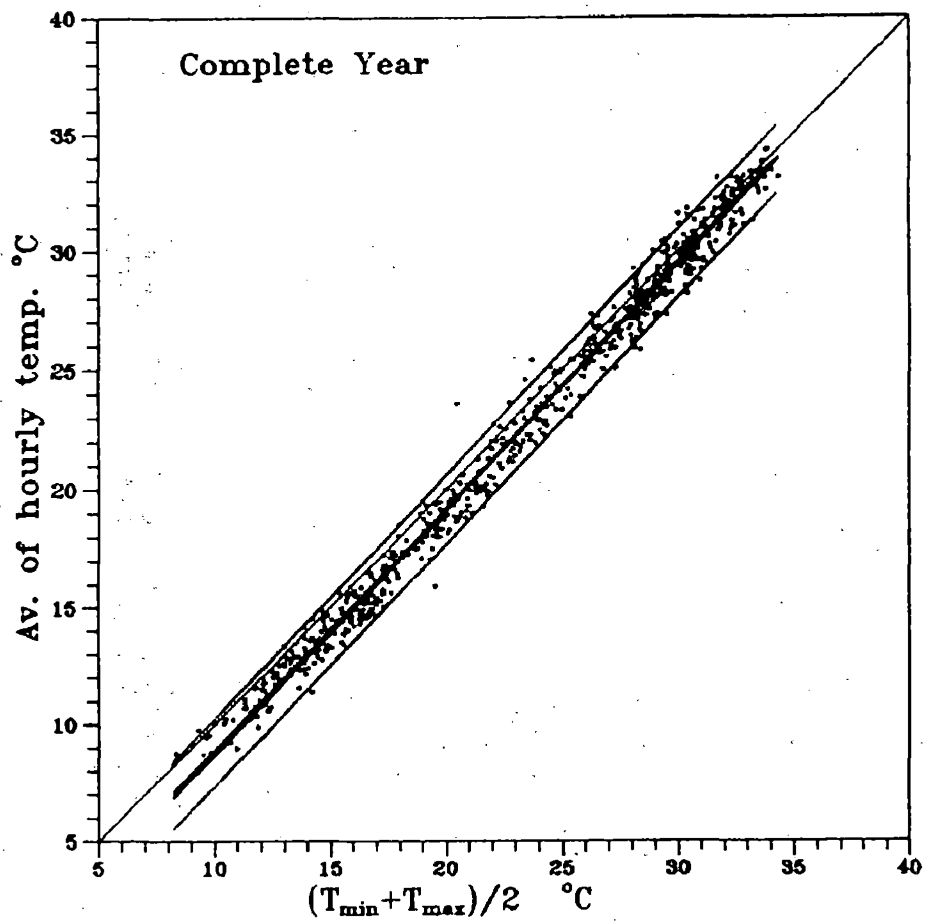


FIG. 4.2 REGRESSION LINE PLOTS OF DAILY MEAN OF HOURLY AND EXTREME AIR TEMPERATURE FOR ONE COMPLETE YEAR-1990.

CHAPTER - 5

ARIMA MODELLING OF SHORT INTERVAL AIR TEMPERATURE DATA

5.0 INTRODUCTION

The time series modelling of short interval air temperature data has been attempted in this chapter with the following broad objectives:

i) to study the problems of analysing the short interval data and to develop user friendly software with graphic capability in **FORTRAN-77** for modelling of univariate time series.

ii) to obtain hourly data from half hourly data of Automated Hydrologic Station by aggregation and to model it by Autoregressive Integrated Moving Average **(Box and Jenkins, 1976)** model.

This chapter first presents the details of ARIMA model, **Box and Jenkins (1976)** and then gives the results of analysis. Programme listing is presented in Annexure-I and the results in the form of tables and output graphs in Annexure-II.

5.1 AUTOREGRESSIVE INTEGRATED MOVING AVERAGE (ARIMA) MODEL

5.1.1 The Model

The Autoregressive (**AR**), Moving average (**MA**), Autoregressive Moving Average (**ARMA**) models are short memory models and used to model stationary time series. **Box and Jenkins (1970)** developed a model, called an autoregressive integrated moving average (**ARIMA**) process, capable of describing a wide range of behaviour in time series. This model is used for modelling nonstationary time series. The multiplicative seasonal ARIMA model for Z_t series is given by:

$$\phi(B)\ \phi(B^s)\ \nabla^d\ \nabla_s^\lambda = \theta(B)\ \Theta(B^s)\xi_t \qquad \text{......(1)}$$

where

s: seasonal length equal to 12 for monthly river flows

B: Backward shift operator defined by $B^s z_t = z_{t-s}$

ξ_t: Normally independently distributed white noise residual with mean equal to zero and variance σ_a^2

$\phi(B)$: $(1-\phi_1 B-\Phi_2 B^2.....\phi_p B^p)$ non seasonal auto-regressive operator , where ϕ_1 , $\phi_2 ...\phi_p$ are non seasonal parameters.

$\phi(B^s)$: $(1-\phi_1 B^s-\Phi_2 B^2 s.....\phi_p B^{sP})$ seasonal AR operator of order P and ϕ_i = 1, 2 .... P, are the seasonal AR parameters.

$\theta(B)$: $(1-\Theta_1 B-\Theta_2 B^2.....\Theta_q B^q)$ non seasonal moving average operator (MA), $\theta_1, i=1,2,3........q$. are the non seasonal MA parameters.

$\Theta(B^s)$: $(1 - \Theta_1 B^s - \Theta_2 B^2 s.....\Theta_q B^{sQ})$ are the seasonal MA operator of the order Q, θ_i = 1, ...Q. are the seasonal MA parameter&.

$Z^{(\lambda)}$: Some appropriate transformation of Z_t such as Box Cox transformation **Box-Cox(1964)**.

∇ : (1-B)

The notation $(p,d,q).(P,D,Q)_s$ is used to represent the seasonal ARIMA model of Eq(1). The first set of brackets contains the order of the non-seasonal operators and the second pair of brackets has the order of the seasonal operators.

5.1.2 Steps Used for Model Building

While applying a Box Jenkins model or in general any type of stochastic model to a particular problem, it is recommended that the three stages of model development be adhered to. The first step is to identify the form of the model that may fit the given data. Once the model is tentatively identified the next step is to estimate the parameters of the model by an efficient parameter estimation technique. Once the parameters are estimated, the model is checked for the possible inadequacies. If the diagnostic check reveals serious anomalies, appropriate model modification be made by repeating the identification and estimation stage. The ARIMA class of models building for a process is therefore a three stage iterative process consisting of:

i). Identification of the model
ii). Parameter estimation
iii). Diagnostic checking

5.1.2.1 Identification of the model

The purpose of the identification stage is to determine the order of differencing required to produce stationarity and also the order of both seasonal and nonseasonal AR and MA operators of the Z_t series. The steps used for identifying the order of the model are:

i) **Plot the original series:** A visual inspection of a plotted time series may reveal one or more of the following characteristics (a) seasonality (b) trends either in the mean level or in the variance of the series (c) persistence and (d) long term cycles.

ii) Autocorrelation function (ACF)

To use the ACF in model identification, we first calculate and then plot r_k against lag-k upto a maximum lag upto n/4. Later we examine the plot of the ACF to detect the presence of non stationarity in the Z_t series. When the data are non-stationary, differencing is required. For seasonally correlated data with seasonal length equal to s, the ACF often follows a wave pattern with peaks, s, 2s, 3s and other integer multiple of s as shown in **Box and Jenkins(1970)**. If the ACF at lags which are integer multiples of the seasonal length 's' that do not die out rapidly, indicates that seasonal differencing is required to bring about the characteristics of stationarity. Failure of ACF to damp out at other lags may imply that non-seasonal differencing is also required.

Once the data has been differenced enough to produce non-seasonal stationarity ($\nabla^d Z_t$) and both seasonal and nonseasonal stationarity ($\nabla^d \nabla_s^D Z_t$) of the seasonal data, we check the ACF of the differenced to series to determine the number of AR and MA parameters required in the particular model. Now, the ACF of the differences series is plotted. If ($\nabla^d \nabla_s^D Z_t$) is a white noise, the r_k is approximately NID(o, 1/n). By plotting the confidence limit on the ACF diagram and checking whether the significant number of r_k values fall outside the chosen confidence limit. When ($\nabla^d \nabla_s^D Z_t$) is not a white noise then the following general rules may be invoked to help determine the type of the model required.

Non seasonal model: For a sure (0,d,q) process r_k cuts off and is not significantly different from zero after lag-k. If r_k tails off and does not truncate, suggests that AR terms are needed to model the time series.

Seasonal model: When a process is a pure MA (0, d, q).(0,D,Q)$_s$ model, r_k truncates and is not significantly different from zero after lag q + SQ.

iii) PACF - PARTIAL AUTOCORRELATION FUNCTION

The theoretical PACF can be calculated by using the Box & Jenkins approach **Box Jenkins(1970)**. For model identification, we plot the PACF coefficients ϕ_{kk} against lag-k. The following general rule may prove useful.

Non seasonal model: When the process is pure AR(P) ϕ_{kk} truncates. If and is not significantly different from zero after lag-p. After lag-p, ϕ_{kk} is approximately NID(o,1/n).

Seasonal model: When the process is pure AR(p,d,0).(P,D,0)$_s$ model ϕ_{kk} cuts off and is not significantly different from zero after lag-(p+sP). After lag-(p+sP), ϕ_{kk} is approximately NID(0,1/n). If ϕ_{kk} damps out at lags that are multiples of 's', suggests presence of a seasonal MA component into the model.

Inverse autocorrelation function (IACF): Claveland(1972) defines the IACF of a time series as the ACF associated with the inverse of the spectral density function of the series. The IACF of the ($\nabla^d \nabla_S^D Z_t$) series is defined by the ACF of (q,d,p).(Q,D,P)$_s$ process. When the process is a pure AR process, r_k cuts off and is not significantly different from zero after lag-p.

Inverse partial autocorrelation function (IPACF): IPACF is the inverse of the PACF and has the characteristics interchanged between the AR and MA process. The ACF, PACF, IACF and IPACF transfer the given information into a format whereby it is possible to detect the number of AR and MA terms required in the model. In general, the ACF and IPACF truncates the pure MA process, while PACF and IACF cuts off the AR process. For mixed process all four functions attenuate.

In order to get the details of the model identification the reader is advised to see the works of **Hipel** and **Mcleod(1977)**, **Ledolter(1978)**, **Cline(1979)**, **Chander et al.(1980)**, **Merkrecher** and **Delleur(1974) and Chatfield** and **Prothero(1973)**.

5.1.2.2 ESTIMATION OF PARAMETERS

If the parameters in the model are linear (AR models), they can be estimated by the use of Yule Walker equations or with the help of least square minimisation. However, these methods are not applicable when the parameters are non-linear. In such cases, **Box & Jenkins(1970)** suggest the use of approximate minimum least estimates of the ARIMA model parameters be obtained by base employing the unconditional sum of the squares method **Clarke(1973)**. In this case, the unconditional sums of the squares function is minimised to get the least square parameter estimates. **Mcleod(1978)** has described a modified sum of the squares method which provide the closest approximation to the Box-Jenkins exact maximum likelihood estimates.

When the moving average terms are present in the model, optimisation techniques are required to estimate the parameters. Some of the optimisation algorithms that have extensively been applied include the (a) Gauss linearization (b) Steepest Descent and (c) Marquardt Algorithm. Box and Jenkins have recommended the use of Marquardt. The algorithm (has fast convergence even when the initial estimates are wrong) for the estimation of parameters. **Chander et**

al.(1980) have used the Marquardt algorithm in the estimation of ARIMA models parameters for the monthly flows of the Krishna and the Godavari river.

5.1.2.3 SELECTION OF MODEL

At the identification stage it is quite likely that not a single is uniquely identified. In fact, two or three models are subjectively identified based on correlogram analysis and their parameters estimated. Now the problem of selecting the final model arises. Many times, model which gives the minimum variance in residuals is selected. This model selection rule can often lead to incorrect results. The main difficulty in the minimum variance rule is that it does not include the **Principle of Parsimony** of parameters. One of the model selection rule including parsimony is based on the classical **F-test** in hypothesis testing **Astrom(1967), Kashyap and Rao(1976)**. Although this test weighs the order of the model in the decision, the test threshold is set by subjectively selecting an acceptable risk rate.

An approach not requiring arbitrarily specified parameters like significance levels has been proposed by **Akaike(1974)**. Based on information theoretical arguments, the information criterion is defined as twice the difference between the number of unknown model Parameters and the maximum log likelihood. For ARIMA model the **Akaike Information Criterion(AIC)** reduces to:

$$AIC = -2 \ln (\text{max. likelihood}) + 2(k) \qquad (3)$$

Where k is the number of AR and MA parameters (i.e. p&q OR P&Q) used to define the model. The model which gives the minimum AIC is finally chosen as the model. AIC criterion has been applied in hydrological time series by **Mcleod and Hipel(1978), Cline(1979), Ozaki(1980).** However, Mcleod studies showed that by using the AIC criterion, the model order increases as compared to minimum error variance model. Another model selection criterion is the posterior probability(PP) criterion, developed independently by **(Schwarz(1977)** and **Kashyap(1977)).** The PP criterion also expresses parsimony but penalizes more heavily the extra parameters than the AIC criterion. It has been shown by **Kashyap(1980)** that PP criterion gives a more consistent decision rule for selecting a model than the AIC decision. Extensive literature exist in control Engg. journals about the time series model selection.

5.1.2.4 DIAGNOSTIC CHECKING

Most diagnostic checks deals with the residuals assumptions in order to determine whether ξ_t are independent, homo scedastic and normally distributed. Residual estimates ξ_t are needed for the tests used in checking the three aforementioned residual assumption. It may be mentioned that data transformation cannot correct dependence of the residuals because lack of independence indicated that the present model is inadequate. Rather the identification and estimation stages must be repeated in order to determine a suitable model.

Another class of diagnostic checking is done by over-fitting. Overfitting involves fitting a more elaborate model than the one estimated, to check if inclusion one or more parameters greatly improve the fit. For example, the PACF and the IACF rosy show decreasing but significant values at lag-1, lag-2 and at lag-9. If an ARMA (2,0) model is originally estimated, then a model to check by overfitting would be

$$(1 - \phi_1 B - \phi_2 B^2 - \phi_9 B^9)\ Z_t = 0 \qquad \ldots\ldots(4)$$

A mle of ϕ_9 , three or four times its standard estimate would definitely indicate that a more elaborate model should be selected. Likelihood ratio test **Mcleod(1978)** can also be used.

In order to determine whether the residuals are white noise appropriate procedure would be to examine the residual auto correlation coefficient. Another but less sensitive check is to calculate and to perform a significance test for the Portemantau Statistic.

5.1.3 Program Details

The programme for ARIMA model is presented in Annexure-I. While developing the programme for Analysing the half hourly data, some problems were faced and hence LAHE Compiler was used. For various stages of the programme **Box & Jenkins(1976)** may be referred, which is self explanatory and therefore not described here in the present context.

5.2 MODELLING OF HOURLY AIR TEMPERATURE

5.2.1 The Data

The data used in this present study is obtained from the Automated Hydrologic Station(AHS), installed in the campus of National Institute of Hydrology(NIH), Roorkee. This provided half hourly good quality data, which was aggregated to hourly values with the help of HYMOS package. Though a good length of data on various hydrometeorological variables are available on regular basis for about

5 years w.e.f. 1990. In the present study only one month data was used. The missing values were completed by the help of the thermographic charts of the manual observatory of the NIH. These data are presented in **Annexure-II, Table 5.1.**

The hourly air temperature of January 1990 was subjected to statistical analysis. The results of statistical analysis are presented in **Annexure-II, Table 5.2**. The result shows that the temperature for this month varies from 5.4°C to 18.7°C with a mean of 11.5°C. The median and mode coincide, standard deviation is 2.92, which means that the density of variation in temperature is near to it in a small bandwidth. The value of skewness is low i.e. 0.4 only, indicating deviation of its distribution leaned towards left from normal. The maximum values nearby 18°C were for a small period only. Frequency distribution and probability for each class of 2°C is presented vide **Annexure-II, Table 5.3**, whereas the results of various tests of randomness of data are presented vide **Annexure-II, Table 5.4.**

5.2.2 Results

For modelling of hourly temperature data, following options were tried:

a) Differencing at
   i) lag-1 ii) lag-24 iii) lag-1 and lag-24

b) Order selection of the model

For selection of the differencing schemes, the order of each of AR and MA were varied from 0 to 2. For different combinations, the following statistics were computed.

i) model parameters ϕ_1, ϕ_2, θ_1 and θ_2 etc.
ii) mean and variance of residuals
iii) AIC for different models

The histogram of the raw data was plotted as the first step of analysis and presented with computer code in the Annexure-I vide **Fig. 5.1**, indicative of non-normal distribution. The next steps give plots presented as **Fig. 5.2**, **Fig. 5.3**, **Fig. 5.4** and **Fig. 5.5**. These figures show scatter plots, autocorrelogram or autocorrelation function **(ACF)**, partial autocorrelogram **(PACF)** and spectral density function**(SDF)** plots respectively. These plots are indicative of the short range trends, periodicities and their extent. The low values of the temperature responses in the scatter plot, however, indicate the presence of cloudy or partially cloud weather in some days viz. 1,2,3,8,9,29 and on 30th. These plots pertain to raw data and provide first hand information on the nature of the data received by the temperature sensor. The presence of clear sinusoidal nature in ACF is a clear indication of strong periodicity of 24 hour period. The SDF plot also indicates this single periodicity by its powerful spectrum peak. This also indicates the presence of some low frequency oscillations near the peak, may be due to small changes in weather conditions or sampling errors.

Next operation of differencing on data set was performed to remove the dominant effects of trends and periodicities. By inspection of the ACF plot of this differenced series and by the knowledge of the physical phenomenon or the nature of the variable, operation by taking two differencing, one at shorter period at lag-1 and the other at longer at lag-24, was proposed. The lag-1 differencing is done to remove the non-stationarity, whereas lag-24 differencing removes or reduces the power of diurnal periodicity.

Other plots are subject to modeller's choice and hence not presented herewith. These subsequent plots are repetition of simple scatter plots, ACF, PACF and SDF plots of data after one or two differencing of the data series. The ACF plot after differencing indicates the possibility of Markov process of order 1 or 2. The series show stationarity with creation of negative correlation at the differenced lag-24 and its multiples, which may be due to aliasing of periodic frequency. The PACF does not show any significant contribution of any significant short or long range characteristics in the data. However, a small contribution appears at some short lags. The reason may be attributed to differencing where it results in removal of some extreme fluctuations, it simultaneously creates some oscillations with varied magnitudes also. The SDF of the differenced series present periodic peaks of very small power which die out slowly. The residuals appear to maintain normality.

Histogram plot of the differenced series is taken into the account by the programme before proceeding to the next step to fit the varied choices of order of ARMA model to the differenced series. Next step is to plot the residuals after fitting of desired ARMA model exercise. Various fitted model parameters are presented in **Annexure-II, Table 5.5**. This table also gives the statistics of residuals. The table has been obtained after trying many combinations of orders of ARMA model and various differencing options.

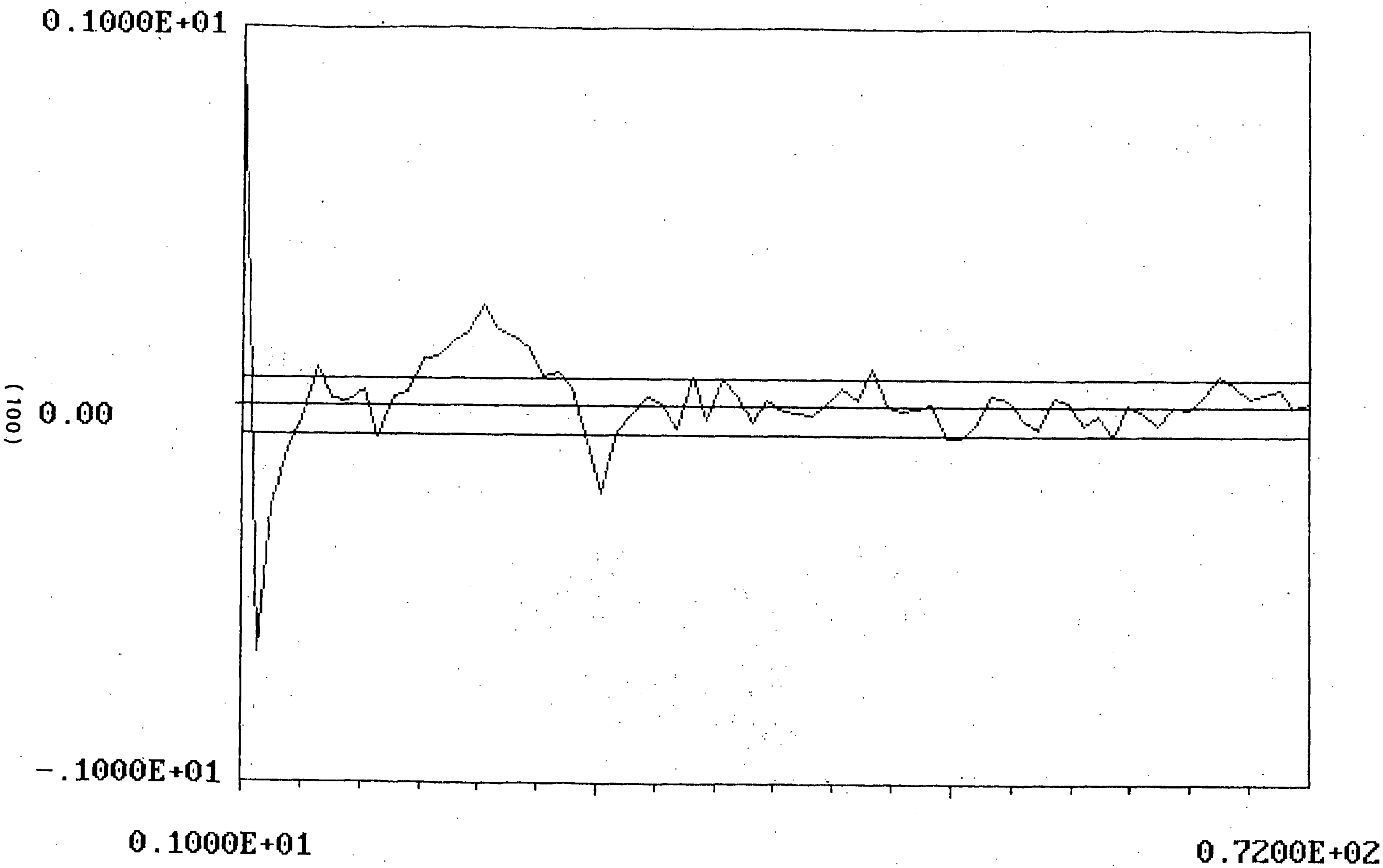
In view of the selection criteria of variance and AIC, it may be seen from the Table 5.5, that the most competitive model amongst all appears to be ARMA(2;2) with one differencing at lag-1. But, in view of the physical phenomenon and nature of the ACF and SDF, the model ARMA(2,1) with two differencing at lag-1 and lag-24 having comperable variance and AIC to above may be considered to be the most appropriate model.

5.3 RECOMMENDATIONS

The work in the present assignment is just an attempt and exercise in the direction of ARIMA modelling. The work carried out here may be very useful in other disciplines of science and engineering and a series of even less time step may be analysed and employed in a number of energy management system devices. A little more effort of inclusion the outcome as an element of forecast may bring out the concept of super intelligent and smart procedure for imposing artificial control of internal environment. The ARIMA modelling of various hydrometeorlogical variables with its multivariate approach may provide better solution and open new vistas of application, specially in the area of hydrology provided an element of radiation also is included as suggested by **Lovedy and Graggs(1992)**.

It suggests that for each month of the year a similar modelling exercise may be undertaken and repeated for many years. Then an average model for modelling hourly temperature data may be recommended for a particular place for every month of the year.

Fig. 5.4 : Plot of PACF of Raw Data



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```
c     GENERAL PROGRAM FOR TIME SERIES ANALYSIS
c     ARIMA MODELLING
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/se/ phi(10), tht(10)
      common/res1/iper(5),iord(5),rmean,rvar,s3,s4,chi1,sumn,aic
      implicit real*8 (a-h,o-z)
      open(3,file='ts.res',status='unknown')
      call BJM
      write(*,*) ' No of AR Param, No of MA Param ?'
      read (*,*) npar, npma
      npr = npar
      if(npar.eq.0) npr = 1
      call ARMA
      if(npar.ge.1) ake(1) = par(1)
      if(npar.ge.2) ake(2) = par(2)
      if(npar.ge.3) ake(3) = par(3)
      if(npma.ge.1) ake(npar+1) = pma(1)
      if(npma.ge.2) ake(npar+2) = pma(2)
      if(npma.ge.3) ake(npar+3) = pma(3)
      isa = 0
      ism = 0
      if(isa.gt.0) then
      phi(1) = 0.5
      if(isa.eq.1) ake(kmn+1) = phi(1)
      km = km +1
      endif
      if(ism.gt.0) then
      tht(1) = 0.5
      if(ism.eq.1) ake(kmn+isa+1) = tht(1)
      km = km +1
      endif
      call MARQ(SUMN)
      aic = nval*alog(sumn/nval) + 2*(npar + npma)
      write(*,31)
      if(ndf.eq.0)  write(*,32) xmean*(1-par(1)-par(2)-par(3))
      if(npar.gt.0) write(*,33) (ake(i), i=1,npar)
      if(npar.gt.0) write(*,36) (conf(i),i=1,npar)
      if(npma.gt.0) write(*,34) (ake(i), i=npar+1,kmn)
      if(npma.gt.0) write(*,36) (conf(i),i=npar+1,kmn)
      if(isa.gt.0)  write(*,37) (ake(i), i=kmn+1,kmn+isa)
      if(ism.gt.0)  write(*,38) (ake(i), i=kmn+isa+1,km)
      write(*,35) sumn/nval
      write(*,39) aic
      write(2,31)
      if(ndf.eq.0)  write(2,32) xmean*(1-par(1)-par(2)-par(3))
      if(npar.gt.0) write(2,33) (ake(i), i=1,npar)
      if(npar.gt.0) write(2,36) (conf(i),i=1,npar)
      if(npma.gt.0) write(2,34) (ake(i), i=npar+1,kmn)
      if(npma.gt.0) write(2,36) (conf(i),i=npar+1,kmn)
      if(isa.gt.0)  write(2,37) (ake(i), i=kmn+1,kmn+isa)
      if(ism.gt.0)  write(2,38) (ake(i), i=kmn+isa+1,km)
      write(2,35) sumn/nval
      write(2,39) aic
31    format(/' *** FINAL RESULTS ***'/)
32    format(' Overall Constant  :', f10.3)
33    format(/' AR Parameters     :',5f10.3)
34    format(/' MA Parameters     :',5f10.3)
35    format(/' Residual Variance :', f10.3)
36    format( ' Confidence Limits :',5f10.4)
37    format(/' Seasonal AR Parm  :',5f10.3)
38    format(/' Seasonal MA Parm  :',5f10.3)
39    format(/' Akaike Info. Criteria  AIC ='f9.3/)
      call RESD
      write(3,'(i2,2x,$)') ndf
      do i=1,ndf
      write(3,'(i4,1x,i1,2x,$)') iper(i),iord(i)
```

```
      enddo
      write(3,'(i2,1x,i2,12(f8.4,1x),$)') npar,npma,
     1          (ake(i),i=1,npar),(conf(i),i=1,npar),
     1          (ake(i),i=1+npar,kmn),(conf(i),i=1+npar,kmn)

      write(3,'(7(e12.5,2x))') rmean,rvar,s3,s4,chi1,sumn/nval,aic
      stop
      end
      subroutine BJM
      character*50 tit, iys*1
      dimension xx(1002), yy(1,1002),xxac(102),zz(1002)
      DIMENSION PY(1002,3)
      dimension rh(102),rl(102),pl(102)
      common/title/tit
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/sacf1/ rh,rl,pl
      common/res1/iper(5),iord(5),rmean,rvar,s3,s4,chi1,sumn,aic
      implicit real*8 (a-h,o-z)
      real*4 py,xx,yy,xxac,ymin,ymax,zz
      open(1,file='ts.dat')
      open(2,file='ts.out')
      do i = 1,1000
      read(3,*,end=991)
      end do
991   backspace(3)
      read(1,*) ipri
      write(*,*) ' Series No. ?'
      read(*,*) isn
19    read(1,*) isr
      read(1,1) tit
1     format(a)
      read(1,*) nval, mxl
      read(1,*) (z(i),i=1,nval)
      if(isr.ne.isn) go to 19
      write(*,1) tit
      write(2,1) tit
      imiss = 1
      do 29 i =1, nval
      xx(i) = i
      zz(i) = z(i)
      py(i,1) = z(i)
29    yy(1,i) = z(i)
      tit = 'Fig.     : Histogram of Raw Data                    '
      nhisto = nval
      call histo(nhisto,zz)
      write(*,'('' No. of raw data points are : '',i5)') nval
      tit = 'Fig.     : Plot of Raw Data                         '
      write(*,*) tit
      call pregraf(nval,1,xx,py)
      call sacf( 1, 1, 1, z)
      do ixac = 1,mxl
      xxac(ixac) = ixac
      end do
      do i = 1,mxl
      py(i,1) = rl(i)
      py(i,2) = rh(i)
      py(i,3) = ac(i)
      end do
      ac(0) = 1.
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.     : Plot of ACF of Raw Data                  '
      write(*,*) tit
      call pregraf(mxl,3,xxac,py)
      do i = 1,mxl
      py(i,1) = pl(i)
      py(i,2) = pac(i)
```

```
      py(i,3) = -1.*pl(i)
      end do
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of PACF of Raw Data                    '
      write(*,*) tit
      call pregraf(mxl,3,xxac,py)
      do i = 1,mxl
      ff = 0.5*i/mxl
      xx(i) = ff
      sumff = 0.
      do j = 1,mxl - 1
      sumff = sumff + ac(j)*cos(2.*22./7.*j*ff)
      enddo
      sff = 1 + 2 * sumff + ac(mxl)*cos(2.*22./7.*mxl*ff)
      py(i,1) = sff
      enddo
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of SDF of Raw Data                     '
      write(*,*) ' No. of Differences Reqd. ( 0 for NO) ?'
      read (*,*) ndf
      if(ndf.gt.0) then
      call sdiff(ndf, iprint, nlost, nobsx)
      nval = nobsx
      do i = 1,nval
      py(i,1) = x(i)
      xx(i) = i
      end do
      write(*,'('' No. of differenced data points are : '',i5)') nval
      tit = 'Fig.      : Plot of Differenced Series                  '
      write(*,*) tit
      call pregraf(nval,1,XX,py)
      call sacf( 1, 1, 1, x)
      do i = 1,mxl
      py(i,1) = rl(i)
      py(i,2) = rh(i)
      py(i,3) = ac(i)
      end do
      ac(0) = 1.
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of ACF of Differenced Series           '
      write(*,*) tit
      call pregraf(mxl,3,xxac,py)
      do i = 1,mxl
      py(i,1) = pl(i)
      py(i,2) = pac(i)
      py(i,3) = -1.*pl(i)
      end do
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of PACF of Differenced Series          '
      write(*,*) tit
      call pregraf(mxl,3,xxac,py)
      do i = 1,mxl
      ff = 0.5*i/mxl
      xx(i) = ff
      sumff = 0.
      do j = 1,mxl - 1
      sumff = sumff + ac(j)*cos(2.*22./7.*j*ff)
      enddo
      sff = 1 + 2 * sumff + ac(mxl)*cos(2.*22./7.*mxl*ff)
      py(i,1) = sff
      enddo
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of SDF of Differenced Series           '
      write(*,*) tit
      call pregraf(mxl,1,xx,py)
      do 129 i =1, nval
129   yy(1,i) = x(i)
      else
       write(2,*)
```

```
      write(2,*) ' No Difference of the series taken'
      do 20 i=1,nval
20    x(i) = z(i)
      endif
      return
      end
      subroutine MARQ(sat)
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/res/  at1(-50:1002), chi
      common/se/ phi(10), tht(10)
      dimension at0(-50:1002), del(10,-50:1002),
     1d(10), ast(10,10), a(10,10), g(10), gst(10)
      implicit real*8 (a-h,o-z)
      pi = 0.01
      L = 0
      iter = 0
      dta = 0.05
9     call object(at0, sat)
      iter = iter + 1
      if(iter.gt.100) go to 150
      do 10 j=1,km
      ake(j) = ake(j) + dta
      call object(at1, sat1)
      ake(j) = ake(j) - dta
      do i=-9,nval
      del(j,i) = (at0(i)-at1(i))/dta
      enddo
10    continue
      do 30 i=1, km
      g(i) = 0
      do m=-9,nval
      g(i) = g(i) + del(i,m)*at0(m)
      enddo
      do 20 k=1,km
      a(i,k) = 0
      do m=-9,nval
      a(i,k) = a(i,k) + del(i,m)*del(k,m)
      enddo
20    continue
      d(i) = sqrt(a(i,i))
      if(d(i).eq.0) then
      write(*,*) ' MARQ - i, d(i) ', i, d(i)
      d(i) = 1
      endif
30    continue
      do 50 i=1,km
      do 45 j=1,km
      if(i.ne.j) ast(i,j) = a(i,j)/d(i)/d(j)
      if(i.eq.j) ast(i,j) = 1 + pi
45    continue
      gst(i) = g(i)/d(i)
50    continue
      call ge(km, ast, gst, gst)
      icn = 1
      do 60 i=1, km
      gst(i) = gst(i)/d(i)
      if(abs(gst(i)).gt.0.000001) icn=0
60    ake(i) = ake(i) + gst(i)
      l = l + 1
      call object(at1, sat1)
      if(sat1.gt.sat) then
      do i = 1, km
      ake(i) = ake(i) - gst(i)
      enddo
      pi = pi*2
      go to 9
```

```
      else
      if(sat.eq.0) write(*,*) ' MARQ - sat ', sat
      if(icn.eq.1.or.abs(sat-sat1)/sat.lt.0.000001) go to 150
      pi = pi/2
      go to 9
      endif
100   continue
150   write(*,*) a(1,1), a(2,2), a(3,3)
      call mti (km, a, 10, ast)
      do i = 1,km
      conf(i) = sqrt(sat/nval*ast(i,i))
      enddo
      write(*,*) ' Exit - MQ, Iterations = ', iter
      return
      end
      subroutine object(at, sats)
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/se/ phi(10), tht(10)
      dimension at(-50:1002), wt(-50:1002), et(-50:1002)
      implicit real*8 (a-h,o-z)
      do i=1,km
      if(ake(i).gt.5.0.or.ake(i).lt.-5.0) then
      sats = 10000000000.
      return
      endif
      enddo
      if(npar.gt.0) par(1) = ake(1)
      if(npar.gt.1) par(2) = ake(2)
      if(npar.gt.2) par(3) = ake(3)
      if(npma.gt.0) pma(1) = ake(npar+1)
      if(npma.gt.1) pma(2) = ake(npar+2)
      if(ism .gt.0) tht(1) = ake(kmn+1)
      nn=nval
      do i=1,nn
      wt(i) = x(i)
      enddo
      et(nn-npar+1) = 0
      do 20 i=nn-npar,1,-1
20    et(i) = wt(i) -(par(1)+phi(1))*wt(i+1) -(par(2)-par(1)*phi(1))
     1*wt(i+2) + wt(i+3)*par(2)*phi(1)
     1+pma(1)*et(i+1) + pma(2)*et(i+2) +tht(1)*et(i+12) -
     3pma(1)*tht(1)*et(i+13) - pma(2)*tht(1)*et(i+14)
      do 40 i=0,15
40    wt(-i) = (par(1)+phi(1))*wt(-i+1) + (par(2)-par(1)*phi(1))
     1*wt(-i+2) - wt(-i+3)*par(2)*phi(1)
     1-pma(1)*et(-i+1) - pma(2)*et(-i+2) -tht(1)*et(-i+12) +
     3pma(1)*tht(1)*et(-i+13) + pma(2)*tht(1)*et(-i+14)
      sats=0
      do 60 i=-15,nn
      at(i) = wt(i) - (par(1)+phi(1))*wt(i-1) -(par(2)-par(1)*phi(1))
     1*wt(i-2) + wt(i-3)*par(2)*phi(1)
     1+pma(1)*at(i-1) + pma(2)*at(i-2) + tht(1)*at(i-12) -
     2pma(1)*tht(1)*at(i-13) - pma(2)*tht(1)*at(i-14)
      sats = sats + at(i)*at(i)
60    continue
      return
      end
      subroutine sdiff(ndiff, iprint, nlost, nobsx)
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/res1/iper(5),iord(5),rmean,rvar,s3,s4,chi1,sumn,aic
      dimension xin(1002)
      implicit real*8 (a-h,o-z)
      nobsz = nval
```

```
      nlost=0
      do i=1,ndiff
      write(*,*) ' Diff. No ', i, ', Lag & Order ?'
      read (*,*)  iper(i), iord(i)
      write(2,*)
      write(2,*) ' Series Differenced Lag & Order ',iper(i), iord(i)
      nlost = nlost + iper(i)*iord(i)
      enddo
      nobsx = nobsz - imiss*nlost
      if(ipri.ne.0) write(*,*) ' NLOST, NOBSX = ', nlost, nobsx
      do i=1,nobsz
      x(i) = z(i)
      enddo
      ivr = nobsz
      do i=1,ndiff
      ip = iper(i)
      do j=1,iord(i)
      do k=1,ivr
      xin(k+ip) = (x(k+ip) - x(k))
      enddo
      ivr = ivr - ip
      do k=1,ivr
      x(k) = xin(k+ip)
      enddo
      enddo
      enddo
      if(ipri.le.2) return
      do k=1,nobsz,2
      if(k.gt.nobsx) x(k) = 0
      write(2,11) k, z(k), x(k), k+1, z(k+1), x(k+1)
      enddo
11    format(i5,2f12.4, i8, 2f12.4)
      return
      end
      Subroutine resd
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
      dimension rc(102), rcv(0:102)
      dimension xx(1002), yy(1,1002),xxac(102),zz(1002)
      DIMENSION PY(1002,3)
      dimension rh(102),rl(102),pl(102)
      common/sacf1/ rh,rl,pl
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/res1/iper(5),iord(5),rmean,rvar,s3,s4,chi1,sumn,aic
      common/res/  at1(-50:1002),chi
      implicit real*8 (a-h,o-z)
      real*4 py,xx,yy,xxac,ymin,ymax,zz
      character*50 tit, iys*1
      common/title/tit
      rmean = 0
      if(ipri.eq.3) write(2,*) ' Model Residuals'
      if(ipri.eq.3) write(2,51) (at1(i),i=1,nval)
51    format(10f8.4)
      do 10 i=-3,nval
10    rmean = rmean + at1(i)
      rmean = rmean/(nval + 4)
      chi = 0
      do 50 k=0,mxl
      rcv(k+1) = 0
      do 20 i=1,nval-k
20    rcv(k+1) = rcv(k+1) + (at1(i) - rmean)*(at1(i+k) - rmean)
      rcv(k+1) = rcv(k+1)/nval
      rc(k+1) = rcv(k+1)/rcv(1)
      if(k.gt.0) chi  = chi + rc(k+1)**2
50    continue
      chi1=chi
      imiss = 1
      do 29 i =1, nval
```

```
      xx(i) = i
      zz(i) = at1(i)
29    py(i,1) = at1(i)
      tit = 'Fig.      : Histogram of Residuals                    '
      nhisto = nval
      call histo (nhisto,zz)
      ymin = -99.
      ymax = -99.
      write(*,'('' No. of raw data points are : '',i5)') nval
      tit = 'Fig.      : Plot of Residuals                         '
      write(*,*) tit
      call pregraf(nval,1,XX,py)
      call sacf( 1, 1, 1, at1)
      do ixac = 1,mxl
      xxac(ixac) = ixac
      end do
      do i = 1,mxl
      py(i,1) = rl(i)
      py(i,2) = rh(i)
      py(i,3) = ac(i)
      end do
      ac(0) = 1.
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of ACF of Residuals                  '
      write(*,*) tit
      call pregraf(mxl,3,xxac,py)
      do i = 1,mxl
      py(i,1) = pl(i)
      py(i,2) = pac(i)
      py(i,3) = -1.*pl(i)
      end do
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of PACF of Residuals                 '
      write(*,*) tit
      call pregraf(mxl,3,xxac,py)
      do i = 1,mxl
      ff = 0.5*i/mxl
      xx(i) = ff
      sumff = 0.
      do j = 1,mxl - 1
      sumff = sumff + ac(j)*cos(2.*22./7.*j*ff)
      enddo
      sff = 1 + 2 * sumff + ac(mxl)*cos(2.*22./7.*mxl*ff)
      py(i,1) = sff
      enddo
      write(*,'('' Maximum no. of lags are : '',i5)') mxl
      tit = 'Fig.      : Plot of SDF of Residuals                  '
      write(*,*) tit
      call pregraf(mxl,1,xx,py)
      rvar = rcv(1)
      sum3 = 0.
      sum4 = 0.
      do i= 1,nval
      sum3 = sum3 + (at1(i) - rmean)**3
      sum4 = sum4 + (at1(i) - rmean)**4
      end do
      sum3 = (nval*sum3)/((nval-1)*(nval-2)*rvar**1.5)
      sum4 = (nval**2.*sum4)/((nval-1)*(nval-2)*(nval-3)*rvar**2.)
      s3 = sum3
      s4 = sum4
      write(*,11) rmean, rvar, sum3, sum4
      write(2,11) rmean, rvar
11    format(/' Statistics of Residuals'/' Mean : ',e15.8,', Var : '
     1,e15.8,/' Skewness : ',e15.8,',  kurtosis : ',e15.8)
      write(2,*) '  Lag       ACV         AC'
      do k=2,mxl+1
      write(2,14) k-1, rcv(k), rc(k)
      enddo
14    format(i5,2f11.3)
```

```
      chi = chi * nval
      idf = mxl - ndf - npar - npma
      write(*,16) chi, idf
      write(2,16) chi, idf
16    format(/' Portmanteau Test Result ***'/' Q-Statistic = ',
     1e15.8,',   Degrees of Freedom =',i4/)
      return
      end
      subroutine movave (z,nval)
      dimension z(1002),zma(1002,3),x(1002)
      common/res1/iper(5),iord(5),rmean,rvar,s3,s4,chi1,sumn,aic
      character*1 iys
      character*50 tit
      implicit real*8 (a-h,o-z)
      ymin = -99.
      ymax = -99.
1     write(*,'('' No. of data to be used for moving average?  '',$)')
      read(*,*) imano
      write(3,'(1x,i4,2x,$)')imano
      ima1 = -imano/2  + 2
      ima2 = imano/2 + 1
      do i = 1, nval
      x(i) = i
      zma(i,1) = 0
      do j = ima1, ima2
      if (j.le.0) az = z(nval + j)
      if (j.gt.nval) az = z(j - nval)
      if ((j.gt.0).and.(j.le.nval)) az = z(j)
      zma(i,1) = zma(i,1) + az
      end do
      ima1 = ima1 + 1
      ima2 = ima2 + 1
      zma(i,1) = zma(i,1)/imano
      end do
      write(*,'('' No. of data points are : '',
     1      i5)') nval
      tit = 'Fig.     : Plot of Moving Average of      Data       '
      write(*,*) tit
      call pregraf(nval,1,X,zma)
      write(*,*) ' Do you want to make more trial (y/n) ?'
      read (*,*) iys
      if(iys.eq.'y'.or.iys.eq.'Y') then
      go to 1
      else
      do i = 1,nval
      IF (I.GT.NVAL/2.) ZMA(i,1) = (zMA(i,1)+ZMA(I-NVAL/2,1))/2.
      IF (I.LE.NVAL/2.) ZMA(i,1) = (zMA(i,1)+ZMA(I+NVAL/2,1))/2.
      z(i) = z(i) - zma(i,1)
      end do
      endif
      return
      end
      Subroutine sacf(iprint, iseopt, imean, y)
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/sacf1/ rh,rl,pl
      implicit real*8 (a-h,o-z)
      dimension y(1002),rh(102),rl(102),pl(102)
      if(imean.eq.0) go to 15
      xmean = 0
      do 10 i=1,nval
10    xmean = xmean + y(i)
      xmean = xmean/nval
15    continue
      do 50 k=0,mxl
      acv(k+1) = 0
      do 20 i=1,nval-k
```

```
20    acv(k+1) = acv(k+1) + (y(i) - xmean)*(y(i+k) - xmean)
      acv(k+1) = acv(k+1)/nval
      ac(k+1) = acv(k+1)/acv(0+1)
50    continue
      i25b = 0
      if(i25b.eq.1) then
      do k=0,mxl
      stk = 0
      do i=1,nval-k
      stk = stk + y(i+k)
      enddo
      amtk = stk/(nval-k)
      s1 = 0
      s2 = 0
      s3 = 0
      do i=1,nval - k
      dx = y(i) - xmean
      dt = y(i+k) - amtk
      s1 = s1 + dx*dt
      s2 = s2 + dx*dx
      s3 = s3 + dt*dt
      enddo
      ac(k+1) = s1/sqrt(s2*s3)
      enddo
      endif
      if(iseopt.eq.1) then
      do 60 k = 1, mxl
      seac(k) = 0
      do 55 i= k-1, mxl
55    seac(k) = seac(k) + ac(i+1)*ac(i+1) + ac(i-k+1)*ac(i+k+1)-
     14*ac(i+1)*ac(k+1)*ac(i-k+1) +2*(ac(i+1)*ac(k+1))**2
60    if(seac(k).gt.0) seac(k) = sqrt(seac(k)/nval)
      endif
      if(ipri.eq.0) return
      write(2,11) nval, xmean, acv(0+1)
11    format(/' No. of data ='I4,',  Mean ='f11.3,',  Variance =',e9.4
     1 //'  Lag          ACV        AC      95% LL/ HL         PACF  95%Lim'
     2  /)
      pad(1,1) = ac(2)
      pac(1) = ac(2)
      do 59 k=2,mxl
      ts = 0
      bs = 0
      do 30 j=1,k-1
      ts = ts + pad(k-1,j)*ac(k-j+1)
      bs = bs + pad(k-1,j)*ac(j+1)
30    continue
      pac(k) = (ac(k+1) - ts) / ( 1. - bs)
      pad(k,k) = pac(k)
      do 40 j=1,k-1
      pad(k,j) = pad(k-1,j) - pac(k)*pad(k-1,k-j)
40    continue
59    continue
      do i=1, mxl
      rh95 = (-1. + 1.96*sqrt(nval-i-1.))/(nval-i)
      rl95 = (-1. - 1.96*sqrt(nval-i-1.))/(nval-i)
      pl95 = 1.96/sqrt(nval + 0.0000001)
      rh(i) = rh95
      rl(i) = rl95
      pl(i) = pl95
      write(2,12) i, acv(i+1), ac(i+1), rl95, rh95, pac(i), pl95
      enddo
12    format(i5,f13.2,f10.4,f8.3,'/',f6.3,f10.4,f8.3)
      return
      end
      subroutine arma
      common/par/ npar, npma, ndf, km, par(10), pma(10), ake(10)
     1,conf(10), ac(0:102), acv(102), seac(0:102), pac(102)
     2,pad(102,102), kmn, isa, ism, mxl, ipri
```

```
      common/da/ nval, imiss, xmean, x(1002), z(1002)
      common/res1/iper(5),iord(5),rmean,rvar,s3,s4,chi1,sumn,aic
      dimension  b(10,10), s(10), cp(0:20), ppr(0:10), pr(10)
      implicit real*8 (a-h,o-z)
      par(1) = 0.1
      par(2) = 0.1
      par(3) = 0.1
      pma(1) = 0.1
      pma(2) = 0.1
      km = npar + npma
      kmn= km
      write(*,11) npar,npma
      write(2,11) npar,npma
11    format(/ ' ARMA( ',i1,', ',i1,') Model Identified'/)
      if(npar.gt.0) then
      do 110 i=1,npar
      s(i) = acv(npma+i+1)
      do 110 j=1,npar
110   b(i,j) = acv(npma+abs(i-j)+1)
      call ge(npar, b, s, pr)
      do i=1, npar
      par(i) = pr(i)
      enddo
200   const = xmean*(1-par(1) - par(2)- par(3))
      write(2,13) const, (par(k),k=1,npar)
      endif
13    format(/' Initial Estimates'/' CONST ='f9.4/
     1' AR Params :',5f9.3)
      if(npma.le.0) return
      ppr(0) = -1
      do i=1, npar
      ppr(i) = par(i)
      enddo
      do 320 j=0, npma
      pma(j+1) = 0
      cp(j) = 0
      do 305 i=0, npar
305   cp(j) = cp(j) + ppr(i)**2*acv(j+1)
      do 320 i=1, npar
      trm = 0
      do 310 k=0, npar-i
310   trm = trm + ppr(k)*ppr(k+i)
      ji = abs(j-i) + 1
      if(i.eq.j) ji = 1
      ij = i+j+1
      if(i.eq.0.and.j.eq.0) ij = 1
320   cp(j) = cp(j) + trm*(acv(ij) + acv(ji))
      sigao = 0
      do k=1, 100
      sth = 0
      do i=1, npma
      sth = sth + pma(i)**2
      enddo
      siga = cp(0)/( 1. + sth)
      if(siga.eq.0) write(*,*) ' Siga = ',siga
      if(siga.eq.0) go to 400
      if(abs( (siga-sigao)/siga) .lt.0.000001) go to 400
      sigao = siga
      if(sth.gt.200000) then
      pma(1) = 0
      pma(2) = 0
      pma(3) = 0
      go to 400
      endif
      do i=1, npma
      sth = 0
      if(npma.gt.1) then
      do j=1, npma-1
      sth = sth + pma(j)*pma(i+1)
```

```
      enddo
      endif
      pma(i) = -(cp(i)/siga - sth)
      enddo
      write(*,*)  k, siga, (pma(i),i=1,npma)
      enddo
400   write(2,9)  siga, (pma(i),i=1,npma)
9     format(/' AVAR = ',f9.4,//,' MA Param = ',4f8.4)
      return
      end
      subroutine ge(n, a, s, x)
      dimension a(10,10), y(10), x(10), s(10)
      implicit real*8 (a-h,o-z)
      do 66 i=1,n
66    y(i) = s(i)
      m = n - 1
      do 10 i=1,m
      l=i+1
      do 10 j=1,n
      if(a(j,i)) 6,10,6
6     do 8 k=1,n
8     a(j,k)=a(j,k)-a(i,k)*a(j,i)/a(i,i)
      y(j)=y(j)-y(i)*a(j,i)/a(i,i)
10    continue
      x(n)=y(n)/a(n,n)
      do 30 i=1,m
      k=n-i
      l=k+1
      do 20 j=1,n
20    y(k)=y(k)-x(j)*a(k,j)
      x(k)=y(k)/a(k,k)
30    continue
      return
      end
      subroutine mti(nr, aa, ia, b)
      dimension aa(10,10), b(10,10), al(10,10), au(10,10), iv(10)
      common/mt/ ai(10,10)
      implicit real*8 (a-h,o-z)
      ia = 10
      do i=1,ia
      ai(i,i) = 1
      enddo
      call alud(nr, aa, b, al, au, iv, ia, ipr)
      call minv(nr, b, al, au, iv, ia, ipr)
      call wrt(' Res', nr, nr, b, 10, 1, 0)
      a1 = anor(aa, nr, nc, 0, ia, ipr)
      a2 = anor(b,  nr, nc, 0, ia, ipr)
      if(a1*a2.gt.10000) write(*,*) ' MATI - Cond. No.', a1*a2
      return
      end

      subroutine ALUD(n1, a, b, al, au, iv, ia, ipr)
      DIMENSION A(ia,*), B(ia,*), iv(ia), d(10), s(10), al(ia,*)
     1  , au(ia,*)
      implicit real*8 (a-h,o-z)
      do 10 i=1,n1
      iv(i) = i
      do 10 j=1,n1
10    b(i,j) = a(i,j)
      do 20 i=1,n1
      d(i) = b(i,1)
      do 20 j=2,n1
20    if(abs(b(i,j)).gt.abs(d(i)) ) d(i) = abs(b(i,j))
      do ir=1,n1
      do i=ir,n1
      s(i) = b(i,ir)
      if(ir.gt.1) then
      do k=1,ir-1
      s(i) = s(i) - b(i,k)*b(k,ir)
```

```
      enddo
      endif
      enddo
      if(ipr.ge.3) write(*,*) ' ALUD-S',(s(i),i=ir,n1)
      if(ipr.ge.3) write(*,*) ' ALUD-D',(d(i),i=ir,n1)
      sdmx = abs(s(ir)/d(ir))
      isdm = ir
      do i=ir,n1
      if(abs(s(i)/d(i)).gt.sdmx) then
      sdmx = abs(s(i)/d(i))
      isdm = i
      endif
      enddo
      if(isdm.ne.ir) then
      do i=1,n1
      az = b(ir,i)
      b(ir,i) = b(isdm,i)
      b(isdm,i) = az
      enddo
      az = s(ir)
      s(ir) = s(isdm)
      s(isdm) = az
      az = iv(ir)
      iv(ir) = iv(isdm)
      iv(isdm) = az
      endif
      b(ir,ir) = s(ir)
      do j=ir+1,n1
      b(ir,j) = b(ir,j)
      do k=1,ir-1
      b(ir,j) = b(ir,j) - b(ir,k)*b(k,j)
      enddo
      b(j,ir) = s(j)/b(ir,ir)
      enddo
      if(ipr.ge.2) call wrt('ALUD- Matrix B', n1, n1, b , ia,1, 0)
      enddo
      if(ipr.eq.3) write(*,*) 'ALUD- V', (iv(i),i=1,n1)
      do i=1,n1
      do j=1,n1
      if(j.ge.i) au(i,j) = b(i,j)
      if(j.eq.i) al(i,j) = 1.0
      if(j.lt.i) al(i,j) = b(i,j)
      enddo
      enddo
      if(ipr.ge.2) then
      call wrt('ALUD- Matrix B', n1, n1, b , ia, 1, 0)
      call wrt('ALUD- Matrix U', n1, n1, au, ia, 1, 0)
      call wrt('ALUD- Matrix L', n1, n1, al, ia, 2, 0)
      endif
      return
      end
      subroutine minv(n1, b, al, au, iv, ia, ipr)
      DIMENSION B(10,10), iv(20), al(ia,*)
     1,au(ia,*), at(10,10), an(10,10), bb(10,10)
      common/mt/ ai(10,10)
      implicit real*8 (a-h,o-z)
      an(1,1) = 1
      do k=2,n1
      an(k,k) = 1.0
      do j=k-1,1,-1
      sm = 0
      do i=j+1,k
      sm = sm + an(k,i)*al(i,j)
      enddo
      an(k,j) = -sm/al(j,j)
        enddo
      enddo
      if(ipr.ge.2) call wrt('MINV - Inv. of L', n1, n1, an, ia,1, 0)
      do k=n1,1,-1
```

```
      at(k,k) = 1./b(k,k)
      do j=k+1,n1
      sm = 0
      do i=k,n1
      sm = sm + at(k,i)*au(i,j)
      enddo
      at(k,j) = -sm/au(j,j)
      enddo
      enddo
      if(ipr.ge.2) call wrt('MINV - Inv. of U', n1, n1, au, ia,1, 0)
      call mul(n1, n1, n1, at, an, b, ia, ia, ia)
      do 24 i=1,n1
      do 24 j=1,n1
24    bb(i,iv(j)) = b(i,j)
      call mad(n1, n1, bb, ai, b, ia)
      if(ipr.ge.1) call wrt('MINV - Mat Inv.', n1, n1, b, ia,2, 0)
      return
      end
      subroutine mcp(n1, n2, a, b, ia)
      DIMENSION a(10,10), b(10,10)
      implicit real*8 (a-h,o-z)
      do 10 i=1,n1
      do 10 j=1,n2
10    b(i,j) = a(i,j)
      return
      end
      function anor(a, nr, nc, id, ii, ipr)
      DIMENSION A(ii,1)
      implicit real*8 (a-h,o-z)
      if(id.eq.1) go to 100
      ir = nr
      ic = nc
      anor = 0
      do i=1,ir
      sum = 0
      do j=1,ic
      sum = sum + abs(a(i,j))
      enddo
      if(sum.gt.anor) anor = sum
      enddo
2     format(/' Infinity-norm of the Matrix is',f9.3)
      return
100   ir=nc
      ic=nr
      anor = 0
      do i=1,ir
      sum = 0
      do j=1,ic
      sum = sum + abs(a(j,i))
      enddo
      if(sum.gt.anor) anor = sum
      enddo
3     format(/' One-norm of the Matrix is',f9.3)
      return
      end
      subroutine mad(n1, n2, a, b, c, ia)
      DIMENSION a(10,10), b(10,10), c(10,10)
      implicit real*8 (a-h,o-z)
      am = 0
      do 10 i=1,n1
      do 10 j=1,n2
10    c(i,j) = a(i,j) + am*b(i,j)
      return
      end
      subroutine mat(n1, n2, a, b, ia, ib)
      implicit real*8 (a-h,o-z)
      dimension a(ia,1), b(ib,1)
      do 10 i=1,n1
      do 10 j=1,n2
```

```
10    b(i,j) = a(j,i)
      return
      end
      subroutine mul(n1, n3, n2, a, b, c, ia, ib, ic)
      DIMENSION A(ia,1), B(ib,1), C(ic,1)
      implicit real*8 (a-h,o-z)
      DO 10 I=1,N1
      DO 10 J=1,N2
      C(I,J)=0
      DO 12 K=1,N3
12    C(I,J)=C(I,J)+A(I,K)*B(K,J)
10    CONTINUE
      RETURN
      END
      subroutine wrt(Tit1, nr, nc, a, ia, io, iu)
      character*(*) tit1, fmt(5)*60
      dimension a(ia,1)
      implicit real*8 (a-h,o-z)
      common/title/tit
      fmt(1) = '(i3, 8e16.9,(/3x, 8e16.9))'
      fmt(2) = '(i3,12f10.5,(/3x,12f10.5))'
      if(iu.eq.0) write(* ,1) tit
      if(iu.ne.0) write(iu,1) tit
      do i=1,nr
      write(*,*) (a(i,j),j=1,nc)
      if(iu.ne.0) write(iu,fmt(io)) i, (a(i,j),j=1,nc)
      enddo
1     format(1x,a)
      return
      end
      SUBROUTINE GRAF(ymina,ymaxa,N1,N2,NP,X,Y)
      DIMENSION X(1002), Y(1002,3)
      REAL XARRAY(4),YARRAY(4)
      REAL RARRAY(7)
      INTEGER*4 IARRAY(9)
      CHARACTER*50 TIT, iys*1
      CHARACTER*10 STRING
      CHARACTER*10 STR
      common/title/tit
      write(*, '('' Do you want to tic mark y-axis (y/n)? '',$)')
      read(*,*) iys
      if(iys.eq.'y'.or.iys.eq.'Y') then
      write(*,'(''  npx, nspx : '',S)')
      read(*,*) npx, nspx
      else
      npx = 4
      nspx = 2
      endif
      call graf1(npx,nspx,ymina,ymaxa,N1,N2,NP,X,Y)
      return
      end
      SUBROUTINE GRAF1(npx,nspx,ymina,ymaxa,N1,N2,NP,X,Y)
      DIMENSION X(1002), Y(1002,3)
      REAL XARRAY(4),YARRAY(4)
      REAL RARRAY(7)
      INTEGER*4 IARRAY(9)
      CHARACTER*50 TIT
      CHARACTER*10 STRING
      CHARACTER*10 STR
      common/title/tit
      CALL PLOTS(0,1,0)
      CALL GRINFO(IARRAY,RARRAY,STRING)
      IWHITE=IARRAY(4)-1
      CALL NEWPEN(IWHITE)
      CALL GTEXT(1,10,TIT)
      X1=1.5
      Y1=1.5
      CALL PLOT(X1,Y1,3)
      CALL PLOT(0.0,6.0,12)
```

```
CALL PLOT(8.0,0.0,12)
CALL PLOT(0.0,-6.0,12)
CALL PLOT(-8.0,0.0,12)
xmin = 1.e10
xmax = -1.e10
ymin = xmin
ymax = xmax
DO J = 1,NP
DO I = N1,N2
if(xmin.gt.x(i)) xmin = x(i)
if(xmax.lt.x(i)) xmax = x(i)
if(ymin.gt.y(i,J)) ymin = y(i,J)
if(ymax.lt.y(i,J)) ymax = y(i,J)
END DO
END DO
if ((ymina.ne.-99.).and.(ymaxa.ne.-99.)) then
ymin = ymina
ymax = ymaxa
else
endif
write(str,'(e10.4)') xmin
CALL GTEXT(26,5,str)
write(str,'(e10.4)') xmax
CALL GTEXT(26,63,str)
write(str,'(e10.4)') ymin
CALL GTEXT(24,0,str)
write(str,'(e10.4)') ymax
CALL GTEXT(3,0,str)
xs = 8./(xmax - xmin)
ys = 6./(ymax - ymin)
x0d = 8./npx
xs0d = x0d/nspx
do i = 1,npx
x0 = x0d*(i-1)
do j = 1,nspx-1
x1 = x0 + (j)*xs0d + 1.5
CALL PLOT(x1,1.45,3)
CALL PLOT(0.,0.05,12)
enddo
x0 = x0 + 1.5
CALL PLOT(x0,1.42,3)
CALL PLOT(0.,0.08,12)
end do
if (ymin.lt.0..and.ymax.gt.0.) then
y0 = (0. - ymin)*ys + 1.5
CALL PLOT(1.45,y0,3)
CALL PLOT(8.05,0.,12)
ny0 = 3 + 21.*ys*ymax/6. + 0.5
write(str,'(f4.2)') 0
CALL GTEXT(ny0,0,str)
else
do i = 1,3
y0 = (ymax - ymin)*ys*i/4. + 1.5
CALL PLOT(1.45,y0,3)
CALL PLOT(8.05,0.,12)
y0 = ymax - (ymax - ymin)*i/4.
ny0 = 3 + 21.*i/4 + 0.5
write(str,'(e10.4)') y0
CALL GTEXT(ny0,0,str)
end do
endif
DO J = 1,NP
x0 = xs*(x(N1) - xmin) + 1.5
y0 = ys*(y(N1,J) - ymin) + 1.5
CALL PLOT(x0,y0,3)
do i = N1 + 1, N2
dx = xs*(x(i) - x(i-1))
dy = ys*(y(i,J) - y(i-1,J))
CALL PLOT(dx,dy,12)
```

```
end do
END DO
ymina = -99.
ymaxa = -99.
I = IXKEY()
CALL PLOT(0.0,0.0,-999)
RETURN
end
SUBROUTINE histo(n,h)
dimension h(1002),y(20)
CHARACTER*50 TIT, iys*1
CHARACTER*10 STR
common/title/tit
axmin = 1.e10
axmax = -1.e10
aymin = 0.
aymax = -99999.
do i = 1,n
if(h(i).lt.axmin) axmin = h(i)
if(h(i).gt.axmax) axmax = h(i)
end do
write(*,*) ' total = ',n,'axmin & axmax = ',axmin,' , ',axmax
write(*, '('' Do you want new xmin & xmax (y/n)? '',$)')
read(*,*) iys
if(iys.eq.'y'.or.iys.eq.'Y') then
write (*,'(''  new axmin & axmax are : '',$)')
read(*,*) axmin, axmax
else
endif
write(*,'('' no. of classes : '',$)')
read(*,*) nclass
a = axmin
c = (axmax-axmin)/float(nclass)
b = a + c
do i = 1, nclass
y(i) = 0
do j = 1, n
if((h(j).ge.a).and.(h(j).lt.b)) y(i) = y(i) + 1.
end do
a = a + c
b = a + c
end do
do i = 1,nclass
if(y(i).gt.aymax) aymax = y(i)
end do
write(*,*)  ' aymin & aymax = ',aymin,' , ',aymax
write(*, '('' Do you want new ymax (y/n)? '',$)')
read(*,*) iys
if(iys.eq.'y'.or.iys.eq.'Y') then
write (*,'(''  new aymax is : '',$)')
read(*,*) aymax
else
endif
call GRAFhis(aymin,aymax,axmin,axmax,Nclass,c,Y)
return
end
SUBROUTINE GRAFhis(aymin,aymax,axmin,axmax,Nclass,c,Y)
DIMENSION Y(20)
REAL XARRAY(4),YARRAY(4)
REAL RARRAY(7)
INTEGER*4 IARRAY(9)
CHARACTER*50 TIT
CHARACTER*10 STR
CHARACTER*15 STR1
CHARACTER*10 STRING
common/title/tit
CALL PLOTS(0,1,0)
CALL GRINFO(IARRAY,RARRAY,STRING)
IWHITE=IARRAY(4)-1
```

```
CALL NEWPEN(IWHITE)
CALL GTEXT(1,10,TIT)
X1=1.5
Y1=1.5
CALL PLOT(X1,Y1,3)
CALL PLOT(0.0,6.0,12)
CALL PLOT(8.0,0.0,12)
CALL PLOT(0.0,-6.0,12)
CALL PLOT(-8.0,0.0,12)
write(str,'(e10.4)') axmin
CALL GTEXT(26,5,str)
 write(str,'(e10.4)') axmax
CALL GTEXT(26,63,str)
write(str1,'('' Classes = '',i4)') nclass
CALL GTEXT(26,30,str1)
write(str,'(e10.4)') aymin
CALL GTEXT(24,0,str)
write(str,'(e10.4)') aymax
CALL GTEXT(3,0,str)
xs = 8./(axmax - axmin)
ys = 6./(aymax - aymin)
do i = 1,9
y0 = (aymax - aymin)*ys*i/10. + 1.5
CALL PLOT(1.45,y0,3)
CALL PLOT(0.10,0.,12)
y0 = aymax - (aymax - aymin)*i/10.
ny0 = 3 + 21.*i/10. + 0.5
write(str,'(e10.4)') y0
CALL GTEXT(ny0,0,str)
end do
x0 = xs*(axmin - axmin) + 1.5
y0 = ys*(aymin - aymin) + 1.5
CALL PLOT(x0,y0,3)
do i = 1, nclass
dx = xs*0.
dy = ys*(y(i) - aymin)
CALL PLOT(dx,dy,12)
dx = xs*c
dy = ys*0.
CALL PLOT(dx,dy,12)
dx = xs*0.
dy = -1.*ys*(y(i) - aymin)
CALL PLOT(dx,dy,12)
end do
I = IXKEY()
CALL PLOT(0.0,0.0,-999)
RETURN
end
subroutine pregraf(nval,noplot,x,y)
DIMENSION X(1002), Y(1002,3)
CHARACTER*50 TIT, iys*1
common/title/tit
ymin = -99.
ymax = -99.
write(*,'('' In how many plots you want them : '',$)')
read (*,*) nplots
write(*, '('' do you want fixed y-axis limits(y/n)? '',$)')
read(*,*) iys
if(iys.eq.'y'.or.iys.eq.'Y') then
write(*,'('' give your limits - (ymin,ymax) : '',$)')
read(*,*) ymin,ymax
naxis = 1
aymin = ymin
aymax = ymax
else
naxis = 0
endif
iplotn = nval/nplots
N1P = 1
```

```
do iplots = 1, nplots
if(iplots.eq.nplots) iplotn = nval - (nplots-1)*iplotn
N2P = N1P + IPLOTN - 1
if (naxis.eq.1) then
ymin = aymin
ymax = aymax
else
endif
call graf(ymin,ymax,N1P,N2P,noplot,X,y)
N1P = N2P + 1
end do
return
end
```

ANNEXURE-II

RESULTS OF ANALYSIS OF HOURLY AIR TEMPERATURE DATA: JANUARY, 1990

TABLE 5.1 HOURLY AIR TEMPERATURE DATA FOR JANUARY, 1990

9.0	8.8	8.8	8.6	8.4	8.2	8.0	8.4	8.9	9.0	9.2	9.8	10.2	10.7	11.5	11.5	11.0	11.0	10.2	10.1	9.5	9.5	9.2	9.2
9.1	8.9	8.9	8.8	8.7	8.0	8.1	8.3	8.8	9.1	9.5	9.6	9.7	9.8	10.1	10.1	9.5	9.4	8.9	8.3	7.7	7.3	7.1	6.6
6.4	6.0	6.0	5.5	5.4	5.4	5.7	5.4	5.4	8.4	8.7	9.1	9.2	10.4	10.5	10.9	11.1	11.0	10.9	10.5	10.0	9.5	8.9	8.6
8.3	8.2	7.1	6.9	6.0	6.0	6.2	6.6	6.7	6.8	7.1	7.6	7.7	8.9	10.7	11.8	13.0	12.4	11.2	10.2	10.1	10.1	9.9	9.5
9.2	8.9	8.9	8.3	7.7	6.3	6.6	7.1	7.7	8.3	9.0	9.3	9.8	10.7	11.6	12.4	13.0	12.7	11.7	10.7	10.1	9.5	8.9	8.8
8.5	8.3	7.7	7.7	7.1	6.4	7.1	7.1	7.1	8.3	9.8	11.2	11.8	12.2	12.4	13.0	13.6	13.0	12.7	11.8	11.4	11.1	11.1	10.7
10.1	10.0	9.5	8.9	8.3	7.7	7.8	8.0	8.1	8.9	10.4	11.6	12.4	13.5	14.9	14.9	14.9	14.5	14.0	12.9	11.8	11.2	10.7	10.1
9.0	8.9	8.8	8.3	8.3	7.7	7.8	8.0	8.1	8.3	9.2	11.0	11.5	12.7	13.6	15.0	15.0	13.9	12.4	13.0	12.4	11.8	11.2	11.2
10.7	10.4	10.1	9.8	9.2	7.7	8.1	8.7	9.4	9.6	10.0	10.1	10.3	10.4	10.7	10.9	10.8	10.1	10.1	10.0	9.8	9.5	9.4	8.9
8.3	8.3	8.3	7.8	7.7	7.1	7.1	7.1	7.1	8.3	9.5	10.5	12.4	13.0	13.5	13.9	13.6	13.3	13.0	12.4	11.8	11.2	10.4	10.2
9.6	9.4	8.9	8.3	7.7	6.6	6.9	7.1	7.4	7.4	8.9	10.1	10.7	12.4	13.6	14.0	15.9	15.6	14.2	13.6	12.7	12.4	11.8	10.7
10.1	9.5	8.3	7.7	7.7	7.4	7.6	7.6	7.1	8.2	9.5	11.8	13.0	14.5	14.8	15.3	15.5	15.3	14.3	12.4	11.8	11.2	10.7	10.2
10.0	9.5	9.2	8.9	8.6	8.0	8.3	8.8	8.9	9.5	10.4	12.4	14.2	15.3	15.9	16.0	16.0	15.9	14.2	12.4	11.8	11.2	10.7	10.2
10.1	8.8	8.9	8.3	8.0	7.7	8.3	8.4	8.5	9.5	11.2	13.0	14.3	15.3	15.9	16.5	16.5	15.9	14.8	13.6	13.0	12.1	11.8	10.8
10.7	10.2	9.5	8.9	8.3	8.2	8.3	8.6	8.8	9.2	9.5	10.7	13.0	15.2	15.8	16.0	16.1	15.8	13.7	12.5	12.3	11.8	11.1	10.8
10.7	10.1	9.8	9.6	8.9	8.3	8.6	8.8	8.9	10.7	11.1	13.0	14.8	15.3	16.0	16.4	17.1	16.5	15.3	14.2	13.3	12.4	11.4	11.2
11.2	10.7	10.7	10.7	10.7	10.1	9.5	8.9	8.9	10.7	11.4	13.6	15.2	16.4	16.5	17.1	17.8	17.1	15.9	15.3	14.2	14.2	14.2	13.6
13.0	12.4	11.5	10.7	10.4	10.1	10.9	11.2	11.8	11.8	13.0	14.8	16.5	17.1	18.1	18.3	18.1	17.7	15.9	14.2	13.6	13.0	12.4	11.8
11.4	11.2	11.2	10.7	10.5	10.2	10.1	10.0	10.1	11.2	12.1	13.6	16.2	17.1	17.2	17.6	18.7	17.1	15.9	14.8	13.7	13.0	13.0	12.4
12.3	11.8	11.2	10.7	10.7	10.5	10.1	10.5	9.5	11.8	12.4	14.2	15.8	16.5	17.0	17.0	18.3	17.7	17.1	16.2	15.9	14.5	14.2	13.0
12.4	11.2	10.5	10.1	9.6	9.5	9.4	8.9	8.9	11.5	12.4	14.5	15.9	16.8	17.2	17.3	17.1	16.5	15.3	14.1	13.0	12.4	11.8	11.8
11.2	10.7	10.5	10.3	9.6	9.5	9.6	9.7	10.4	11.2	12.4	14.8	15.9	17.1	17.7	17.6	17.2	16.5	15.3	14.2	13.0	12.4	11.8	11.2
11.1	10.5	10.5	10.4	9.6	9.5	9.5	9.5	9.5	10.7	10.7	11.7	13.5	14.8	15.9	17.1	18.3	17.4	16.6	14.8	13.6	12.9	12.4	11.8
11.2	11.1	10.8	10.7	10.5	10.1	10.0	10.0	10.0	10.2	10.7	11.2	13.6	14.8	15.9	17.1	18.6	17.1	15.3	14.2	13.6	13.0	11.8	11.7
11.2	10.7	10.1	9.5	8.9	8.3	8.7	8.9	8.9	9.6	10.7	13.0	14.8	16.5	17.2	17.7	17.7	17.1	15.9	14.2	13.6	13.0	12.4	11.8
11.4	10.7	10.5	10.1	9.5	8.9	9.0	9.3	9.5	9.8	10.1	12.4	14.8	16.4	17.1	17.7	17.7	17.7	15.9	14.2	13.6	12.4	12.3	11.8
11.8	11.8	11.8	11.2	10.9	10.7	10.9	10.9	10.9	11.2	11.8	14.2	15.2	16.0	17.0	17.1	17.0	16.5	15.3	14.3	13.6	13.0	12.4	12.3
11.8	11.8	11.8	11.8	11.2	11.1	10.7	10.8	10.8	12.4	12.4	13.0	14.2	15.3	15.3	16.0	18.0	16.5	15.9	15.3	14.6	14.2	14.0	13.1
12.5	11.8	11.8	11.2	11.1	10.7	10.2	10.1	10.1	10.3	10.6	10.2	12.7	13.7	14.2	15.3	16.5	14.8	14.2	13.0	11.8	11.2	11.1	10.7
10.1	9.5	9.5	9.0	9.0	8.9	8.8	8.4	8.3	10.1	10.7	11.9	13.7	14.8	15.8	15.8	15.3	15.2	14.6	13.6	13.0	12.4	11.8	11.2
11.2	10.7	10.7	10.2	10.1	10.1	10.1	10.1	10.1	9.5	10.7	13.0	14.6	15.8	15.9	16.5	16.5	16.3	16.0	14.3	13.6	13.0	12.4	11.2

TABLE 5.2 STATISTICAL SUMMARY OF HOURLY AIR TEMPERATURE

MONTH : JANUARY , 1990

SL.NO.	PARTICULARS	VALUES
i.	Total number of data points	744
ii.	Total Number of Effective data points	744
iii.	Maximum Temperature	18.70
iv.	Minimum Temperature	05.40
v.	Mean Air Temperature	11.50
vi.	Median	11.00
vii.	Mode	11.00
viii.	Standard Deviation	02.92
ix.	Skewness	00.41
x.	Kurtosis	02.40

TABLE 5.3 SUMMARY TABLE OF FREQUENCY AND PROBABILITY OF DIFFERENT CLASSES OF HOURLY AIR TEMPERATURE

MONTH : JANUARY , 1990

Sl.No	CLASS	PROBABILITY	FREQUENCY
i.	02-04	00.000	0000
ii.	04-06	00.013	0010
iii.	06-08	00.084	0053
iv.	08-10	00.325	0179
v.	10-12	00.625	0224
vi.	12-14	00.769	0107
vii.	14-16	00.899	0097
viii.	16-18	00.988	0066
ix.	18-20	00.999	0008

TABLE 5.4 **TABLE SHOWING THE TEST RESULTS OF RANDOMNESS OF THE DATA**

MONTH : JANUARY , 1990

---

i) Turning Point Test

No of turning points	=	58
z	=	2.576

⇒ The series is random at 1% significance level

ii) Spearman Rank Correlation Test

Rank Serial Correlation Coefficient	=	0.962
$t_{abs(dof=741)}$	=	95.305
critical	.	2.583

⇒ The series is not random at 1% significance level

iii) Test of Significance of Trend

Intercept	=	9.227
Slope	=	0.006224
Standard deviation of the slope	=	0.004442
Standard deviation of Residuals	=	2.603
$t_{absolute(dof=742)}$	=	14.010
$t_{critical}$	=	02.583

⇒ The Series is not random at 1% significance level

TABLE 5.5 MODEL PARAMETERS AND RESIDUAL STATISTICS

[A] Differencing at lag-1

AR	MA	ϕ_1	ϕ_2	θ_1	θ_2	Resi mean	Resi var	AIC
0	1			0.3926		0.92637E-03	0.44732E+00	-0.59570E+03
0	2			-0.4284	-0.2019	0.56429E-03	0.42330E+00	-0.63473E+03
1	0	0.6553				-0.52703E-03	0.41090E+00	-0.65880E+03
1	1	0.6022		0.0545		-0.38285E-03	0.40217E+00	-0.67277E+03
1	2	0.5715		0.0425	-0.0692	-0.32517E-03	0.40056E+00	-0.67374E+03
2	0	0.6389	0.1225			-0.58084E-03	0.41069E+00	-0.65718E+03
2	1	0.4041	0.2348	0.0372		-0.35282E-03	0.40149E+00	-0.67203E+03
2	2	1.8036	-0.8685	0.8849	-0.3999	0.77979E-01	0.33179E+00	-0.79757E+03

[A] Differencing at lag-24

AR	MA	ϕ_1	ϕ_2	θ_1	θ_2	Resi Mean	Resi Var	AIC
0	1			-0.6623		0.49052E-01	0.53802E+00	-0.44105E+03
0	2			-0.8614	-0.4000	0.35944E-01	0.42614E+00	-0.60795E+03
1	0	0.8203				0.10391E-01	0.36312E+00	-0.72716E+03
1	1	0.7471		-0.1637		0.13379E-01	0.34059E+00	-0.77112E+03
1	2	0.7378		-0.1744	-0.0316	0.13677E-01	0.34034E+00	-0.76963E+03
2	0	1.2097	-0.1298			0.12794E-01	0.34457E+00	-0.76279E+03
2	1	1.8325	-0.8430	0.9442		0.18371E-01	0.33894E+00	-0.77216E+03
2	2	1.8307	-0.8401	0.9214	-0.0278	0.18194E-01	0.33879E+00	-0.77050E+03

[A] Differencing at lag-1 and lag-24

AR	MA	ϕ_1	ϕ_2	θ_1	θ_2	Resi Mean	Resi Var	AIC
0	1			0.1357		-0.18819E-03	0.37143E+00	-0.71009E+03
0	2			0.1335	0.1573	-0.44875E-04	0.36371E+00	-0.72319E+03
1	0	0.0717				-0.11366E-03	0.36473E+00	-0.72319E+03
1	1	-0.6691		0.7262		-0.17901E-03	0.36850E+00	-0.71378E+03
1	2	0.7520		0.8614	0.1301	-0.12958E-02	0.34347E+00	-0.76236E+03
2	0	0.0753	0.0546			-0.76864E-04	0.36398E+00	-0.72267E+03
2	1	0.9144	-0.0490	0.9977		-0.60019E-02	0.34162E+00	-0.76618E+03
2	2	0.8211	0.0092	0.8849	0.0699	0.30207E-02	0.34919E+00	-0.74836E+03

Fig. 5·1 : Histogram of Raw Data

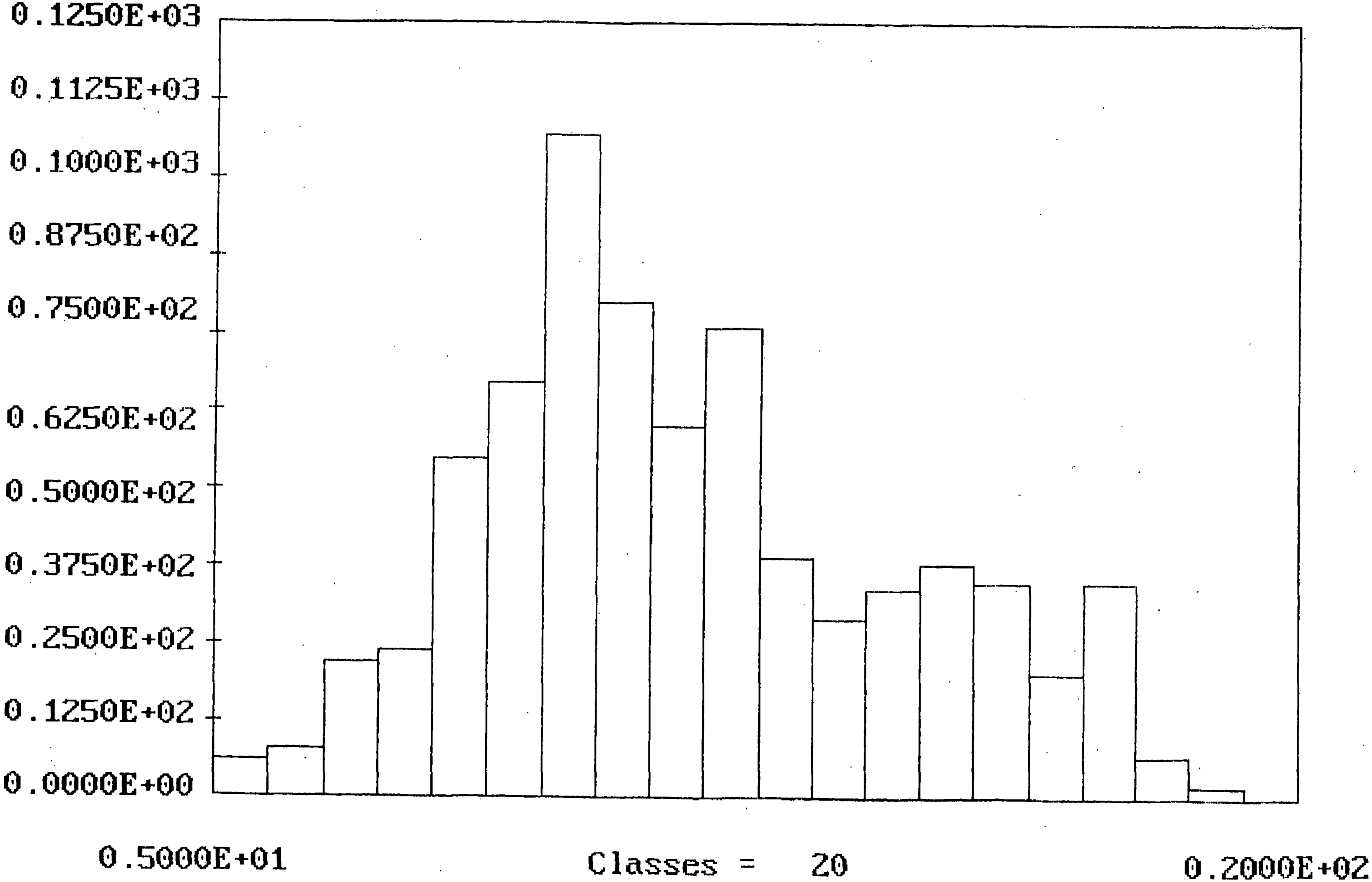

Fig. 5.2 : Plot of Raw Data

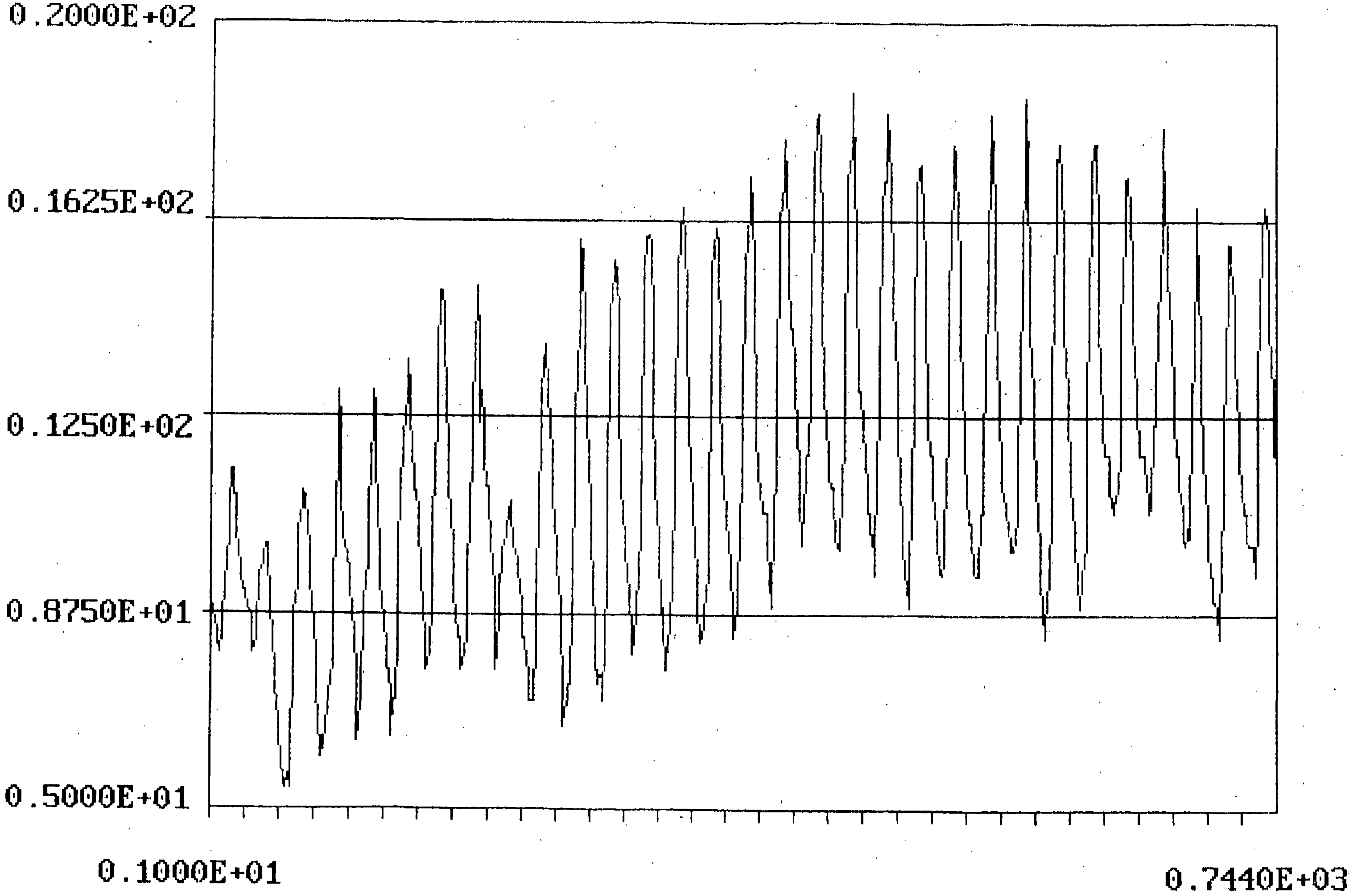

Fig. 5·3 : Plot of ACF of Raw Data

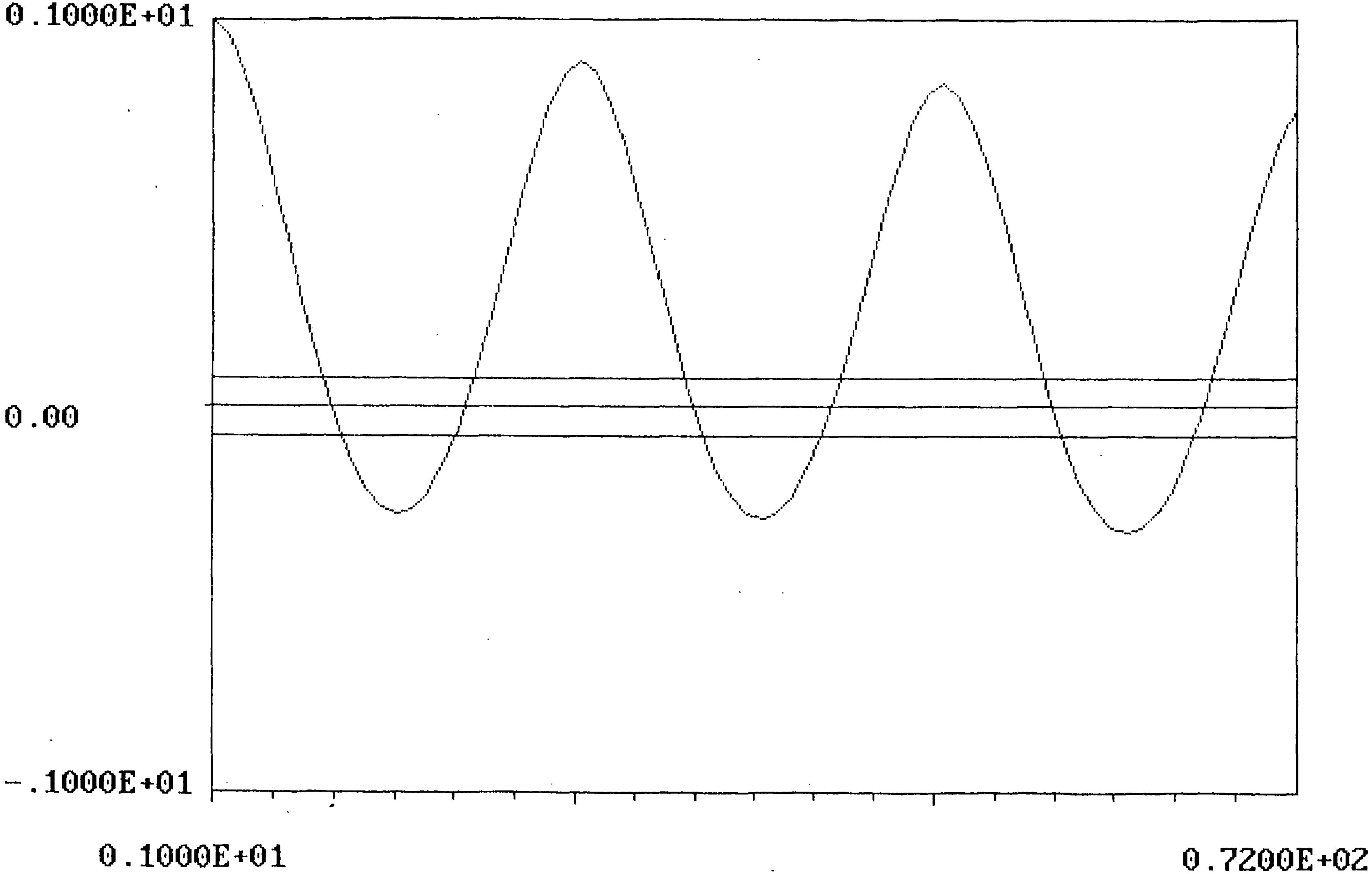

Fig. 5·4 : Plot of PACF of Raw Data

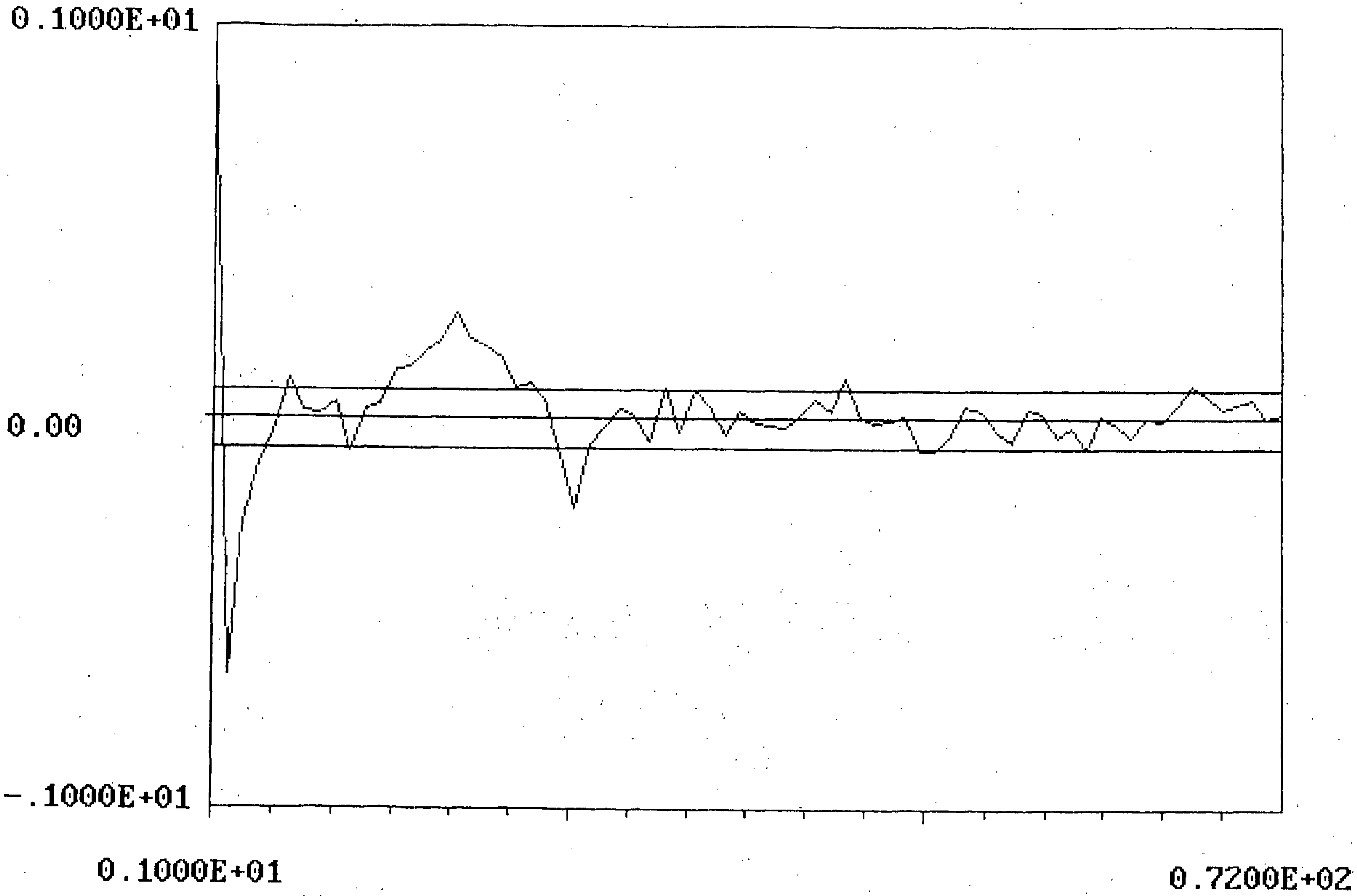

Fig. 5.5 : Plot of SDF of Raw Data