THE DESIGN OF A REAL-TIME NOWCASTING SYSTEM FOR LOCALISED WEATHER

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In the Name Of Allah
Most Compassionate and Most Merciful

Dedication

To my parents, for their love,...........

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Contents

List of abbreviations and symbols

CAS	Commission for Atmospheric Science
PROFS	Prototype Regional Observation and Forecasting Service
FRON-	Forecasting Rain Optimised using New Techniques of
TIERS	Interactive Enhanced Radar Satellite
PROMIS	Programme Operational Meteorological Information System
JMA	Japan Meteorological Agency
AMeDAS	Automatic Meteorological Data Acquisition System
LFO	Local Forecast Office
MAC	Meso-scale Analysis Centre
NWS	National Weather Service
AFOS	Automatic of Field Operation Services
EDF	Exploratory Development Facility
AWS	Automatic Weather Station
GLNS	Ground Local Nowcasting Station
ms^{-1}	Metres per second
m.p.h.	Miles per hour
$mm\ s^{-1}$	Millimetres per second
R.H.	Relative Humidity
T	Temperature
Tw	Temperature of wet bulb
es	Saturation vapour pressure
AP	Constant
TIROS	Television and InfraRed Observation Satellite
AVHRR	Advanced Very High Resolution Radiometer
HRPT	High Resolution Picture Transmission
APT	Automatic Picture Transmission
GARP	Global Atmospheric Research Program
FGGE	First GARP Global Experiment
WWW	World Weather Watch
CGMS	Co-ordination of Geostationary Meteorological Satellites
WMO	World Meteorological Organisation
DATTS	Data Acquisition Telemetry and Tracking System
MGCS	METEOSAT Ground Control Centre
ESA	European Space Agency

ESOC	European Space Operation Centre
DTRS	Data Transmission Routing System
GTS	Global Telecommunication System
FEP	Front End Processor
HR	High Resolution
PDUS	Primary Data User Station
SDUS	Secondary Data User Station
NOAA	National Oceanic and Atmospheric Adminstration
PC	Personal Computer
DOS	Disk Operating System
NMI	Non-Maskable Interrupt
INTR	Interrupt
PIC	Programmable Interrupt Controller
EGA	Enhanced Graphic Adapter
LUT	Look-Up table
TSR	Terminate and Stay Resident
RTC	Real-Time Clock
ARIMA	AutoRegressive Integrated Moving Average
ACF	Auto Correlation Function
PACF	Partial Auto Correlation Function
ASOS	Adjusted Sum Of Squares
AIC	Akaike Information Criterion
SBC	Schwartz Bayesian Criterion
RV	Residual Variance
MA1	Moving Average first order
ERL	Experimental Research Laboratory
WSR	Weather Satellite Receiver

μ	Mean of the series
$\hat{z}$	Deviation from the mean
$\hat{z}_t$	Value of the series at time t
Φ	Weight of AutoRegressive operator
Θ	weight of Moving Average operator
a_t	White noise process
w_t	Difference ARIMA process

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Chapter 1

1.0 Introduction

1.1 Weather

The total depth of the atmosphere is about 160 km.; however, at great heights the air is very thin, resulting in half of the atmosphere's weight being in the lower 6 km.. This lower part of the atmosphere is constantly varying and it is this instability of the atmosphere that leads to the various weather events which have a profound effect on the planetary life and its development.

Weather has been defined with qualities such as wet, fine, warm or cold. Although these were adequate for most purposes some hundred years ago, today, with the growth of industry, population and food demand, the weather has become increasingly significant and its study has been put on an organised and scientific footing. The branch of science concerned with the weather study is called meteorology[1]. Weather affects us all in some aspect or another. It determines when a farmer plants and harvests his crops; it determines what route an ocean liner or an airplane should take; fuel companies (which must be able to meet the energy demand of its consumers), emergency services, construction industry, picknickers, outdoor hobbiest, etc. would all like to know what is going to happen to the weather. For many years, attempts have been made to predict weather, but only with limited success. Although ground measurements, such as temperature, pressure, humidity and wind has been in existence for many years, It was only the arrival of high technological equipment, such as satellites, balloon data systems, radars and sophisticated atmospheric models with high speed computers that has enabled the meteorological community to make reasonably accurate weather predictions.

Computer simulations are used to model the behaviour of the atmosphere (see chapter 6). The basic concepts of simulations are well understood, i.e. develop a mathematical model (a series of differential equations of the atmosphere's behaviour over time), reduce it to the form that can be numerically integrated by a computer, then set up the initial conditions and let the model run. However, an enormous number of complexities exist (such as unknown disturbances which migrate into the prediction areas and contaminate the forecast) which make the prediction invalid.

1.2 Weather forecasting

One of the eventual outputs of primary importance is the weather forecast, which is the meteorological package most frequently placed at the disposal of man in economic and social pursuits, some of which maybe more weather sensitive than others. The increasing scale of intensity of social mobility for both work and leisure has sharpened the interest in and demand for weather forecast.

The world weather watch program has as one of its goals the improvement in understanding the global atmosphere and its prediction[2]. In addition to this, each country has its own national weather service that is devoted to providing weather information to its inhabitants.

Because of the dynamic interactions between different weather phenomena and their rapid movements on some occasions, it is necessary to account for conditions over a wide area (i.e. to make a forecast for the whole of U.K. for 24 hours or so ahead requires observations from North Atlantic, Europe, North America and the Arctic region). The area coverage of observations is related to forecast lead times.

Current literature has highlighted three different forecasting strategies :

(1) Synoptic-scale

(2) Meso-scale

(3) Nowcasting

1.2.1 Synoptic-scale

The traditional weather service is built-up to cope with the synoptic-scale phenomena such as lows and highs, based on observations with a horizontal spacing of 75 km. or more (especially inland). In this case the weather phenomena have a life time of one or two days making it possible to detect their evolution with observation frequency of 6-12 hours[3].

Here in the British Isles, it is widely accepted that the weather is the most variable and the most unpredictable in the world. To cope with such diverse weather variations, there is an extensive network of weather stations with the central office based in Bracknell. Routine ground-level observations are made every hour at major stations (airports) and every three hours at other stations. These are transmitted to the central office where a synoptic-scale model is run every 6 hours to produce a prebaratic chart, corresponding charts for selected levels in the upper atmosphere are produced every 12 hours.

The forecasting process of the weather for 24 hours or so ahead involves three operations on the part of the forecaster[3]:

(1) The analysis of the existing weather situations.

(2) Forecasting of the surface pressure pattern and frontal position (prebaratic).

(3) Interpreting the prebaratic in terms of weather.

The general forecast for the U.K. is prepared at the central office, where a senior forecaster interprets the information available to him. The six hour prebaratic charts called 'synoptic reviews' giving general forecast guidance for the whole country are distributed to various outstations scattered throughout the country. The forecaster at the outstation has knowledge of local instability, topography, and heating effects. He interprets these prebaratics according to his knowledge of the locality to prepare the local forecast. The synoptic reviews form the frame work for a local forecast.

The general public forecasts which are disseminated via the media, lag the most detailed ground-level observations by a period between two and ten hours. Further, the forecast is neither detailed enough about specific locality nor timely enough to be more than of general use. As changes are continuously taking place, circumstances arise when local conditions seem to indicate that the latest forecast is going wrong, but this discrepancy may not even enter the nation's observations to affect the next forecast.

Although there have been many advances in forecasting skill for periods more than 24 hours ahead, it has had little influence on local forecasts. Guidance issued centrally is still lacking in local detail, while at outstations, where most of the short-period forecasts are issued, the mode of working is still in many respects as it was 30 years ago, and Browning[9] indicates that there is little prospect of its improvement by conventional means.

1.2.2 Meso-scale

A major problem in providing adequate warning of localised weather related conditions has been recognised for many years. It is the general lack of discrete information on which to base effective warnings which are appropriate to local interests. The key problem which limits attempts to provide these meaningful warning services which can serve as valid triggers to local users has consistently been the lack of real-time information. This problem provides an acute limitation in meeting specific requirements for local users and results in generalised statements which have very little value. Information needed locally must apply to discrete local situations[4] and it must be accurate and timely.

Since weather variations are also greatly influenced by locally-induced situations[5], and coupled with this is the fact that local changes develop at a much faster rate, leads to weather phenomena that the synoptic-scale system is unable to cope with. A primary requirement in local forecasting is to identify small-scale weather features having significant variability on scale of tens of kilometers and over short-period of time.

The terminology for small-scale weather features is meso-scale, with scales ranging from 2 to 5000 km. Any system designed to cope with meso-scale phenomena will necessarily identify itself with very-short-range forecasting (VSRF). However, VSRF must not be synoptic-scale forecasts valid for short lead times[4]. This fact couples VSRF with meso-scale phenomena and leads to quite different and new demands for observations, processing and dissemination of weather information[6]. The term VSRF is very losely defined. The Commission for Atmospheric Science (CAS) working group on weather prediction research at its Moscow meeting in October, 1981 agreed that the period 0-12 hours should be assigned to VSRF, while another common term used in VSRF 'nowcasting' should be a subclass of VSRF with the prediction period of 0-2 hours.

The economic value of VSRF has been known for a long time in aviation for safety reasons. However, studies by Murphy et. al[7] have shown how industrial countries have become vulenerable to weather hazards.

Current research is directed towards understanding meso-scale phenomena and developing models to predict its evolution.

The representation of the initial state of the atmosphere is of critical importance to the quality of forecast that can be expected from these models. The current model undergoing trials in the U.K.[8] takes its initial state from a six-hour synoptic model output as well as synoptic observations at ground-level. However, it does not incorporate any information from radar networks, satellite pictures or radiosonde ascents. It is expected that these will be incorporated in to the model in the next phase.

There is no unified or final picture of how the future VSRF components of the weather services will look. Current systems under development {see chapter 2} indicate that they will differ from country to country because of the structure of their respective economies, climatologies and how the synoptically-based weather service has been organised over the years. In the U.K., Browning[9] has indicated that meso-scale forecasts will be generated centrally for guidance; as the synoptic-scale are presently done.

1.2.3 Nowcasting

Browning[9], Bodin[10] have indicated that the basis of the nowcasting approach is for the current state to be monitored closely and the evolution of the future state to be derived by assuming the current patterns will continue to move in the same way essentially without development or decay. Very detailed site-specific forecasts can be derived using this approach but their accuracy falls off rapidly with forecast period. The use of the term nowcasting underlines the heavy dependance on the description of the current situations.

Bodin[10] made a distinction between the requirements for nowcasting (0-2 hours ahead) and VSRF (2-12 hours ahead). He points out that the nowcasting range time is limited for data processing and forecasts have to use simple extrapolation techniques. On the other hand, for range 2-12 hours ahead intensity changes (growth or decay) in the movement of weather phenomena are equally important to forecasting. This requires a more complete picture of the dynamic and thermodynamic states of the atmosphere which can be based on quantitive information on temperature, humidity, and winds. Nowcasting is then a description of the state of the current weather and forecasts within the valid extrapolation range of each phenomena. Forecasts based upon physics, dynamics, or application of numerical or conceptual models lie outside of nowcasting.

Burnash[11] points out that a system operating at a local level as a cost-effective solution to local problems is capable of providing an increasing variety of meteorological and hydrological data. With such data, warnings can be produced on the same scale, space, and time in which people live - a highly localised and truly real time scale. However, an effective real-time system is one which includes not only data, but also the evaluation techniques which provide sufficient information immediately to identify and guide the local users.

1.3 Conclusion

Accurate weather forecasting is a notoriously difficult real-time problem. Although current research in meteorology has led to an improved understanding of the many phenomena constituting weather, supercomputers lack the processing power to predict, in real-time the future changes in the weather on a global scale.

Countries in which extreme weather variation prevail constantly destroying life and property are attempting to develop systems to cope with these diverse changes in the weather. They have outlined need to observe the state of the atmosphere more frequently and report the likelihood of hazardous situations to its inhabitants. Phenomena of this kind are generally confined to a locality and develop much faster than the frontal weather systems.

These VSRF systems {see chapter 2} are large scale projects using a system configuration comprising several computers (VAX's, PDP11's, etc.). The scale on which the state of the atmosphere is observed extend to state or country , these large computers forming the tasks of data acquisition, manipulation, and analysis. These VSRF systems are being developed for interactive operation, using state-of-the-art technology for presenting differing sources of atmospheric data in high resolution graphics, overlays, animation, etc. to enable a forecaster to make better judgements for predicting the weather for the locality (being state or country). These systems will evidently incorporate models for forecasting meso-scale weather features and also implement simple extrapolation techniques for nowcasting. Presently, VSRF and nowcasting are used synonymously in the literature, and no clear definition exists which allows one distinguish the basis of system configuration between the two differing concepts of predicting future state of the atmosphere.

1.4.0 Real-time nowcasting system

Several researchers have indicated that true site-specific weather can only be satisfactorily predicted by continuously observing the state of the atmosphere at a site and using physical laws or extrapolation techniques to forecast into various lead times. Burnash[11] highlighted that large scale analysis problem can be resolved from the sum of all the small parts, but by working only with the large scale, the small scale features cannot be necessarily determined.

National meteorological offices are largely concerned with synoptic-scale forecasting. In practice, many local organisations (such as emergency services, construction industries, farming, forestry, sports) require only local, short-term, bespoke, weather prediction and warnings[2]. These less demanding tasks can be met by a modern, desk-top computer system.

The real-time nowcasting system discussed in this thesis is one which continuously observes site-specific ground data (such as temperature, pressure, humidity, wind speed and direction, etc.) augmented with readily available satellite images for above-ground information for producing nowcasts. The system is constrained to provide only nowcasts, as defined in this thesis: a nowcast comprises a statement of the current data plus a forecast for no more than 2 hours. Nowcasts are necessarily kept local due to point observations being limited in general to the surrounding 20 km. radius district. For certain weather systems the forecast may be applicable to a larger region and longer lead times. However, there is no committment to produce a global forecast nor to predict long term trends; spent weather features and the rest of the country are of no concern.

Figure 1.1 depicts diagramatically an overview of the real-time nowcasting system's objectives. Typically, the local site under observation is representative of the three motorways enclosing the Birmingham area (triangle). This site is continuously being observed using two differing sources: local ground measurements being provided by the Local Ground Nowcasting Station (GLNS) and above ground information provided by the METEOSAT geostationary satellite. Weather information extracted from these two differing sources being made available to the local users.

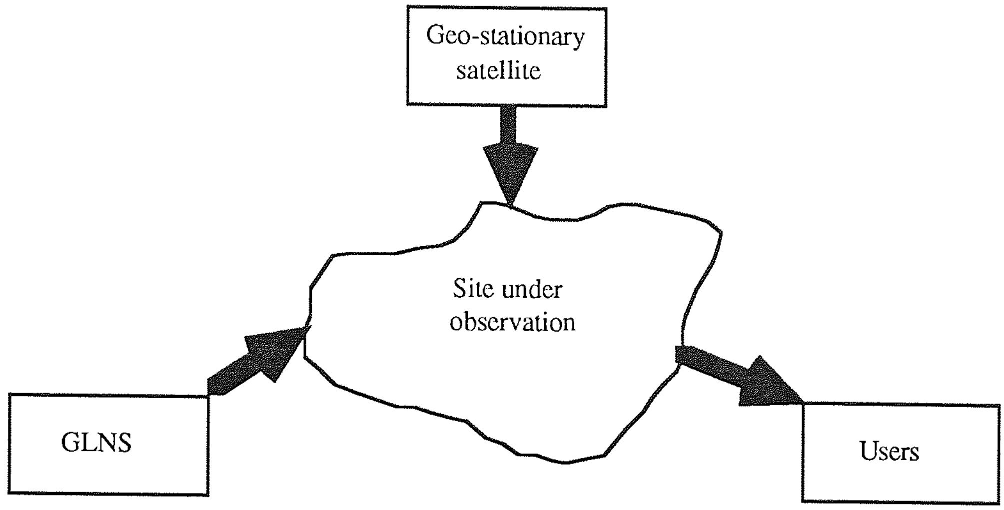


Figure 1.1 Overview of the real-time nowcasting system's objectives

The real-time nowcasting system differs from VSRF systems being developed in five respects : 1) It does not use large scale computers for system configuration, 2) The nowcast is very localised being confined to 20 km radius rather than a state or country, 3) Local conditions are sampled more frequently, 4) it is intended for automatic operation; though interactive facilities will be available, and 5) it is very much a low-cost system making it cost-effective for very localised operations.

The time constraints of the system are not over-severe in producing nowcasts. Weather satellite images are received by the system every thirty minutes; while local conditions are sampled every minute. A delay of less then twenty minutes between data capture and the production of a new nowcast is considered acceptable.

The novel approach adopted in this thesis for the design of a real-time nowcasting system has been highlighted by many researchers for improving local weather forecasts (nowcasts), however, extensive literature review failed to show any author who had worked on a similar problem to that posed.

To achieve the objectives of this thesis, a number of goals had to be attained. Firstly, as there was no previous platform within the Department to build-upon related to the work proposed in this thesis, total system design concept and configuration had to begin from afresh. Practical considerations had to be given to the monitoring of local conditions and the site of the eventual transducers. Any commercial components for integration of the system (such as satellite receiver, PC system and its hardware configuration, etc.) with consideration of the system being cost-effective were considered prior to purchasing them. Every effort was made to develop in-house any products which benefited in two ways : one of gaining expertise in the development of these products design, and secondly reducing cost.

Figure 1.2 indicates the major system components in both hardware and software. The system is based on a desk-top 8 MHz, IBM-AT PC with 640 Kbytes of RAM, 30 Mbytes hard disk, 1024 by 512 bytes frame store, enhanced colour graphic adapter (EGA) but without a co-processor.

The corner stone of the real-time nowcasting system is its ability to receive data in real-time from two differing sources: METEOSAT 4 geostationary satellite, and ground-level conditions from Ground Local Nowcasting Station (GLNS) developed in-house. The data from the satellite is transmitted under strict time scheduling and must be captured in real-time. Image capture is triggered by a signal from the real-time clock within the PC at schedule transmission times. Several formats of the multi-spectral data are transmitted and only those of interest are captured by the system. Local data are transmitted to the PC by the GLNS every 5 minutes. Real-time date handling turned out to be the most crucial, and yet the most difficult task in the design of the real-time nowcasting system.

Any pre-processing on the data received from the local transducers is carried out within the GLNS prior to its transmission to the PC for analysis. The acquisitioning of these two differing sources of data is the background task of the system; requiring no

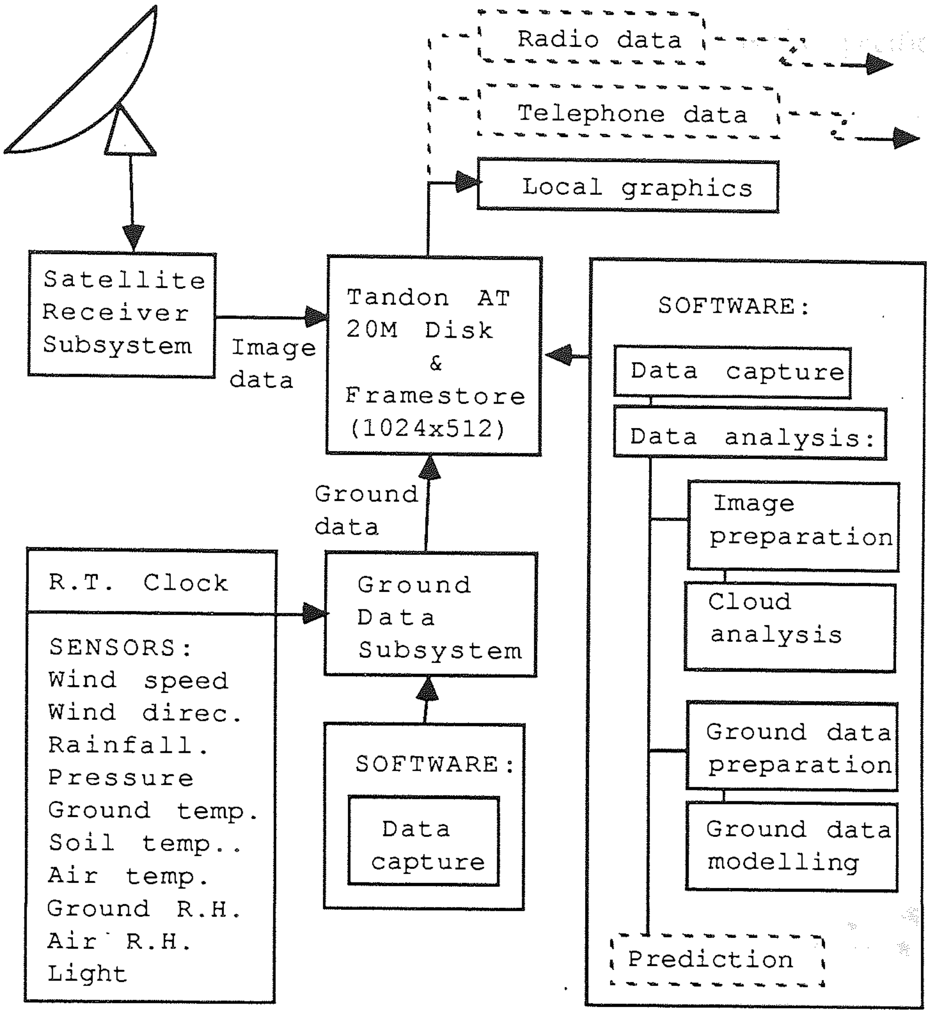


Figure 1.2 Major system components in hardware and software

manual intervention, and demands the greatest amount of in-house computer resources. Data manipulation within the PC is segregated into two general sets of processing software pertinent to: 1) image acquisitioning, preperation, and processing, 2) local ground-level data preperation and analysis. The software within the prototype system provides standardised processes in order to simplify access to those interested in modelling and analysis.

Ground data provides a time series of measurements at a specific location which represents the current and past atmospheric conditions of the particular site and much information can be extracted from these. Generally, a forecaster at an outstation is not provided with much detail information of a locality as is given by the GLNS and further more it is readily available at any time for analysis. The novel approach adopted in this thesis is one of constructing simple statistical models using this site-specific data to predict future changes in these elements based on their past-and-present variations. No work relating to constructing of simple models was found in the literature. The models are based on the AutoRegressive Integrated Moving Average techniques (ARIMA) proposed by Box and Jenkins[58].

Image processing takes several forms. The satellite images contain features (such as cloud formations) which evolve dynamically. The process of extracting a weather feature, following its motion, and predicting its future evolution involves algorithms for normalisation, partitioning, filtering, image enhancement, correlation, and feature classsification using the multi-dimensional signals obtained in different domains. The thesis also proposes an extension to an existing manual cloud classification technique for application in nowcasting.

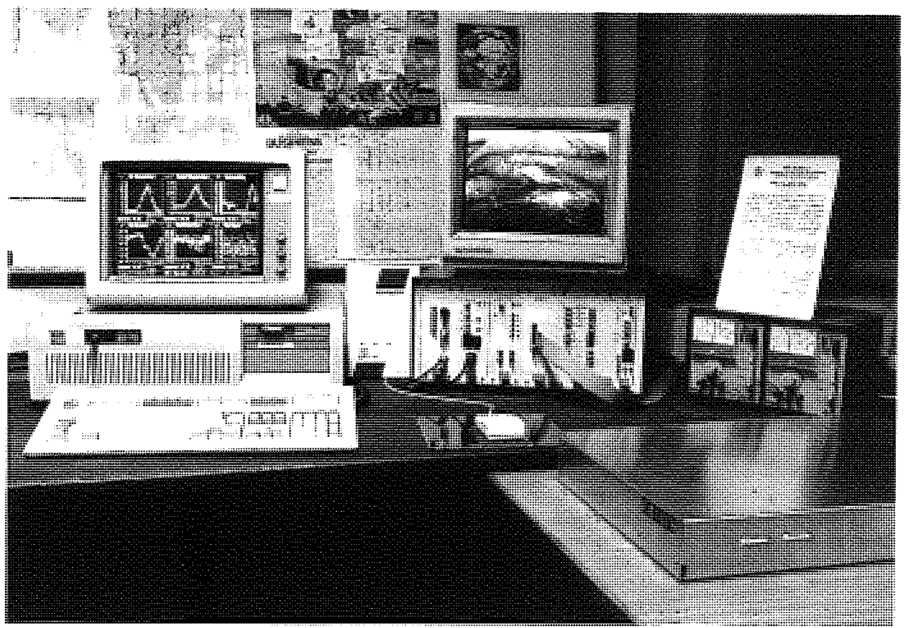


Plate 1.1 The real-time nowcasting system

1.5.0 Summary of thesis

Chapter 2 reviews very-short-range forecasting (VSRF) systems under development or under-going operational trials. Their configuration differs from one country to another depending on their climatology, economics, and the present synoptic weather networks in operation.

In chapter 3, a Ground Local Nowcasting Station (GLNS) developed in-house is discussed. The chapter is divided into two sections giving details of its hardware and software design. The custom-built, stand-alone, Motorola 6809 based sub-system is able to give more detailed information about the variations at the site in real-time than is available to a forecaster at an outstation, and further, it is continuously available for real-time analysis.

Chapter 4 reviews weather satellites that are presently in orbit and discusses the role of the geostationary satellite 'METEOSAT 4' in nowcasting. A brief discussion is presented on the methods deployed for information acquisitioning, pre-processing, and dissemination by the European Space Agency (ESA). The images transmitted for reception are in two forms, and require different ground receivers (PDUS and SDUS), their differences are highlighted. The receiver chosen for the low-cost real-time nowcasting system is the SDUS receiver, however, the algorithms developed for extracting weather information {see chapter 7} can be used on images for both type of reception.

In chapter 5, the two differing sub-systems (satellite receiver and the GLNS) are integrated to form the real-time nowcasting system for localised weather. The standard hardware is modified in-house for automatic operation and is used for capturing a 512 * 512 pixel section of the original 800 * 600 image. which is transferred into the PC frame store under interrupt control. The chapter also discusses deficiencies discovered in both the operating system (DOS) and the language used (C) for real-time operation and shows how these were resolved.

In chapter 6, a novel approach is adopted in constructing statistical models using time series data from the transducers. The models use this site-specific past-and-present data to predict their future values for nowcasting. The statistical models are constructed using AutoRegressive Integrated Moving Average (ARIMA) techniques proposed by Box and Jenkins[58]. Examples are shown of transducer variations at the site on different days. Univariate models are constructed for individual transducers and statistical measures are shown for each to highlight the suitability of the models for nowcasting.

In chapter 7, satellite images are processed to extract weather information. Image processing is constrained to the area of interest. The raw images captured by the system require further pre-processing such as re-construction, image enhancement, removal of spurious noise (coast lines), geometric transformation prior to extracting the weather information. Weather information include tracking a given feature and identifying it in terms of the type of cloud (classification). A manual cloud classification technique proposed by Hawkins[82] is extended for automatic operation for nowcasting.

Finally chapter 8 proposes suggestions for future work on the real-time nowcasting system and draws the thesis to a conclusion .

Chapter 2

2.0 Review of VSRF systems

2.1 Introduction

A number of very-short-range forecasting systems are presently undergoing operational trials or being being developed throughout the world. These systems are a result of demands being placed upon the meteorological communities to improve their services to cope with hazardous weather situations which destroys life and property. The systems design philosophy differs from one country to another due to their respective climatology, economics and the present observation methods. However, in the main, they are orientated towards improving short-range forecasting by integrated use of existing and new observation sources, combined with new processing and human interactive capabilities.

The following gives concise details of their aims.

2.2 PROFS

The Prototype Regional Observing and Forecasting Service (PROFS) is a programme within NOAA in the USA to develop a system concept for local weather services. The local weather service can be taken as VSRF. In the programme-implementation plan (1980)[12], the objectives of PROFS were expressed as:

(a) To collect, define and analyse the requirements for local services and to use this information as a basis for creation of prototype system design.

(b) To asses and tailer state-of-the-art and new solutions necessary for meeting the service requirements.

(c) To design and conduct tests of components, sub-systems and the total system to ensure that the desired level of performance is acheived.

PROFS is continuously designing and testing various components of a VSRF system, from observation to dissemination. In order to reach its goals, PROFS established an "Exploratory Development Facility" (EDF) at ERL in Boulder, Colorado. The EDF has established an experimental system including observations, data processing, work stations with interactive graphic displays and output channels to selected receivers of forecast information.

Input data comes from different sources: radar data from Limon and Cheyenne WSR-radars, satellite data from Colorado State University and University of Wisconsin, synoptic observations and synoptic scale forecasts via Automation of Field Operation Services (AFOS) , local surface mesonet (small network of ground stations) automatic weather stations and a vertical profiling (radiosonde data) system (Denver airport). Data from these services is collected for differing weather situations and the resulting weather associated with these changes. This data is then used for real-time forecasting exercises(13,14,15). The aim of these exercises are:

(1) Improve on operating features of previous PROFS workstations.

(2) Incorporate many data sets not previously used in PROFS exercises.

(3) Introduce forecast procedures to be evaluated for possible future implementation by the National Weather Service (NWS).

Data are placed at the disposal of different forecasters in simulated real-time. Forecasters had to provide real-time forecasts of several weather elements.

Presently, a second workstation(16,17) has been established implementing suggestions resulting from previous trial situations and experience.

These workstations are a tool for use in meso-scale forecasting based upon the continually evolving software and hardware design concept utilising state-of-the-art technology. PROFS primary function is to provide the functional and performance requirements for the operational workstation to be placed in the National Weather Services Forecasting and Warning Offices in the early 1990's[16].

2.3 FRONTIERS

Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar Satellite (FRONTIERS) is the goal for a pilot project on short-period (0-6 hours) weather forecasting which began in 1978. Its aim is to lead to a prototype operational interactive computer analysis and forecast system. The focus is very much on precipitation. The various components of the multiple radar system, data collection, data processing, data analysis, and forecast procedures have been discussed by Browning (1981)[18,19].

Currently (1989), the meso-scale analysis centre (MAC) at Bracknell receives digital data from METEOSAT 4 geo-stationary satellite giving high-resolution cloud images and radar pictures from six sites covering the whole of UK. Radar pictures are obtained every 15 minutes and satellite data every half hour. At the MAC, radar data are converted for display to a resolution of 5 km and 8 intensity levels. The radar rainfall rates are adjusted by using rain gauge information. The satellite images are used to extend the rainfall data beyond the range of the weather radars. Within the area where the radar and satellite information coincide, the radar data is used to calibrate the satellite data. It is planned that rainfall forecasts will be disseminated in video form to special customers.

Numerous progress and application literature[20,21] exists on the FRONTIERS. Similar to PROFS, it is an interactive workstation approach with all meteorological knowledge and understanding needed to interpret the images provided by the forecaster (operator).

On a recent visit to Bracknell (1989) it was discovered that two identical systems are in operation: one which is undergoing operational field trials and the second is being used for system development and enhancement. It was pointed out that due to hardware and software failures on these systems, the strategy of two seperate systems was changed such that in the event of the main system failing; the development system will be used.

2.4 PROMIS-90

PRogramme for an Operational Meteorological Information System (PROMIS-90) is a design of the whole weather service of Sweden for the 1990s. The PROMIS-90 plan was worked out in connection with the government-initiated reorganisation and is well documented in a Swedish report by Bodin and Liljas (1979)[22].

The basic design idea is to separate the weather service into two parts: one for VSRF (0-12 hours) and one for short to medium range forecasts (12 hours -10 days). The organization consequences of this division and the meteorological consideration[22] has led to the creation of a central weather office (CW) and regional weather offices (RWs). Their tasks have been outlined by Bodin and Liljas (1979)[22].

In 1982, a thorough technical specification for the PROMIS -90 Regional Weather Office Pilot Station , PROMIS-600 was completed. Custafsson et al.[23] discusses the development on the PROMIS-600. It is expected that the whole project, as discussed by Bodin and Liljas[22], will be completed during 1988-1991.

2.5 VSRF in the Japan Meteorological Agency (JMA)

The JMA operates a weather service in a very densely populated country with a geographical location that favours the development of devastating weather systems. In summer and autumn tropical cyclones and severe storms cause flooding, especially in eastern Japan. In winter large amounts of snow falls on the northern islands and particular emphasis is therefore placed on the forecasting of large amounts of precipitation and winds.

To cope with such severe weather, dense networks of AWS have been set up and have been in operation since 1979. The Automated Meteorological Data Acquistion System (AMeDAS) was set up to provide real-time information, primarily on precipitation intensity, to help in forecasting severe floods. The AWS part of the system consists of 1317 precipitation gauges (with an average spacing of 17 km.) and 838 stations to observe surface wind, temperature and sunshine (with an average spacing of 21 km.). Data are collected once every hour by the AMeDAS centre in Tokyo. Collection of data from all stations takes eight minutes and distribution to fifty local and ten regional forecast offices takes an additional ten minutes.

Japan also has a radar network of twenty stations with a resolution of 5 * 5 km. Satellite data is received from Japan's own operational geostationary satellite (GMS).

The Local Forecast Offices (LFOs) are responsible for preparing and issuing very-short-range forecasts (0-6 hours). Besides conventional observations and guidance from Tokyo national centre the LFOs have available:

(a) Radar precipitation forecasts every hour via facsimile

(b) AMeDAS regional data via 200 baud lines presented on line printers once an hour

(c) GMS satellite analysis every third hour via facsimile transmission

The JMA has done very little to develop objective or other forecast methods that can be used in the future VSRF system. Each regional and local forecast office will have a personal computer but no more computer power. Computer power for forecast applications will be centralized[24].

2.6 Conclusion

The developn.ent of VSRF systems to cope with meso-scale phenomena has been briefly outlined. These are large scale projects utilising many differing sources of data, requiring vast computer processing power to acquire near real-time atmospheric data, manipulate, analyse and disseminate to local users. The term 'local' implies state or country such as FRONTIERS for U.K.. These systems are being developed to cope with diverse type of weather (such as storms in PROFS).

CHAPTER 3

3.0 GROUND LOCAL NOWCASTING STATION (GLNS)

3.1 Introduction

The meteorological elements are the quantities or the properties of the atmosphere that are regularly measured. Some of them are weather phenomena in their own right; others only relate indirectly to observable weather behaviour. Elements such as temperature, atmospheric pressure, wind speed and wind direction, or precipitation have been observed and recorded for the purpose of analysis for a long time. Prior to mid-60s, all meteorological data was gathered by manual observation or by simple recording instruments (chart recorder, punch-tape recorder)[25], which were unable to operate unattended for very long and relied on frequent visits by the observer.

Advances in semiconductor technology have made possible the development of accurate and reliable atmospheric observation and recording instruments. These instruments are designed not only for an accurate account of the elements observed but must also be robust and durable enough for their exposure to the weather. Strangeways[26] gives a full account of the problems to which meteorological instruments are subjected and suggests design methods to cope with severe weather variations. Similarly, advances in microcomputer technology have made possible the automation of atmospheric observations, which can operate unattended for long periods.

The meteorological network of observations consists of land, sea and upper air operated schemes and are detailed in the meteorological office annual report (1988). The discussions which follow are restricted to land observations and in particular to local site observation.

A system that measures and records atmospheric variations is called an "automatic weather station" (AWS). The basic requirement of an AWS is a number of transducers connected to a data logger where data is captured and recorded. The data logger can be commanded remotely to transfer its information to the control weather centre by telephone call-up over public lines or by data transmission systems such as microwave communication links .Their primary purpose is to replace human observers in remote or exposed locations. Another form is known as data collecting platform (DCP) which is basically a data logger that transmit its data through a satellite[27]. Basic AWS's remain in use at remote sites and the information collected by them is transferred to the central office.

Even with such advances, truly manual data collecting stations remain an essential part of a country's meteorological network. The observers at a given site, report hourly variation of transducer readings and augment these with visual observation of cloud cover, visibility and precipitation.

3.1.1 Published AWS's

The literature has been sparse in respect of AWS's for specific use in the meteorological network. However, recent publications indicate the widespread use of microcomputers for AWSs. Their use is primarily for displaying in-coming atmospheric data for visual interpretation, or for the graphical representation of past data, on very poor resolution graphics. A number of publications exist on an AWS based on the BBC model B microcomputer e.g. Sparks and Sumner (1984)[28]. This system comprises a number of transducers, the majority of which are deployed for measuring soil temperatures at various depths. The software is in BBC Basic and its major contribution includes the acquisition of transducer data, archiving on to floppy disk, and the graphical display of historical data on a monitor screen. The station can either collect data or display historical data but cannot simultanously collect, display and make available for analysis which will be shown (page 25) to be a significant requirement in a semi - intelligent station such as the one proposed here. A similar hardware design by Duncan (1985)[29] uses an Apple II microcomputer with its software developed in UCSD-Pascal. This differs slightly from Sparks and Sumner in that graphical facilities were not reported in the literature but it does include some basic statistical analysis such as; means, daily maxima and minima as well as cumulative recordings etc. An additional facility from Duncan is the inclusion of a chart recorder for continuous data presentation. Strangeway and Smith (1985)[30] developed one of the first AWS for hydrometeorological data collection in the mid-60s at the Institute of Hydrology (U.K) and continued improving its design as technology advanced. The paper[30] outlines the development of the AWS from its beginning to its current status, and includes comparison with commercially available AWSs. It highlights the shift in data recording methods from reel-to-reel magnetic tape with transmission via post to the direct transmission of sampled data via satellite. There is no mention of a real-time clock with their AWS and the paper fails to point out how the raw data is related to the time of day for which it was recorded. The AWS initialisation is pre-programmed in EPROM without operator intervention; there is no provision for the operator to give time of day at which recording comenced. It further fails to highlight how the AWS decides on the transmission times if it is not aware of the time of day since it can be powered at any time of the day, or how the receiving system sorts the incoming data with no time information. The paper also points to the need for onboard storage for future AWS's, which has been implemented on the system discussed in this thesis.

A number of commercial AWSs are available from leading instrument manufacturers. In the main, these are deployed by private organisations (Building industries, farmers, etc.) as simple weather observation and display stations. These AWSs range from a single transducer station to several transducers; offering restricted hardware expansion facilities . They have very limited onboard storage; typically a few kilobytes, but offer battery back-up, as required at remote-site operation. Their dedicated software is written in low level languages appropriate to the microprocessor utilised, although a number of them have recently introduced a limited version of high level language (Basic).

The AWS's in general use capture data from transducers at variable sampling time and present the data in summary form of maxima and minima along with the current reading from the transducers on a display (in most cases on an LCD display) or hardcopy to a printer. In some cases an audible warning facility is provided indicating a drop below a pre-set level of a particular transducer. The user is given very little provision for changes in either the hardware or the software from the AWS's original specification design. The lack in provision is understandable when taking into account development costs. These AWS's are designed to meet specific requirements within the field of their use.

3.1.1 Summary

The AWSs designed specifically for use within the meteorological network are characterised for remote operation and, as indicted previously, are developed to relieve human observers in remote or exposed locations. Each design is unique in data capture, storage and its subsequent transmission.

Although widely different in their detail; the AWS's introduced(28,29,30) share the common philosophy of observing atmospheric variations using a microcomputer . Those described by Spark and Sumner[28], Duncan[29] are in the main display stations with facilities for archiving on to a floppy disk. The philosophy behind their design of AWS's show a tendency towards climatology; archiving of historical atmospheric data rather than meteorology. Strangway and Smith[30] developed a purpose built AWS for remote operation; relieving human observers of this mundane task.

3.1.2 The 'nowcast' station in this thesis

It is fundamental to the present thesis that the various architectures of the above schemes make them less than ideal for adoption in nowcasting; continuous observation and analysis of local site atmospheric variations. The strategy adopted for nowcasting is a semi-intelligent data station that can: i) observe local atmospheric variations, ii) display this real-time data for visual interpretation, iii) archive the data for climatology, and iv) most importantly continually make available the real-time observations for analysis. The semi-intelligent data station proposed for nowcasting is the Ground Local Nowcasting Station (GLNS).

At the heart of the GLNS is a 6809 microprocessor based development system. This provides a favourable hardware configuration for its adoption in the GLNS design {see section 3.2.1}. Figure 3.1 depicts in block diagram form an overview of the GLNS. Software developed {see section 3.3} for the GLNS interrogates transducers observing the dynamic variation in atmosphere at pre-determined intervals. The output provided by the transducer in many cases is not in a form suitable for direct input to the microcomputer and must be conditioned; Figure 3.2 depicts a typical path taken by an analogue transducer. Since the transducers and the GLNS are at seperate locations, the output presented by any of the transducers is transmitted via a screened cable to the individual plugin module. The analogue signals require signal conditioning due to their inherently small outputs. Signal conditioning is carried out in the individual transducer modules and consists of amplification, scaling, and offsetting. The analogue signals must be translated to equivalent digital outputs using the analogue-to-digital converter (ADC) prior to their capture by the microcomputer, the continuous process being represented as discrete samples within the microcomputer. After capturing the current

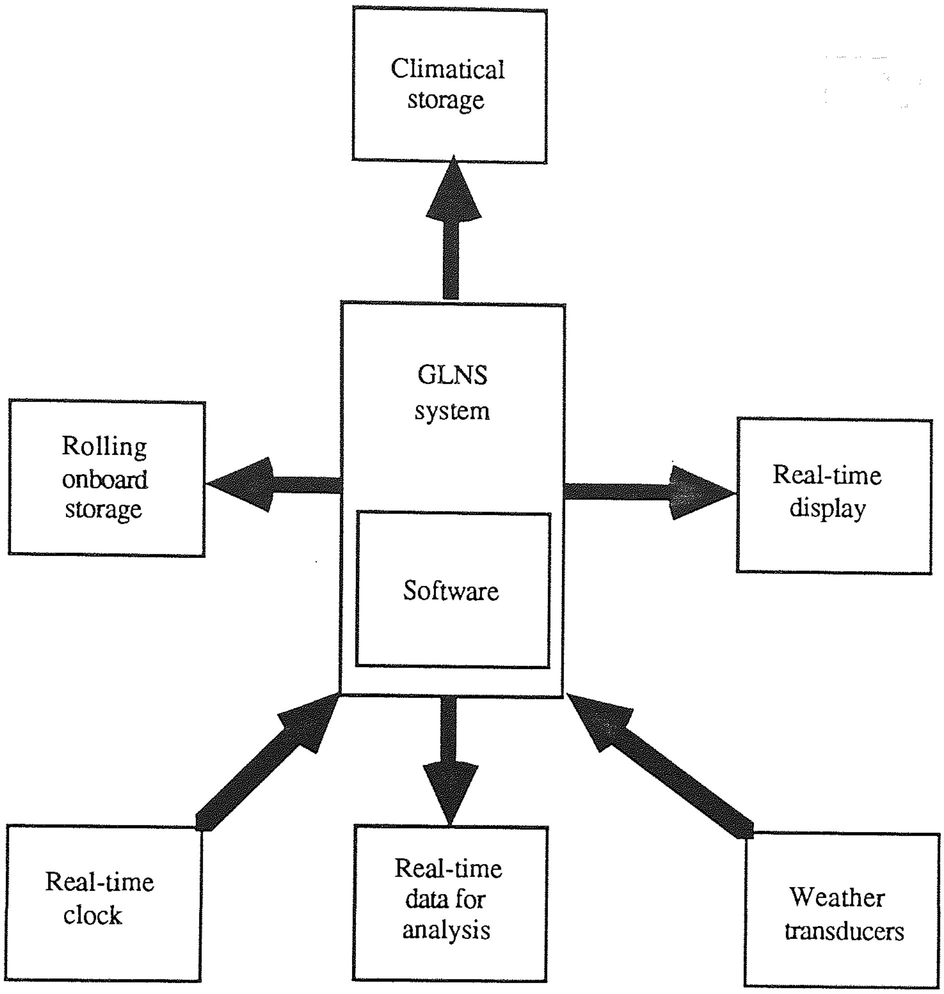


Figure 3.1 Overview of the GLNS

value from the transducer, further pre-processing is needed within the microcomputer in terms of erroneous input, sign checking, overflow, averaging of consecutive readings before the particular input is finally available for display, archiving and analysis.

The onboard rolling archive maintains a past-to-present 24 hour record of each transducer. At the end of the 24 hour cycle, previous day samples are overwritten by the current observations, however, at any instant in time the past-to-present 24 hour record for each transducer is maintained. This form of flexibility of providing rapid samples of past-to-present atmospheric observations encompasses the complete

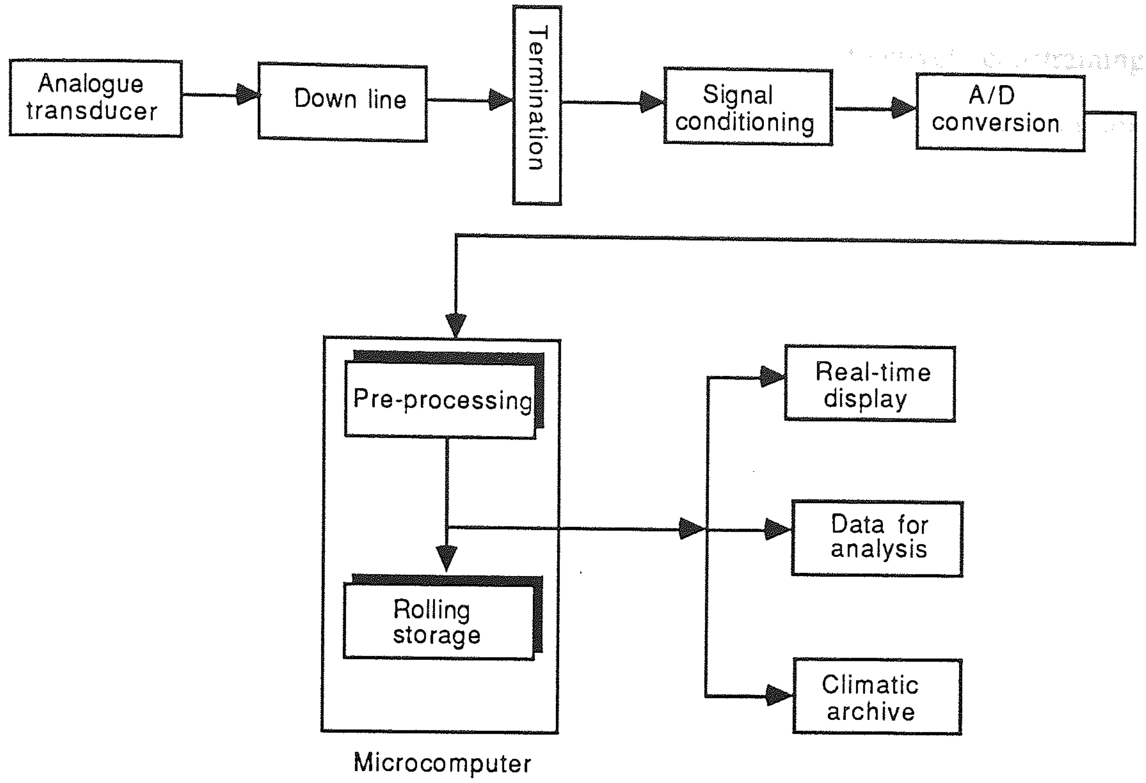


Figure 3.2 Typical path taken by an analogue signal for capture by the GLNS

range of meteorological data analysis philosophies (synoptic-scale, meso-scale and nowcasting), ensuring that this data can be utilised for the varying forecasting periods.

The continually observed atmospheric elements can be displayed in various formats {chapter 6} for visual interpretations.

The GLNS is designed to provide a real-time clock/calender {see section 3.2.2.1}.

The concept of using a front end sub-system (GLNS) for local observation was intended to remove the following obstacles :

(1) Menial tasks such as data capture, pre-processing and data preperation places a burden on the nowcasting system. The GLNS provides a dedicated sub -system which effectively prepares atmospheric data for real-time analysis.

(2) Remote global atmospheric data is provided by the METEOSAT geo-stationary satellite {chapter 4} giving details of cloud formations. The satellite data must be captured in real-time to avoid loss of information since it is not repetitive.

Each image occupies a 4 minute slot for transmission, effectively constraining the nowcasting system to capturing these images during the transmission period.

The GLNS has a modular architecture with each transducer having individual plugin modules; enabling the GLNS to continue to operate in the event of any transducer(s) failure. Any signal conditioning on the analogue signals prior to their conversion is provided within the individual transducer module. Figure 3.3 depicts in block diagram form the functional components of the GLNS.

The rest of this chapter is devoted to the hardware and the software of the GLNS. It is sub-divided in to two sections, giving details of their design methods.

3.2.0 GLNS hardware design

The fundamental requirement of a microprocessor based data acquisition system is input of data, processing of data and output of data of a given physical process or processes. In many respects the principles involved in interfacing transducers (irrespective of the physical process which they observe) to a microcomputer differ only marginally from one field of use to another: variation in stress, strain, vibrations etc. in materials to fluid flow, viscosity, heat etc. in chemical processes to variations in atmospheric elements related to weather all generate electrical voltage, current or charge impedances in proportion to the physical value of the process under observation. As indicated earlier, the output provided by a transducer is generally not in a form appropriate for direct input to a microcomputer, so it must be reconditioned prior to being converted into digital form.

Fundamental to the proper representation of a continuous signal in the discrete domain is the concept of sampling. The sampling theorem[31] states that : Any continuous signal with a finite bandwidth of f-Hertz can be completely described in the

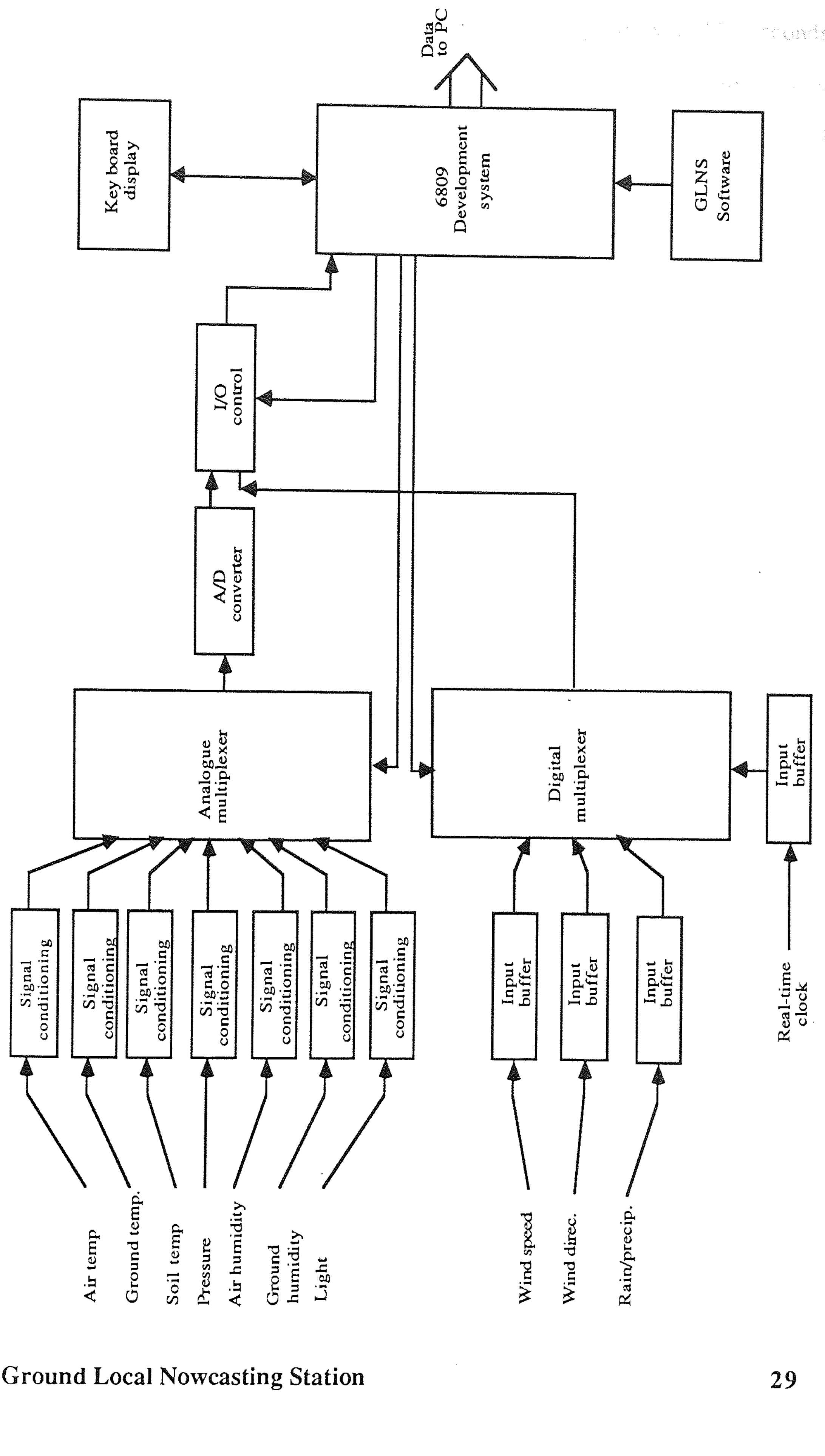


Figure 3.3 GLNS block diagram

discrete domain by sampling it at time intervals seperated by T=1/2f seconds. This implies that the signal must be sampled at a rate of at least twice the highest frequency in the signal's spectrum. The resultant impulse sample train could then be passed through an ideal filter and the original signal reproduced. If the sampling rate is reduced, sample pulses spread apart in the time domain, and the spectra of the frequency domain move closer together. Eventually the spectra will touch and finally overlap. Once the spectra have overlapped, aliasing occurs to the detriment of the original information.

Previous publications(28,29,30) all failed to address or report the sampling procedures adopted in the design of their AWS. The physical nature of atmospheric variations is such that abrupt change does not occur in many of its elements; and changes are gradual. This rate of change varies and could be sufficient enough for weather conditions at a given location to deteriorate within half an hour. The sampling rate must cater for such deviations. However, practical constraints due to limited onboard memory must be considered in deciding the number of samples which can be stored. The need to maintain a 24 hours rolling onboard archive had meant that samples at 1 minute intervals should be taken (encompassing all weather situations).

With the availability of historical site data, investigation could be conducted to determine the optimum sampling rate. Thus, a calm day in summer produces very little variation in atmospheric elements over several hours, but a turbulent day can produce drastic changes over a short period of time This suggests the need for some form of adaptive sampling rate.

Noise is a constituent companion in the world of data acquisition and every effort needs to be made to reduce it. The connecting cables between the transducers and the microcomputer are all screened and their lengths were too short to warrant any filtering operation prior to their interface. The quantum levels of the analogue-to-digital converter is chosen to be 12 bits which improves the signal-to-noise ratio thus reducing any superimposed noise on the original signal in excess of -70 dB. Each element is sampled twice consecutively and averaged prior to its storage, reducing any spurious noise.

3.2.1 Microcomputer

The basic criteria for selecting a microcomputer for the GLNS design was governed by : sufficient memory RAM to facilitate a 24 hour onboard rolling data archive, ROM memory for housing the dedicated GLNS software and peripheral expansion capabilities for interfacing the required transducers. These criteria are not over severe as most of the currently available 8 bit microprocessor based systems would have sufficed.

The GLNS makes use of a commercially available 6809 based microprocessor development system, . Its flexibility in terms of memory expansion and several onboard 8 bit parallel peripheral interface adapters (PIA's) made it an ideal choice for the GLNS.

The development system is a single board with 32 Kbytes onboard R/W memory. Its complete memory map is depicted on Figure 3.4.

A 4K ROM space for expansion is used by the GLNS dedicated software. An additional 32K RAM board was installed to increase storage space to 64 Kbytes for 24h rolling data archive. The major advantage of this development system was the availability of 5 dual parallel peripheral interface adapters (PIA) supplied as standard. This gives an inherent flexibility in the number of transducers that could be connect to the GLNS. The current hardware makes use of only 2 of the PIA's: one used for transducer interface and the other for data transfer to the PC.

The operating environment of the development system is the Technical System

Consultants (TSC) 6809 debug package. This offers extensive debugging facilities for

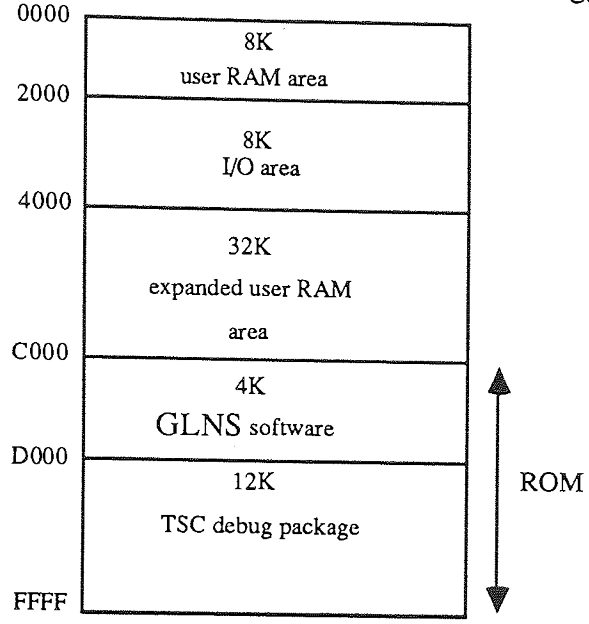


Figure 3.4 GLNS memory map

testing the assembly code. The step execution statement was utilised to the full in the earlier stage of assembly programming.

There were certain limitations posed by the development system of which the major drawback was lack of secondary storage (floppy disk). This meant that only small program modules could be developed for testing transducer interface boards within the system and program modules had to to be re-keyed when ever the system was powered off. The major part of the software development was carried out on the UNIX PDP-11 which has a 6809 cross compiler, with the final code being down loaded into an EPROM for debugging on the development system. The development board makes available for use only one of the two interrupts provided by the microprocessor and the board was modified for making use of both interrupts.

3.2.2 Digital modules

The GLNS is designed with a modular architecture with each transducer being interfaced via its own module enabling ease of operation and maintenance. The individual transducer modules are plugged on to the digital mother-board, depicted on Figure 3.5.

Each module is selected through the 3-to-8 line decoder (74LS138N) under software control {section 3.3}. The selected module places an 8 bit pattern on the data bus (port lines A0 - A7) representing the transducer magnitude for capture by the computer. The steering logic provides the necessary enabling and disabling signals for the individual transducer board.

3.2.2.1 Real-time clock

The real-time clock is an essential component of the GLNS, It is used to initiate data storage, and to control data transfer to the PC under strict timing; the PC captures real-time data from the satellite receiver which cannot be repeated. The 6809 development system does not have a real-time clock and its processor could not provide a real-time clock signal since it is operated under interrupt by the GLNS. This was remedied by purchasing a commercial unit[32] that uses timing signals transmitted from a 60KHz MSF receiver. The MSF is a standard frequency transmitter located in Rugby. It radiates an accurate 60KHz carrier which is keyed with pulses whose widths signal the time and date in serial BCD form. The time reference is the Caesium Beam Standard at the National Physical Laboratory. In addition to the complete time and date (which includes the day of the week), MSF transmits the difference between British Time and Universal Time. A block diagram of the main logic board is depicted in fig 3.6. The single 8-bit output bus is multiplexed and carries both the display data and interface data.

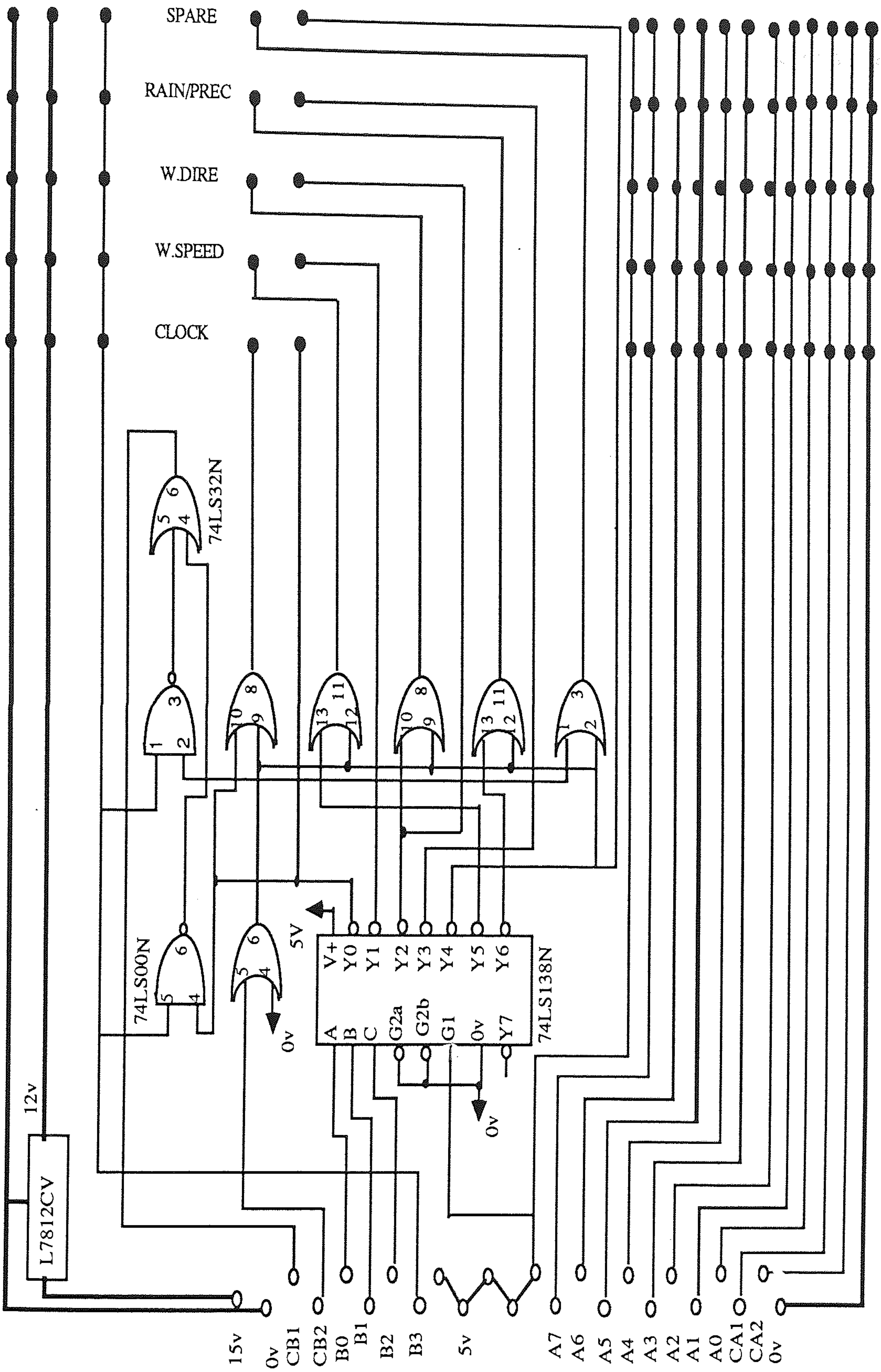


Figure 3.5 Digital mother board

The interface data consist of 7 bytes which are made available once per second after the first successful capture.

The interface data sequence (each a byte) is as follows:

Year

Month

Day of month

Day of week

Hour

Minute

Seconds.

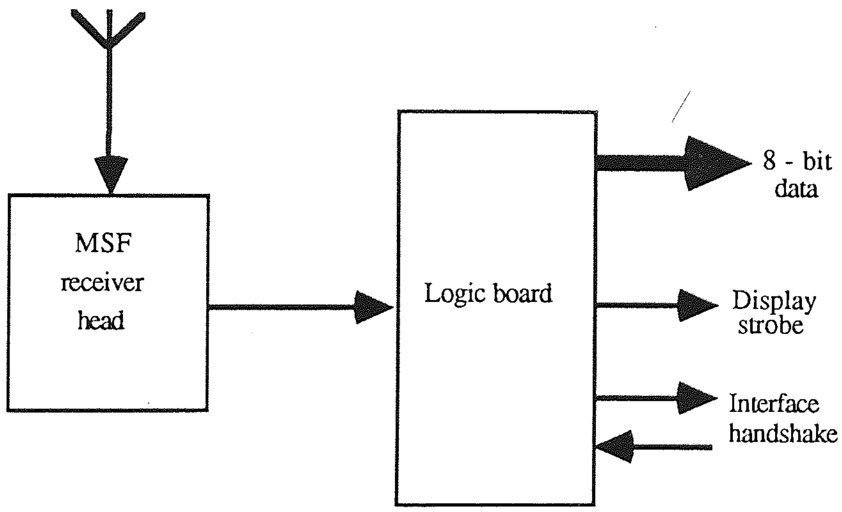


Figure 3.6 Main logic board of the GLNS real-time clock

In addition, a Z80 microprocessor based sub-system is needed to maintain accurate time keeping when the Rugby transmitter is turned off for maintenance. The GLNS clock interface module consists of a transparent latch that inputs the timing data to the development system as depicted by Fig. 3.3.

3.2.2.2 Wind speed

The measurement of wind speed is generally carried out using an anemometer, a three cup rotor arm; one cup is being pushed upwind as the other two are dragged downwind. The anemometer deployed for the GLNS is the standard 3 cup type with a small shaft connected to a slotted disc which interrupts a light beam in an opto-coupler. The output of the opto-coupler is TTL compatible and is free from any bounce effects. The calibration of the anemometer is 5 pulses per meter air run. An 8 bit binary counter is initialised to record these pulses for a predefined period of time prior to input to the development system. The range of wind speed measuring capabilities of the GLNS was designed to cater for most atmospheric wind variations.

3.2.2.2.1 Conditioning and Processing

The range of wind speed measurements possible with the GLNS are :

wind speed = count * calibration* recording time (meter/second)

minimum wind speed

minimum count = 1

recording period = 1 second

wind speed $= 1 * 1/5 = 0.2 \ ms^{-1}$

$= 0.45$ m.p.h

maximum wind speed

maximum count = 255

recording time = 1 second

wind speed = $51.0 \ ms^{-1}$

= 113.8 m.p.h.

3.2.2.3 Wind direction

Wind direction, (the direction from <u>which</u> wind is blowing) is considered by meteorologists to be a more useful predictor of weather than the measurement of wind speed. The track of a depression has a profound influence on weather and this can be determined by observing a combination of wind direction and barometeric pressure. The wind direction measuring instrument is called a wind vane. The type used for the GLNS produces a 6 bit grey encoded output and is TTL compatible derived from a Schmitt- triggered interface.

A circular disc with 6 bit grey code etching is slotted on a spindle and carefully aligned to give a true pattern for the wind direction. This output is detected using miniature LEDs and photo transistors. There are 64 reading positions on the disc giving 5.6 degree resolution as depicted in Fig 3.7.

The output code received from the wind vane is used as a reference to a look-up table to provide a distinct 0-63 hexadecimal coded numbering scheme for storing. This scheme reduces the final computation to a single multiplication when determining wind direction in angular form. This is highlighted in the software {see section 3.3.3.2} for wind direction in this Chapter.

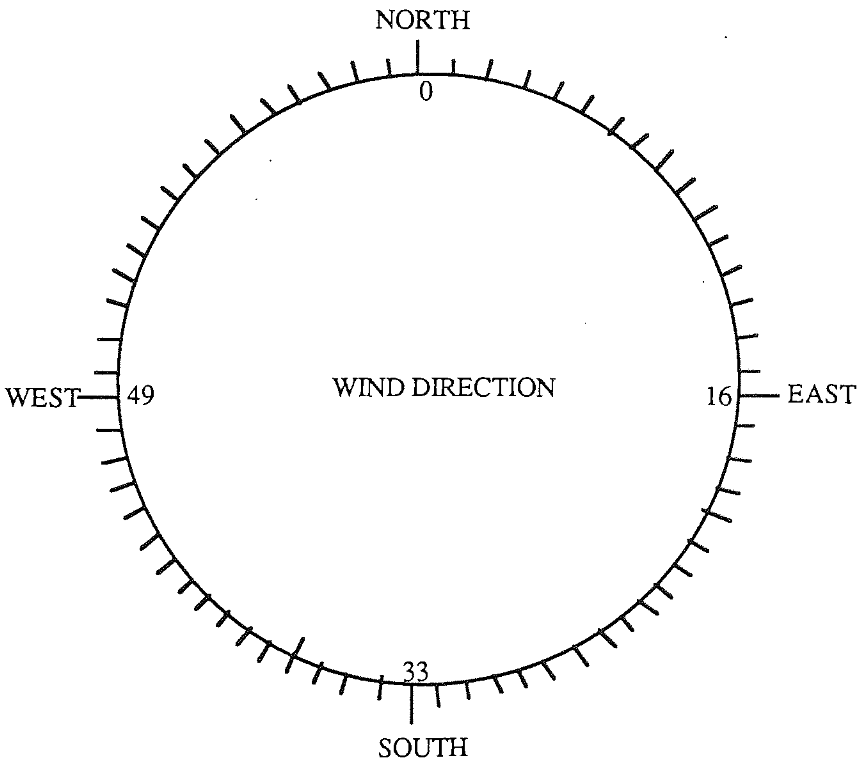


Figure. 3.7 Wind direction disc coding

3.2.2.4 Rain

Rainfall can be measured using a ' tipping-bucket ' rain gauge. This is essentially a funnel enclosed within a cylinder of standard dimensions, which feeds the collected rainwater in to a ' bucket ' type of mechanism (spoon). When the spoon has collected a predetermined quantity (0.24 mm) of water it tips and empties the spoon. A small magnet attached to the spoon mechanism operates a mercury wetted reed switch, giving a pulse for timed interval counting. The rainfall rate is measured by the number of pulses counted in a predefined time interval. In order to determine the maximum rate of rainfall that could be coped with before the spoon becomes permenantly tipped (very heavy rainfall), the switching time during spoon tipping must be known. This was measured to be 340-350 milli-seconds. The maximum rate of rainfall catered by the rain gauge is :

amount of rain held in spoon / time taken for spill

$= 0.24/ 0.35 \ = 0.686 \text{ mms}^{-1}$

$= 0.027$ inches/second

If it continued raining at this rate, it would accumulate to 41 mm's in 1 minute interval. The rainfall in Birmingham for any month for the period 1951-1980[33] was on the average, 75mm.The rain gauge will cope with most severe showers. The rainfall module comprises of a monostable with sufficient duty cycle to eliminate any bounce from the reed switch, this output is fed to a 6 bit binary counter. The binary counter is initialised for approximately 1 minute interval to record rainfall every GLNS loop cycle.

3.2.2.4.1 Conditioning and Processing

The maximum and minimum rainfall rate recording possible is:

minimum rainfall

rainfall count = 1

recording preiod = 1 minute.

rainfall = 0.24 mm/minute.
= 0.0095 inches/minute.

maximum rainfall

rainfall count = 63 , recording period = 1 minute.
rainfall = 0.24 * 63 = 15.12 mm/minute.
= 0.6 inches/minute.

3.2.2.5 Precipitation

Drizzle, snow, hail and intermittent light rain, which does not allow enough rain in liquid phase to be collected to operate the tipping-bucket gauge, is detected using a seperate precipitation transducer. Drops of rain cause the capacity between elements of an interdigitated pattern to increase; this change in capacity is detected as an indicator for precipitation. A small heater is activated when precipitation occurs to ensure shorter drying time of the element. The heater is also activated as the air temperature drops below 2 ^{O}C to maintain the precipitation transducer element above freezing point. The device was developed in-house[34] and comes as a unit with digitised output.

The output from the rain and precipitation module is a single byte which is divided as:

Bit 0 = precipitation indicator (high or low)

Bit 1 = temperature indicator for below +2 ^{O}C. (high or low)

Bit 2,7 = rainfall count for the current period.

The software {section 3.3.3.3 }interprets the individual bits prior to recording.

3.2.3 Analogue modules

The heart of the analogue mother-board is the analogue-to-digital converter (ADC) as depicted on Figure 3.8. The analogue-to-digital converter is the interface between the analogue and the digital domain. Analogue signals are sampled, quantised, and encoded into a digital format for input to the computer environment. All three funtions are accomplished within the A/D converter. The GLNS uses a 12 bit dual-slope integrating A/D converter, where the input signal is integrated over a predefined period of the conversion process. The translated output is multiplexed on an 8 bit data bus, each byte being selectable using the low or high byte select signals. The A/D converter can provide a convert on-demand using the run/hold signal line. This facility is advantagous since A/D conversion can be carried out at times demanded by the sampling rate.

The A/D conversion is triggered by selecting the appropriate transducer module through the analogue multiplexer (LF13508D). The signal to be converted is presented to the A/D converter and conversion triggered using the run/hold signal line. The status signal indicates conversion accomplished and the two byte data is captured.

3.2.3.1 Atmospheric pressure

Atmospheric pressure measurement is an essential component of any weather reporting system. A low pressure centre called a Depression, is the principle feature of the weather in the UK. The approach of a Depression is signalled by a fall in pressure. It is one of the most important element of the synoptic scale forecasting. The normal range of atmospheric pressure variations at sea level is from about 950 mBar to 1050 mBar.

A commercial unit provides an output voltage directly corresponding to the atmospheric pressure with an accuracy of +/- 0.3 mBar. This is fed through the analogue multiplexer for digital conversion prior to recording as depicted by Fig. 3.3. The output provided by the pressure instrument requires no further signal conditioning.

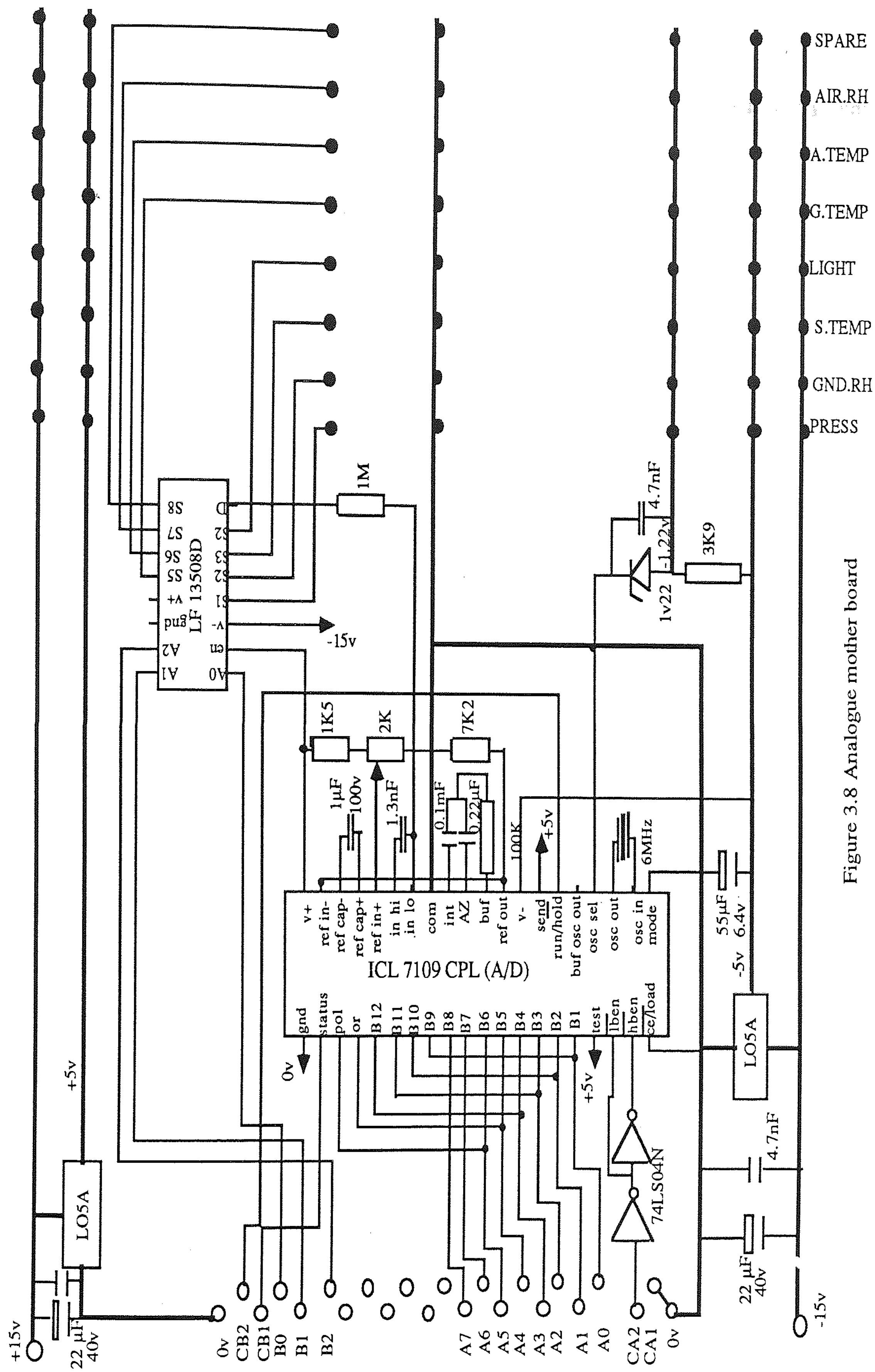


Figure 3.8 Analogue mother board

3.2.3.2 Temperature

In meteorology, temperature measurements are made of air layers near to a ground surface, upper air layers, soil at various depths, the surface water of rivers, lakes and the sea. The inland stations in majority are restricted to air-near-ground-surface and soil temperatures.

The GLNS is currently able to measure temperatures from the following :

Air temperature: measuring temperature on the site roof.

Ground temperature: measuring near ground temperaure.

Soil temperature: measuring earth surface temperature.

The transducer modules for measuring temperature are all identical. The transducers used are the LM 35C series of integrated circuit that operate as three terminal devices and give an output of 10 mV/ ^{o}C. The LM35C operates from -40 ^{o}C to +80 ^{o}C with a typical error over the desired range of +/- 0.5 ^{o}C. The output provided by these transducers is insufficient for translating to digital and requires conditioning. Fig. 3.9 depicts the circuit diagram for the temperature transducer module. It uses a low drift operational amplifier with variable gain and zero offset. The quasi-dc signal provided by the transducers is amplified to a level suitable for the A/D converter.

3.2.3.2.1 Conditioning and processing

The A/D converter has a reference voltage of 2V. The resolution of the ADC is 12 bits. This gives a quantum interval of :

Quantum interval = $V_{ref} / 2^n = 2/2^{12} = 4.8828 * 10^{-4}$

The gain of the module is set at 4.883.

Temperature sensitivity = 10 mV/ ^{o}C.

The gain of each module is set to 4.883 to simplify final conversion to

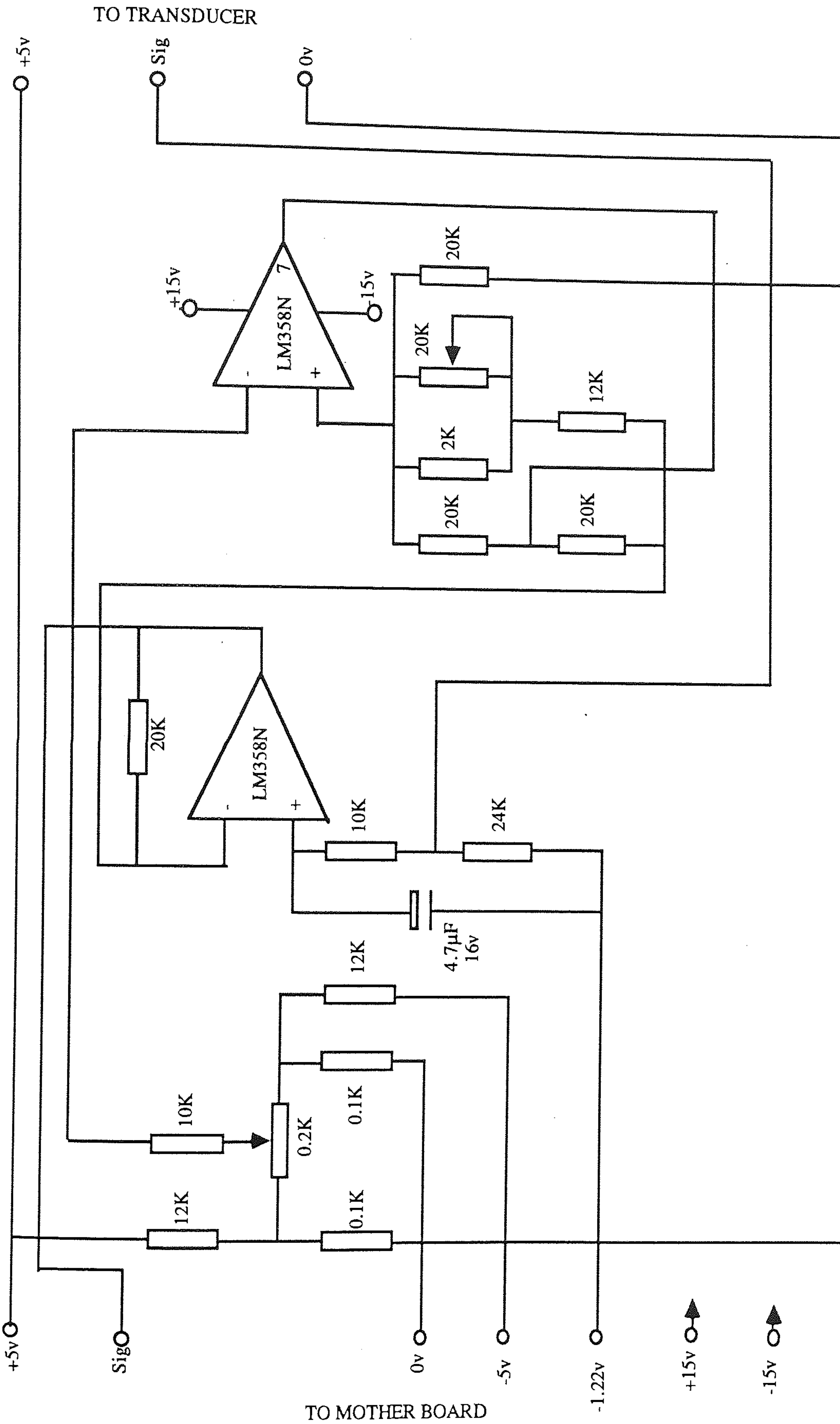


Fig 3.9 Low drift amplifier

^oC. Conversion to ^oC then requires the following steps :

Temperature (^oC) = (Hex * Quantum interval) / (Temperature sensitivity * Gain).

= (Hex * 4.8828 * 10^{-4} * 10^2) / 4.883.

= Hex/100.

Where Hex is the hexadecimal value of the transducer reading.

Thus, a complicated conversion process is now reduced to a simple division. This reduces the number of computational steps in providing temperature reading in the required form for display, archiving and analysis.

3.2.3.3 Humidity

Accurate measurement of humidity is not considered an essential component of the meteorological data network. However, for localised forecasting, it is important to know when humidity is nearing saturation at low temperatures, since this indicates the onset of condensation, icing, ground fog, hoar, frost.

Traditional method of determining relative humidity is based on the knowledge of 'wet' and 'dry' bulb temperatures. The 'wet' thermometer bulb is usually wrapped in a cotton wick, which is supplied with distilled water from a small reservoir. The 'dry' thermometer measures actual air temperature. Relative humidity is calculated by determining vapour pressure and saturation vapour pressure from the wet and dry bulb temperatures as follows :

R.H. = (vapour pressure (e)) / (saturation vapour pressure (e_s))

$$e_s = 6.11 * 10^{7.5T/(T+237.3)}$$

$$e = e_s(T_w) - AP(T - T_w)$$

Where :

T is the temperature of dry bulb in ^oC.

T_W is the temperature of wet bulb in ^oC.

$e_s(T_W)$ is the saturation vapour pressure at the wet bulb temperature.

AP is an appropriate contant (0.8 mb/^oC for thermometer in a Stevenson Screen).

Several transducers are now available with direct relative humidity output quoting accuracy of +/- 2 %. An off the shelf unit was purchased giving direct voltage output of 0-10v corresponding to 0-100 % relative humidty. The GLNS currently has the following transducers :

Air relative humidity : Measuring transducer on the site roof

Ground relative humidity : Measuring transducer near ground level.

The transducer modules for measuring relative humidity are both identical in their hardware. The output from these units are scaled down prior to being digitised.

3.2.3.4 Light

Light intensity is not normally quoted as part of the meteorological weather observations, since it varies rapidly and unpredictably with cloud cover and rainfall. However, for a stand alone GLNS, light intensities with knowledge of time of day will enhance the information extracted from cloud analysis.

The light transducer uses a BPW21 photo diode which gives an output proportional to the logarithm of the light level. The cell outputs about 0.55v in direct sunlight and this is amplified by an operational amplifier by a factor of 10. The transducer module scales it down to the level required by the A/D converter.

3.2.4 Conclusion

A microcomputer system can do extensive linearisation of transducer data, using reduction formulae or look-up tables. Reduction formulae usually require quite extensive arithmetic and is slow in software. Look-up tables are only practical if all replacement transducers have the same characteristic within the measurement accuracy. A look-up table for individual transducers can be provided, but is expensive to maintain as replacement of transducer may require look-up table to be changed. The transducer and interface designs were optimised to be nearly independant of cross sensitivities and as linear as possible. Zero offset and scale trim potentiometers (variable gain) are provided on the interface modules. Changing a transducer then requires only two potentiometers to be adjusted. The temperature coefficient and linearisation terms are small and left uncorrected.

The transducer accuracy is comparable with the meteorological instruments in most of the transducers used by the GLNS with the exception of temperature and pressure. The accuracy of +- 0.1 mb for pressure and 0.1 ^{o}F for air and 0.02 ^{o}F for soil temeratures are the standard quoted for meteorological measurements while +- 0.3 mb and +- 0.9^{o}F are obtainable with the current transducers on the GLNS.

Although the current transducer accuracies in part fall short of those quoted for meteorological purposes, it never-the-less makes provision for modelling of local variations for research.

3.3 Software design

Today, computer software is rapidly overshadowing hardware in cost and complexity and is becoming the dominant, critical component in computer systems.

In designing software, very often, its specification is not completely known when system and implementation are started. Although one can be idealistic and say that software design and implementation should not be initiated until complete specification of the software is available. In practice it may be possible to completely specify the software design only after experience with the partial implementation [35].

The method of software design adhered to for the GLNS is reported by

Simpson[36], Gehani and McGethrick[35] and Leventhal[37]. In designing software for microprocesor systems, several stages must be followed prior to the completion of the overall task and these are:

Problem definiton: Formations of the requirements that the task places on the computer.

Program design: Outline of the program that will meet the requirements.

Coding: Translation of design to program.

Debugging: Making the program perform accordingly to the design.

Testing: Ensuring the program performs the overall task correctly.

Documentation: Description of the program for users to understand.

Maintenance & Redesign: Improvement and extension of the program.

Each of these stages are important in the construction of a working reliable software and consequently of the system. Coding, creating statements in the form that the computer understands, is only one stage in the long process. These individual stages are extensively reported by Leventhal[37].

The GLNS hardware is of modular architecture and its software design conforms with modular programming: the division of the entire task into sub-tasks or modules. Each transducer has its own module, simplifying the task of designing/debugging individual transducer software. The overall task is completed by integrating the individual modules. The initial software was written to test for correct operation of interfaces and accuracy of transducer readings at discrete levels.

In designing any system, consideration must be given to human operator interaction. Care has to be taken to ensure minimum effort on the part of the operator in utilising and understanding the necessary interactions with the system, thus maximising the efficiency of a system. GLNS is designed mainly for automatic operation (gathering, processing, transmitting data in real or near real-time); consequently consideration was given to minimising user interaction at each stage of the design. At system start-up, every effort was made to ensure minimal interaction on the part of the operator.

The software design for the GLNS was translated in assembly code but can be understood by considering high level descriptions. Each module can be considered individually, accepting that part of the design are common to all modules.

3.3.1 Data memory

In order to make the GLNS useful not only for 'nowcasting' but also as a stand-alone weather monitoring station, it is necessary to have access to a rolling archive. it was decided to incorporate facilities for onboard storage of up to 24 hours of past-to -present data for each transducer. This data at the end of the 24 hour period could either be transmitted to a central station, or local climatic archive or lost.

The current memory requirement to achieve this can be determined by considering the memory space required by each transducer:

Memory requirement (1 minute sample)

Digital		
	clock	7 bytes (captured as a header only).
	wind speed	1 byte
	wind direction	1 "
	rain/ precipitation	1 "
analogue		
	air temperature	2 bytes
	soil temperature	2 "
	ground temp.	2 "
	pressure	2 "
	air humidity	2 "

ground humidity 2 "

light 2 "

Total memory required (for 24 hour) = 24.48 kb.

The absolute assignment of memory space to individual transducers is depicted in the data memory map of figure 3.10. At the top of the data memory map is the real-time clock header which only consumes 7 bytes and is updated every minute. An additional feature of displaying the most recent transducer readings and their maxima and minima for the current period is via a data display memory map, depicted in figure 3.11. The GLNS software updates the display area every read cycle. This could form a simple public display area for visual interpretation as highlighted in chapter 6.

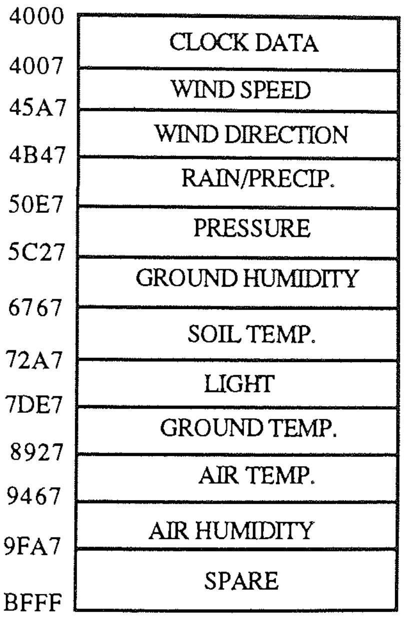


Figure 3.10 GLNS data memory map

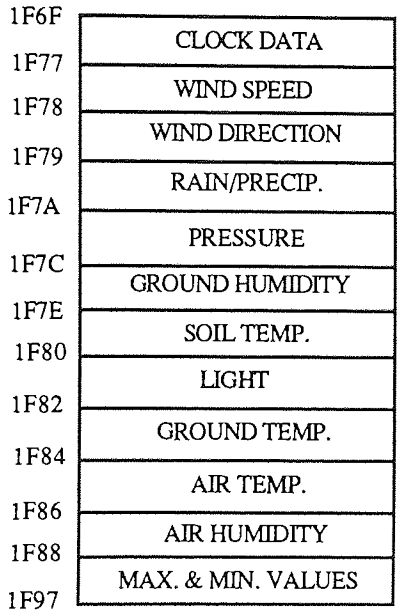


Figure 3.11 GLNS data display memory map

3.3.2 GLNS start-up software

At power up, the GLNS prints a message to the display screen requesting selection of mode of operation. It is capable of operating in three different modes:

1 Automatic mode : GLNS continually records and transmits data.

2 Automatic test : Inputs transducer value to display area for testing transducers.

3 Debug : Allows access to the debug package for software development.

The operator selects the mode of operation for the GLNS with exit to the above main level via reset. In any time related process, the monitoring system must be aware of the absolute time at which initial recording started. Any pointers to time related storage must be adjusted to ensure that the current transducer readings are directed to the appropriate memory location for the time of day and any elapsed time of idleness be filled with a known data pattern. At analysis time, the corrupted data values could easily be distinguished and ignored. This is achieved through interactive input of current time and acknowledgement of whether the GLNS is being started from total idle state. If the GLNS was idle for the elapsed period, its past memory is filled with the known pattern (hexidecimal FF), however, if other modes of operation were selected and the operator wished to continue now in automatic mode then only the elapsed time for which the GLNS was in other modes is filled with the known pattern, any memory adjustment being based on the real-time clock.

It was considered inappropriate to place total dependency of the GLNS on its real-time clock. This was to ensure continued operation of the GLNS in the event of any component failure. If recording and transmission was totally dependent on its real-time clock, the GLNS would have halted if the real-time clock ever failed.

The basic flow of a program is traditionally represented using flowcharts. This is a pictorial view of the major steps taken by the program. However, flowcharts tend to become cluttered for large programs. It becomes difficult to balance between the amount of detail needed to make the flowchart useful and the amount that makes the flowchart a little better than a program listing. The method preferred here is to represent program flow using pseudo code, however, for completion the first module is shown using both methods.Figure 3.12 depicts a flowchart of the start-up module.

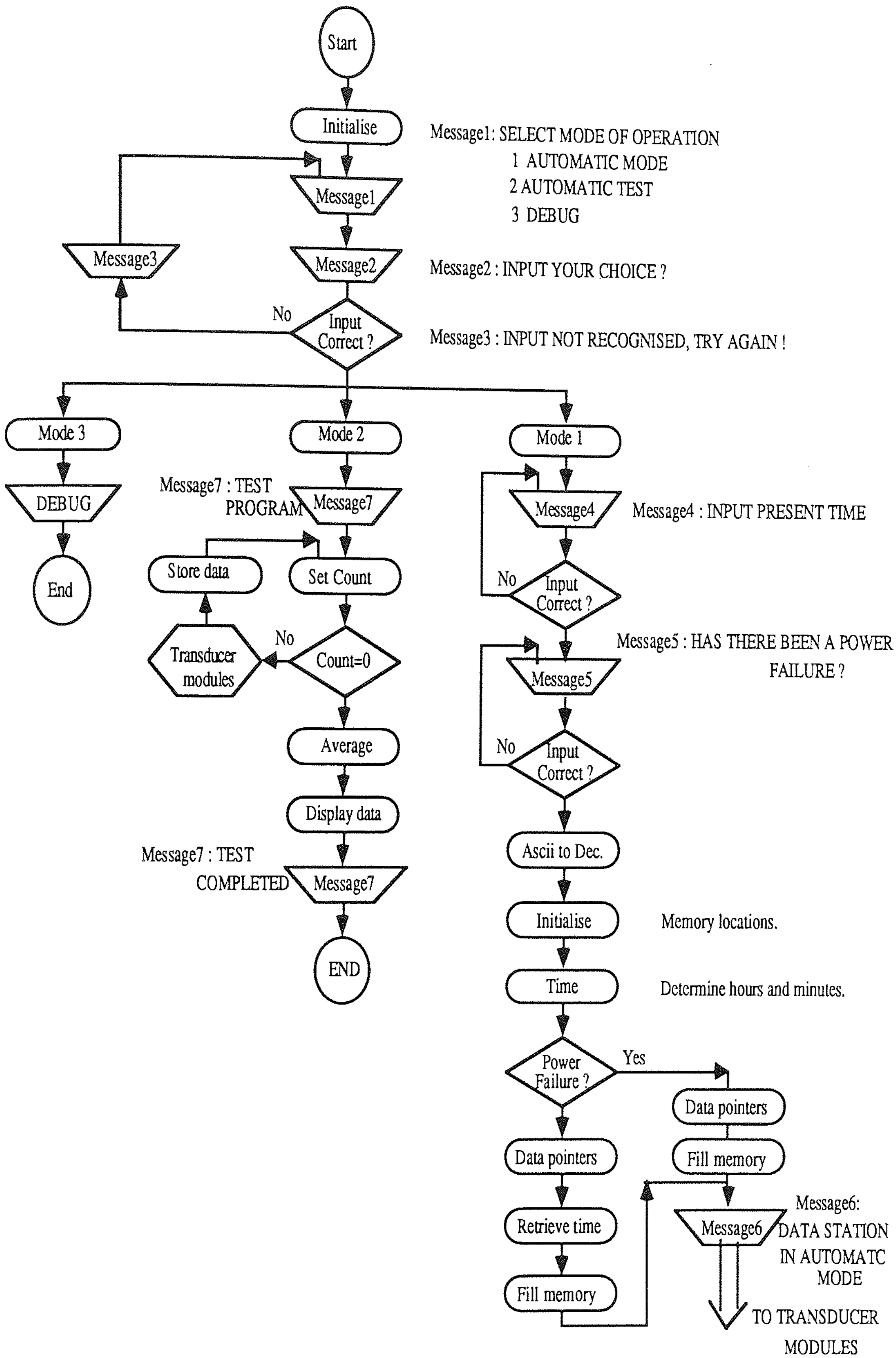


Figure 3.12 Flow diagram of start-up software module

```
Procedure ( power_up )

begin
    initialize interrupts;
    initialize stack;
    program communication ports;
    print message: SELECT MODE OF OPERATION :
                        1 AUTOMATIC MODE
                        2 AUTOMATIC TEST
                        3 DEBUG

    repeat
          print message: INPUT YOUR CHOICE ?
          read input;
          if ( incorrect_input ) do
                print mesage: INPUT NOT RECOGNISED, TRY AGAIN !
    until (correct form of input);
    if ( automatic mode ) do
          automatic mode process;
    else if (automatic test) do
          automatic test process;
    else if (DEBUG) do
          print DEBUG;
          DEBUG package;
end.

Automatic mode process:
    begin
          repeat
                print message: INPUT PRESENT TIME (eg. 1420) ?
                read input;
          until (correct form of input);

          repeat
                print mesage: HAS POWER FAILED ?
                read input;
          until (correct form of input);

          convert all ascii inputs to decimal;
          set time related transfer;
          initialize max. and min. locations;
          determine present time ( hours and minutes );
          if ( power_failed) do
          begin
                calculate data pointer positions;
                retrieve initial pointer position;
                fill elapsed locations with  known pattern;
          end;
          else
          begin
                calculate data pointer positions;
                calculate elapsed locations;
```

```
            fill elapsed locations with known pattern;
        end;
        start automatic recording;
        print message: DATA STATION IN AUTOMATIC MODE
                               PRESS RESET TO STOP
    end. {automatic mode}

Automatic test process:
    begin
        print message: TEST PROGRAM
        set byte_count =0;
        while ( byte_count <2) do
            input each transducer reading;
            store to scratch pad;
            increment byte_count;

        average each transducer readings;
        store to display area;
        print message: DATA IN DISPLAY AREA
    end. {automatic test}

DEBUG:
    begin
        print message: DEBUG
        DEBUG package;
    end.
```

3.3.3 Real-time clock

Once per second after the first successful data capture, the display scanning data is replaced by a 7 byte sequence of parallel interface data for computer capture. The GLNS captures this 7 byte data under interrupt. Strict timing control must be observed in capturing this real-time data since repetition could occur if the interrupt is re-enabled while the present byte strobe is active. The GLNS captures the real-time data once per minute and must disable the appropriate interrupt in between times. The first byte is unique in having a binary '1' in all 4 high bits, and this information can be used to assess the integrity of the incoming data.

The MSF real-time clock has its own alphanumeric display. The display data is multiplexed and its timing fixed under the Z80 software. The display data format is hardware selectable from :

1) Time/ Time + Date

2) 12/24 hour clock display.

The software of the real-time clock can be outlined in the following pseudo code.

```
procedure ( clock )
begin
    enable port interrupt;
    enable procesor interrupt (FIRQ);
    while ( delay  ) do
          nothing;
    disable interrupts,
    convert year data;
    if ( data_corrupted ) do
          fill header and display with known pattern;
    else
          continue;
end; {clock}

procedure ( clock_interrupt )
begin
    select clock module;
    input date byte;
    store byte to header and display;
    while ( delay ) do
          nothing;
    end; {while}
    enable port interrupt;
    enable processor interrupt;
end; {interrupt}
```

3.3.3.1 Wind speed

The transducer translates pulses corresponding to the current wind speed. These pulses are fed to an up-counter for a specified time at the end of which its count is captured for input. Two consecutive counts are averaged prior to recording the current wind speed count to local storage and display area. The basic flow of the wind speed software module is described below.

```
procedure ( wind_speed)
begin
    set scratch pad area;
    set number of bytes to capture (2);
    set byte_count :=0;
```

```
    while ( byte_count < 2 ) do
    begin
        enable wind speed counter;
        while ( delay != 2 sec.) do
            nothing;

        select wind speed module;
        input wind speed count;
        store to scratch pad;
        increment byte_count;
    end;
    average wind speed count;
    store to local storage and display;
    if ( current count > previous maximum ) do
        store as new maximum;
    else if ( current count < previous minimum ) do
        store as new minimum;
end; {wind_speed}
```

3.3.3.2 Wind direction

The arriving input code from the wind vane forms an effective address that selects one of the 64 numbers from a look-up table. This makes the eventual task of determining wind direction easier since a simple product gives exact direction of wind. It could be readily appreciated that wind direction data could not be averaged since the resultant value may not form one of the grey codes and hence the effective address for particular direction.

The basic flow of wind direction software module is highlighted in the following pseudo code.

```
procedure ( wind_direction )
begin
    set pointer to encoded data;
    select wind direction module;
    input grey code from wind vane;
    retrieve encoded data for the current grey code;
    store to local storage and display;
end;
```

3.3.3.3 Rain and precipitation

Rain and precipitation information is obtained from three transducers;

1) Rain.

2) Precipitation.

3) Temperature.

Any software must extract this information. Precipitation and temperature information is contained in the 2 least significant bits of the byte {section 3.2.2.5}, these bits signifying a yes/no occurrence of the event. Rain count specifies the amount of rainfall in a given period of time.

It was initially anticipated that rainfall will only be observed for recording based on the information received from the precipitation transducer, however, since the GLNS samples at 1 minute intervals and remains within a loop wasting time, plus the liklihood of precipitation transducer failure; it was decided to sample rainfall every loop cycle.

The software strips both the precipitation and temperature bits prior to initializing the rainfall count for the specified time and finally adds the bits for storing.

The basic flow of the rain and precipitation software module is highlighted in the following pseudo code.

```
Procedure (rain and precipitation.)
begin
    select rain/precip. module;
    input rain/precip. data;
    extract precip. and temp. data;
    initialize rain counter;
    while ( delay ) do
            count rainfall pulses;
    end; {while}
    read rainfall count;
    if ( rain_count > previous maximum ) do
            store as new maximum;
    else if ( rain_count < previous minimum ) do
            store as new minimum;
    add precip. and temp. data;
    store to local and display area;
end; {rain/precip.}
```

3.3.4.0 Atmospheric pressure

The output from the ADC is 2 bytes and contains magnitude, overflow and sign information. The analogue transducers software is designed to report corrupted data, ensuring that any transducer failure can be rectified immediately.

The pressure transducer module is selected for input to the ADC. The conversion is initiated under software control; enough time is given to ensure that the analogue signal has sufficient time to settle before ADC is initiated.

The pressure software module checks each input for overflow and sign information. If discrepency exists it is immediately reported as an incorrect reading and stored as the known pattern for particular sample. If only one reading is corrupted, the other is stored in the local archive and display area. If both readings are correct , these are averaged and stored.

Previous maxima and minima readings are updated if the current value is not corrupted and differs from the previous maxima or minima readings.

```
Procedure ( pressure )
begin
    set scratch pad area;
    enable interrupts;
    select pressure module;
    set number of readings count for input (2);
    while ( count <2 ) do
    begin
        input pressure transducer reading;
        initiate ADC;
        wait for ADC converted signal;
        retrieve high byte;
        if ( overflow ) do
        begin
            store sign of data to scratch pad;
            if ( count = 2) do
            begin
                if ( both readings corrupted ) do

                    print message: INCORRECT PRESSURE
                    store known pattern to local archive and display area;
                    branch to next module;
            end;
```

```
        end; {overflow}
        else

        begin
                store transducer reading to scratch pad;
                count +=1;
        end;
    end; {while}
    retrieve first transducer reading;
    if ( sign negative) do
        disregard transducer reading;
    retrieve second reading;
    if ( sign negative )
        disregard transducer reading;
    if ( both readings incorrect ) do
    begin
        print message: INCORRECT PRESSURE
        store known pattern to local archive and display area.
    end;
    else if ( one correct ) do
    begin
        store to local archive and display area;
        if ( current pressure > previous maximum) do
                store as new maximum;
        else if ( current pressure < previous minimum ) do
                store as new minimum;
    else if ( both correct ) do
    begin
        average transducer readings;
        store to local archive and display area;
        if ( current pressure > previous maximum ) do
                store as new maximum;
        else if ( current pressure < previous minimum) do
                store as new minimum;
    end;
end; {pressure}
```

3.3.4.1 Ground and Air humidity

Software modules for these differ only in the storage, display pointers and reporting of error messages from one another. Their software is similar to the software outlined for the pressure module. As with pressure readings, the sign must be positive and any errors in this or overflow are reported.

3.3.4.2 Ground, Soil and Air temperature

Software modules for these differ only in the storage, display pointers and reporting of error messages from one another.

The initial portion of the code is similar to the pressure module. The difference being in the sign terms; where pressure can only take positive values, temperature could take both positive and negative values.

If both the current readings are the same in sign and overflow has not occurred, they are averaged and stored. In the event of differing signs where temperature was hovering around the zero point (remembering sign and magnitude of data), the approach adopted is to take the latter reading and store without averaging, otherwise confusion would arise in assigning one of the signs. In any case, they are fairly close.

In checking maxima and minima details, the magnitude as well as signs are checked before any update. The temperature software module is described in the following pseudo code.

```
Procedure ( temperature )
begin
    set scratch pad area;
    enable interrupts;
    set number of reading count for input (2);
    while ( count <2 ) do
    begin
        input pressure transducer reading;
        initiate ADC;
        wait for ADC converted signal;
        retrieve high byte;
        if ( overflow ) do
        begin
            store sign of data to scratch pad;
            if ( count = 2) do
            begin
                if ( both readings corrupted ) do

                    print message: INCORRECT TEMPERATURE
                    store known pattern to local archive and display area;
                    branch to next module;
            end;
```

```
        end; {overflow}
        else
        begin
            store reading to scratch pad;
            count +=1;
        end;
    end; {while}
    check if sign of 2 readings different;
    if ( signs different ) do

    begin
        store second reading to local archive and display;
        if ( current temperature > previous maximum) do
            store as new maximum;
        else if ( current temperature < previous minmum) do
            store as new minimum;
    end;
    else
    begin
        remove sign and overflow bits;
        average transducer readings;
        add sign bit;
        store to local archive and display area;
        if ( current temperature > previous maximum ) do
            store as new maximum;
        else if ( current temperature < previous minimum ) do
            store as new minimum;
    end;
end; {temperature}
```

3.3.4.3 Light

Software module for the light transducer is similar to that of the pressure transducer with only difference being in the storage locations and error messages.

3.3.5 Transmitting data to PC

The GLNS is currently restricted to data capture with limited preprocessing and display facilities. Any analysis of past and present data is carried out on the central PC based system. The GLNS forms a sub-system to the overall reporting station. The current strategy is to transfer the last 5 minute data samples of each transducer after every five minutes to the PC. This is achieved through the PC transmitting module.

At GLNS start-up, the module determines from the timing information, the next transmission time to transmit to the PC; at this time the GLNS interrupts the PC which obtains the previous 5 minute samples of each transducer. A small delay is inserted with handshake to ensure dead lock does not occur. If the PC is not receiving this data, transmission is ceased with a message of unsuccessful data transfer. If the data was transmitted successfully, a message appears indicating successful data transfer.

The basic flow of the module is highlighted in the following pseudo code.

```
Procedure ( transmit )
begin
    increment minute count after each loop cycle;
    check if time for transfer;
    if ( count = 5 ) do
    begin
        reset count to zero;
        retrieve current data pointer;
        calculate transfer pointer position;
        while ( all data not sent ) do
        begin
            retrieve data;
            transmit data to PC;
            while ( delay ) do
                check hand shake signal;
            if ( data  not accepted ) do
            begin
                print message : UNABLE TO TRANSFER DATA
                exit module;
            end;
            else
            begin
                continue transmitting;
                if ( all data transmitted ) do
                    print message: DATA TRANSFERRED
            end;
        end;
    end; {while}
end; {transmit}
```

3.3.6 Conclusion

The inherent variations in the atmosphere makes continuous observation necessary . The physical nature of these variations (which in combination produce the weather at a given location) is such that abrupt change does not occur. Useful predictions of their probable future behaviour can be obtained. It is insufficient to interrogate regularly these transducers regularlywithout making them available for analysis. The semi-intelligent GLNS system proposed here strives to overcome this problem.

The GLNS samples local site weather transducers at 1 minute interval. This data is stored in the onboard 24 hour rolling archive and also made available for display and analysis.

The GLNS is of modular architecture with each transducer interfaced through a seperate plug-in module. This ensures continuous operation in the event of transducer(s) failure. The software has been developed to minimise interactive use. Plates 3.1 and 3.2 depict the completed GLNS.

The complete software for the GLNS occupies 3.8K of the 4K EPROM space within the 6809 development system.

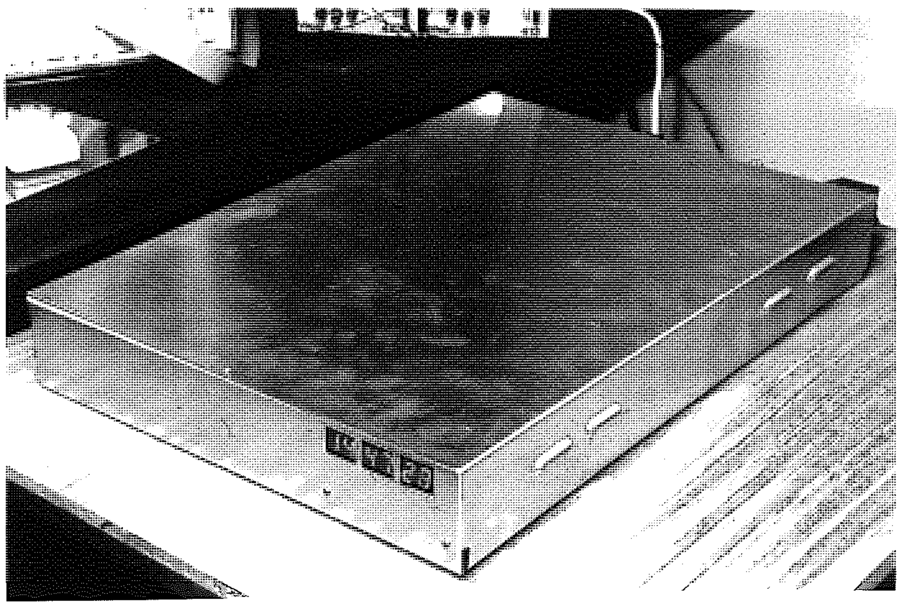


Plate 3.1 Ground Local Nowcasting Station

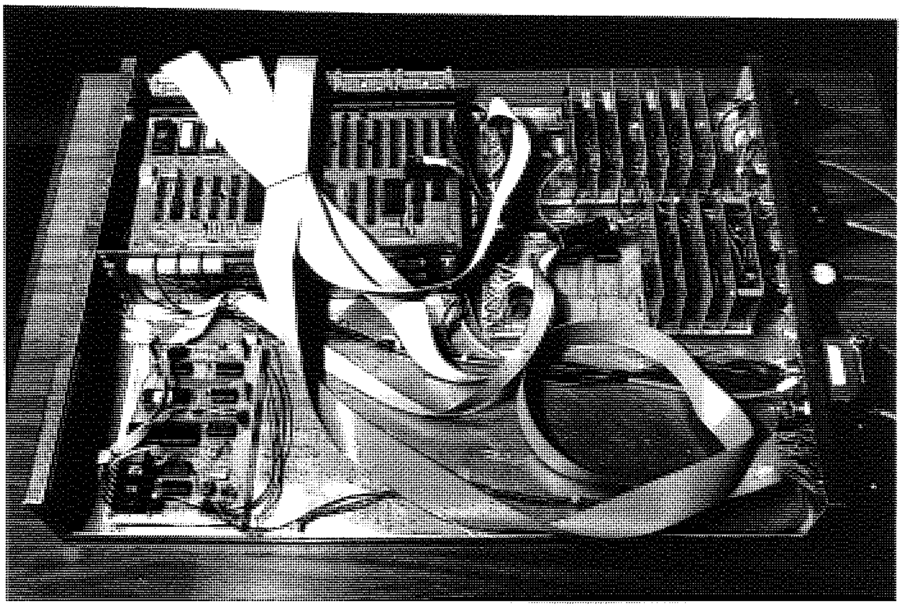


Plate 3.2 Ground Local Nowcasting Station

Chapter 4

4.0 The role of satellite data in nowcasting

4.1 Introduction

The function of a weather satellite is to view the Earth's atmosphere from Earth orbit, and send back to Earth pictures of what it 'sees'. The information in these pictures is used primarily for weather forecasting. The first experimental weather satellite was launched on 1st April, 1960[38] and was an immediate success. The pictures showed structure within weather systems with a clarity never seen before and revealed phenomena that previously were unknown. Within a few days of the first launch, the new data was being used operationally to improve weather services. More satellites followed with improved cameras, longer life times and increasing applications to weather forecasting.

Several factors make satellite data unique. One primary characteristic is the effectiveness of the satellite in providing information, routinely and dependably, in areas where conventional data are sparse and absent. The closing of observational gaps over oceans and remote land areas is cited time and time again as the basic contribution of satellites, effectively leading to improve weather forecasts and other environmental services.

Another factor is the rapidity with which forecast offices receive pictures and weather charts transmitted directly from satellites. In some remote areas, satellite data are received and used hours ahead of the regular data arriving through normal communication channels.

Another aspect that has proven of great value in numerous applications is the overall view of the Earth and atmospheric features obtained from orbital altitude. Observations from this vantage point reveal the large-scale organisation and structure of clouds and sea ice distribution, which have to be inferred from aircraft or conventional ground-based observations.

The major applications of weather satellites have been in the analysis and forecasting services. Weather service offices throughout the world use satellite images as daily guidance for preparing routine public forecasts. These frequently are more accurate and more timely because satellite images have revealed impending weather feature which otherwise would not have been considered in the forecast. Satellite images are specially effective in showing weather conditions in areas where other weather reports are sparse or lacking; and in showing details of structure, movement and growth of both large and small scale weather systems which affect the local forecast. However, satellite data are being used to an increasing extent in other enviromental services- maritime activities, hydrology, space monitoring and others[38].

There two types of weather satellites, classified by their orbit:

(1) Polar. In polar orbit a satellite travels at a height of about 850 km, passing near the North and South poles on every orbit.

(2) Geo-stationary. A geo-stationary satellite orbits in the plane of the equator at a height of 35,900 km. Because the time taken to orbit the Earth at this height is exactly one day the satellite appears stationary in the sky when observed from the Earth's surface.

Figure 4.1 depicts the two types of satellites in operation and their respective positions.

4.2 Polar-orbiting satellites

To provide near global coverage of the atmosphere a satellite in a near polar orbit can be employed. If the orbital altitude is constant at around 1000 km then the satellite passes over each pole about fifteen times each day[39], the plane of the orbit remaining fixed in space while the Earth rotates beneath it. If the inclination of the orbit is slightly different from 90°, then, because the Earth is not a perfect uniform sphere, the plane of the orbit will precess in space[39]. If the precession is arranged to be 360° per year, the phase of the orbit will always remain the same relative to the sun. This is called a

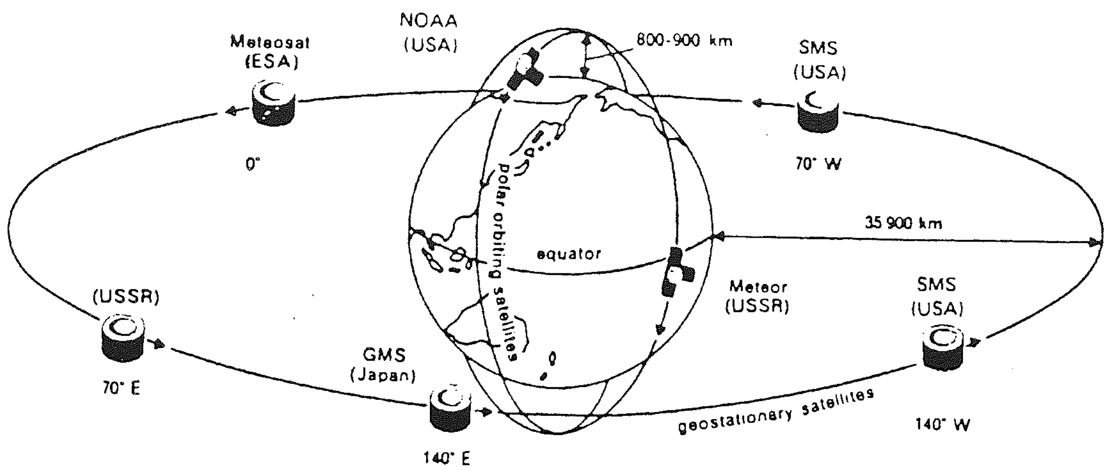


Figure 4.1 Types of satellite in orbit

sun-synchronous orbit. It is useful in atmospheric science because, whichever quantity is observed, it is measured at each location with the sun always in the same place in the sky. Thus one important variable is fixed and changes which are observed to take place must be independent of this.

The first TIROS (Television and Infrared Observations Satellite) experimental weather satellite launched was a polar-orbiting satellite. Its immediate success has resulted in continuous launching of such satellites by the USA National Oceanic and Aeronautical Administration (NOAA). A TIROS series satellite is launched every eighteen months. A similar METEOR series is operated by the U.S.S.R.

The TIROS-N was launched into an approximately 850 km. circular, near polar orbit. The total orbital period is approximately 102 minutes. The Earth rotates beneath the orbit approximately 25.5^{o} during this period, allowing the satellite to observe a different portion of the Earth's surface with sufficient overlap from orbit to orbit. In each orbit the satellite travels over the equator once North-to-South (N-S) and once South-to-North (S-N).

The position of the satellite is often referred to by the subsatellite point, which is the point on the Earth's surface for which the satellite is at the zenith. If the orbit of the satellite is considered to be in a stationary plane in space, during the time taken for one orbit the Earth's rotation will have carried the surface to the East. The subsatellite point will thus move on a path whose longitude increases (more Westerly with respect to the Earth) on successive orbits. The satellite crosses the Earth's equator at fixed local times each day of 0730 and 1530. There are several methods of predicting when a satellite will pass within the range of a particular receiving station[40].

Once the satellite is in orbit , in order for it to be useful it must have some means of taking pictures of the Earth below. Unlike a normal camera it does not take 'snapshots' but scans the ground below continuously. As it moves, successive lines on the ground are scanned. Scanning is continuous; thus, the stripe scanned during one orbit leads into that for the next orbit without a break. On successive orbits adjacent stripes are scanned so every point on the Earth is scanned twice every 24 hours. The angle of view is chosen carefully because if it were too wide the sides of the pictures would be very distorted due to the Earth's surface curving away. Normally two satellites are operational with their orbit planes set 90^{o} apart, so at worst each point on the Earth is scanned every 6 hours. The scanning device on the TIROS series meteorological satellite is the Advanced Very High Resolution Radiometer (AVHRR). It is sensitive in four spectral regions[40] supplying five channels of data in the following bands : visible, infrared, and three thermal infrared. In essence the AVHRR scans a section of the Earth directly below the satellite at a rate of 360 lines/minute; the radiation received is then processed onboard the space craft limited to +- 55.4^{o} from the position directly below the satellite. The information received is then digitized and transmitted on S-band frequencies.

The infromation transmitted from the satellite is in two forms: digital and analogue. The digital data transmitted to stations within the line of sight is the High Resolution Picture Transmission (HRPT). The subsatellite spatial resolution of this is 1.1 km. The analogue form of transmission is referred to as the automatic picture transmission (APT). The analogue data is a subset of the HRPT. The high resolution data of 360 lines/minute is reduced to 120 lines/minute. Every third line of two of the channels is selectively averaged in an onboard digital processor. This averaging is designed to remove the effects of the Earth's curvature in the imagery, creating a nominal along-scan resolution of 4 km. The processed signal is converted to analogue form and modulated to a radio signal in the VHF band. This is then transmitted to Earth to be used by ground stations.

The TIROS satellite provides the following basic services:

- Pictures of the entire globe, day and night , every day .
- Continuous viewing of the Americas and adjacent oceans during day time.
- Vertical temperature sounding at 12-hour intervals throughout the world.
- Wind measurements in selected parts of the Atlantic and Pacific oceans.
- Surface-temperature measurements over the world's oceans.
- Continuous measurements of proton and electron flux activity near the Earth.

Stored pictures are received at the World Meteorological Centre in Washington. These are mapped by computer and distributed through communication channels to a wide variety of users.

The polar-orbiting satellites fall short of providing comprehensive data since coverage is only intermittent - twice daily for most places. This means that the satellites do not provide a satisfactory sample of weather observations. Local forecasts of a few hours ahead require a resolution of a few kilometers in the horizontal and less than an hour in time. For purpose of pure science it might be enough to collect such observations for a limited period only, long enough to obtain a sample of all the important phenomena of meteorology. In the applied science of forecasting, it is not suitable to constrain the time of observations since an attempt is being made to predict the behaviour of an inherently unstable system. This effectively means that weather in the afternoons for example may be systematically different from that in the mornings.

This deficiency of the polar-orbitting satellites can largely be made good by the use of geo-stationary satellites. These can provide quasi-continuous coverage of the whole area within their field of view.

4.3 Geo-stationary satellites

The objectives of the European meteorological satellite program were defined in detail in 1970. A decisive contribution to the fixing of priorities came with the development of the Global Atmospheric Research Program (GARP), which first adopted numerical simulation techniques to determine objective requirements for a rational planning of observation systems. The GARP activity was intended as a preparation for the first GARP Global Experiment (FGGE), a one year campaign of measurements, one of the objectives of which was to define an optimised global observation system to be used as a reference by the operational World Weather Watch (WWW) programme.

The findings of the GARP numerical experiment created a demand for the development of geo-stationary satellites. It was estimated that a chain of four (possibly five) spaced equally around the equator, would satisfy the needs of detecting clouds and recognising their displacements. There are at present five geo-stationary meteorological satellites in orbit around the globe and their respective coverage are depicted by Figure 4.2. The missions and performances of the five geostationary satellites are being co-ordinated technically and operationally under the auspices of a committee for the Co-ordination of Geo-stationary Meteorological Satellites (CGMS), drawn from representitives of the countries or bodies providing the satellites, and from the World Meteorological Organisation (WMO).

If a satellite follows a circular orbit eastward in the plane containing the equator and the radius of the orbit is chosen to make the period of the orbit 24 hours, then the satellite will always stay above the same point on the Earth's surface. This is the condition called 'geo-stationary'. It is achieved by a satellite in circular orbit above the equator at a height of approximately 35,900 km.

A geo-stationary satellite always presents images of the same region of the Earth's surface and is always available for communication with a ground station in that region.

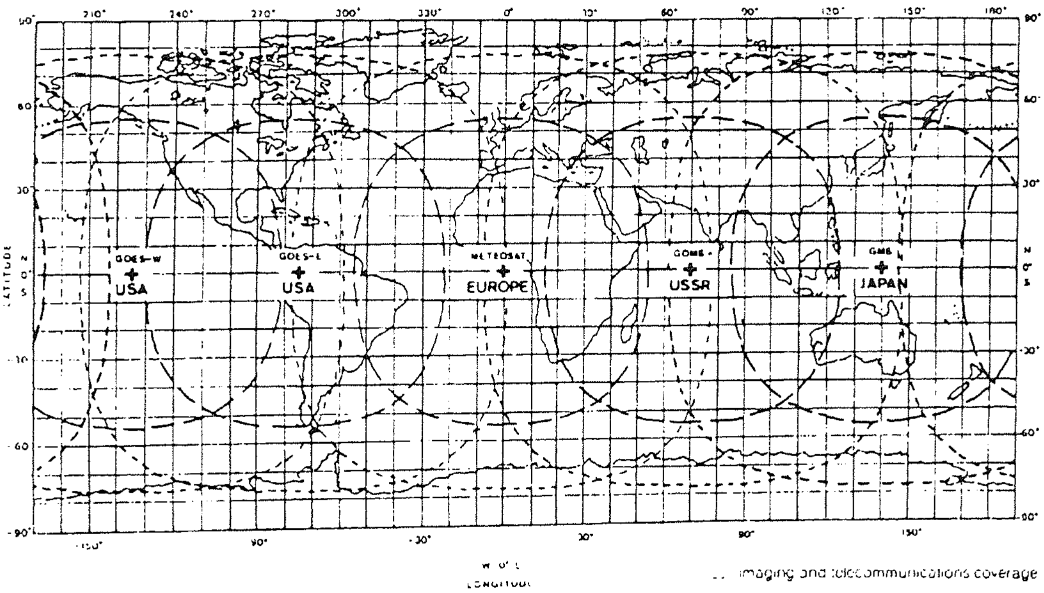


Figure 4.2 Geostationary satellites and their respective coverage

This class of satellite generates data for the same part of the world at very frequent intervals, such as images of the full Earth disc in several spectral channels each half an hour. This high repetition rate is ideally suited to very-short-range forecasting.

The discussion in this thesis is restricted to the European geo-stationary satellite which is in orbit above the equator and the Greenwich meridian (0^{o} N, 0^{o} E).

METEOSAT-1 was successfully launched on 23rd November 1977. The primary objectives of this satellite were to provide a useful daily contribution to the World Weather Watch and to prepare the system for participation in the first GARP Global Experiment. METEOSAT-1 successfully achieved both of these objectives and the system made substantial contribution to meteorology and other Earth sciences in the two years of operation until a fault caused a failure of the imagery and dissemination missions in November 1979. METEOSAT-2 was launched as a replacement on 19th June, 1981 and provided routine images until August 1988. A refurbished METEOSAT-3, with performance characteristics similar to METEOSAT-2 was successfully launched on 15th June 1988. This was followed by METEOSAT 4 early this year (1989) and currently provides routine images.

The METEOSAT system comprises the satellite itself and the ground system of which the main components are the Data Acquisition Telemetry, and Tracking Station (DATTS) and the METEOSAT Ground Computer System (MGCS). The MGCS is located in the European Space Operation Centre (ESOC) in Darmstadt, Federal Republic of Germany, and DATTS is situated in open country about 50 km from Darmstadt.

4.3.1 METEOSAT satellite

The spacecraft is powered by N/P silicon solar cells which provide 280W power at the beginning of the satellite's life. It has six thruster motors which are fed by hydrazine propellent contained in three fully interconnected spherical tanks having sufficient capacity for a five year life time in normal circumstances. This system is used to control METEOSAT's altitude in space and can be used to make small changes in its orbit; principally to move the satellite in its orbital plane to make fine adjustments to the longitude over which METEOSAT is stationed. In operation the thruster motors are activated by telecommands from the ground station and normally several months at a time elapse between operations.

In orbit the whole satellite spins at 100 rpm about its main axis, which is aligned nearly parallel to the Earth's North-South axis.

4.3.2 METEOSAT radiometer

The principle payload of the satellite is a multispectral radiometer. This provides the basic data of the METEOSAT system as visible and infrared radiances providing images of the full Earth's disk as seen from the geo-stationary orbit. The three channel radiometer includes[41]:

- Two identical visible channels in the 0.4 - 1.1 micro-metre spectral band.
- A thermal infrared ('window') channel in the 10.5 - 12.5 micro-metre band.
- An infrared ('water vapour') channel in the water vapour absorption band (5.7 - 7.1 micro-meter) and can be operated in place of one of the visible channels.

Each infrared image is composed of 2500 lines and 2500 picture elements (pixels) with the spatial resolution of 5 km. at the subsatellite point. In the visible, performance can be twice as good (5000 lines and 5000 pixels when the adjacent channels are operated; i.e. when the water vapour channel is 'switched off').

Radiance data from the full disc are acquired during a 25 minute period, followed by a 5 minute retrace and stabilisation period, so that one set of images are available each half an hour. An image consists of a raster of pixels and is telemetered line by line to the ground station. An East-West line of pixels are generated as the radiometer scans the Earth's disk due to the spinning motion of the satellite. A succession of lines is obtained by rotating the radiometer telescope stepwise from South to North synchronously with the satellite spin period.

METEOSAT has a comprehensive communications capability, and operates in three distinct frequency bands. Of interest is the S-band (1670 - 2110MHz), of which 1686.833 MHz is used to transmit raw data to the ground station and 1691.0 & 1694.5

MHz is used to transmit preprocessed data from the ground station to users, and for ranging (Earth location) signals, for reception of telecommands, and transmission of telemetry.

4.3.3 METEOSAT ground station

The raw image data are transmitted to the Data Acquisition Telemetry Station (DATTS). The DATTS is a primary means of communicating with METEOSAT from the ground. The station acts as a complex relay station and communicates the METEOSAT data by ground link to the METEOSAT Ground Computer System (MGCS) and METEOSAT Control Centre (MCC), both of which are located within the European Space Operation Centre (ESOC) in Darmstadt.

The station receives raw image data from the spacecraft at the normal rate of 166 Kbs^{-1}, but can also acquire the data in 'burst' mode at 2.7 Mbs^{-1} should the spacecraft's onboard memory fail, neccessitating transmission at the higher rate. This received data at DATTS is transmitted to MGCS via the Data Transmission Routing System (DTRS) which includes a ground link.

The MGCS is a large computer system used exclusively for the processing of METEOSAT data and for control of the spacecraft. As well as the primary data link with the DATTS, the MGCS is also connected by a computer-to-computer link with the meteorological Global Telecommunication System (GTS). This allows parameters extracted from the image data to be transmitted to the user community. The link is also used in the reverse direction, since conventional meteorological data are needed for the computations made within the MGCS, and some data received this way may also be disseminated via the spacecraft to the data user stations.

The METEOSAT Control Center (MCC) is where all spacecraft and mission control funtions are carried out and the operation of the DATTS is monitored and controlled. Any parameter extraction is accomplished here. The MCC is located at

ESOC in Darmstadt.

The raw image data from the spacecraft are transmitted on a line by line basis to the DATTS, and from there transmitted by landline over 50 km to the MGCS. When they arrive in the MGCS the data are pre-processed by the computer system prior to their use for dissemination, meteorological parameter extraction or archiving. Three stages are carried out prior to the data being ready :

- Raw image acceptance.
- Image conditioning.
- Image reference.

4.3.4 Raw image acceptance

The image data arriving at the Front End Processors (FEP) are in line by line format in the original order as sampled by the spacecraft. Each image line is processed in real-time (0.6 seconds). This line is composed of 2560 32-bit words, each of which contains visible, infrared and possibly water vapour data, corresponding to one sample period of the radiometer. Since the sensors are physically at different locations[41] on the focal plane of the radiometer, the data values from the three channels do not correspond to one Earth location, but are seperated. Furthermore the raw image data suffers from a number of minor defects (described in the next section) which have not been removed at this stage. For safety, the FEPs write all the raw data onto 1600 bpi (bit per inch) computer tapes before doing any further processing. The raw image data are retained only for as long as it takes to confirm that normal processing has been accomplished.

4.3.5 Image conditioning

Image conditioning is accomplished in one of the two redundant FEPs. The software is designed to remove the following defects:

- Optical errors caused by the radiometer optics and the integration over the surface of the detectors.
- Calibration errors due to the varying (ageing) response of the detectors and the slightly unmatched response of the two visible detectors.
- Errors caused by electronic filters.
- Line start errors due to the irregularities in the line start mechanism.
- Registration errors caused by the differing fields of view of the sensors.

The parameters on which these corrections are based are calculated on the main computer and passed to the FEP on an image by image basis.

4.3.6 Image referencing

The purpose of the image referencing is to locate the image in terms of Earth coordinates. This is neccessitated by the fact that no geo-stationary satellite is truly fixed in position with respect to the Earth, and that furthermore, minute changes in the altitude of the radiometer platform some 35900 km above the Earth cause changes in the actual view of the Earth between images, and to a lesser extent, within the space of one image. For these reasons the actual images differ from the ideal, or reference image, and in order to allow for this the deviation from the ideal should be known. The deviation of the real image from the reference image is known as the DEFORMATION, and this quantity is calculated for each image by a process which makes use of a model of the spacecraft dynamics, other orbital and altitude data.

The image referencing completes the standard image preprocessing and the image data is not changed in any way before final archiving, dissemination or parameter extraction.

4.3.7 Dissemination

The METEOSAT dissemination system is the process whereby image data and other meteorological information are relayed via the spacecraft to the user community. The spacecraft has two dedicated dissemination channels, operating at 1691.0 MHz and 1694.5 MHz, which are both used to distribute a wide variety of data. Two forms of transmissions are utilised; conventional analogue transmissions (WEFAX) and special digital transmissions (High Resolution - HR). The WEFAX transmissions are in a format compatible with that of other meteorological satellites, including APT of the polar-orbitting satellites as well as the transmissions from other geo-stationary satellites. The HR digital data are in format specific to METEOSAT and are designed for the user requiring full resolution preprocessed data.

The WEFAX transmissions can be received by a Secondary Data User Station (SDUS). The HR transmissions can be received only by Primary Data User Station (PDUS).

All transmissions pass along the route from the MGCS via DTRS and DATTS to the METEOSAT and hence to the user stations. The dissemination programme includes:

- Pre-processed METEOSAT images.
- Relay of conventional meteorological charts as WEFAX pictures.
- Provisions for transmission of maps of cloud top height extracted from the image data, also as pictures.
- Administratrive messages, sent in image format as WEFAX pictures.

The image data are transmitted after image pre-processing has been completed in the MGCS. The images are cut into convenient formats (see next two sections for detail) and have latitude and longitude grids coastlines added before transmission. In the case WEFAX this information is superimposed on (corrupting) the actual image , but with HR it is added to the transmission as coded data, to be utilised at the discretion of the individual user.

The complete dissemination and reception of the METEOSAT satellite system is depicted on Figure 4.3.

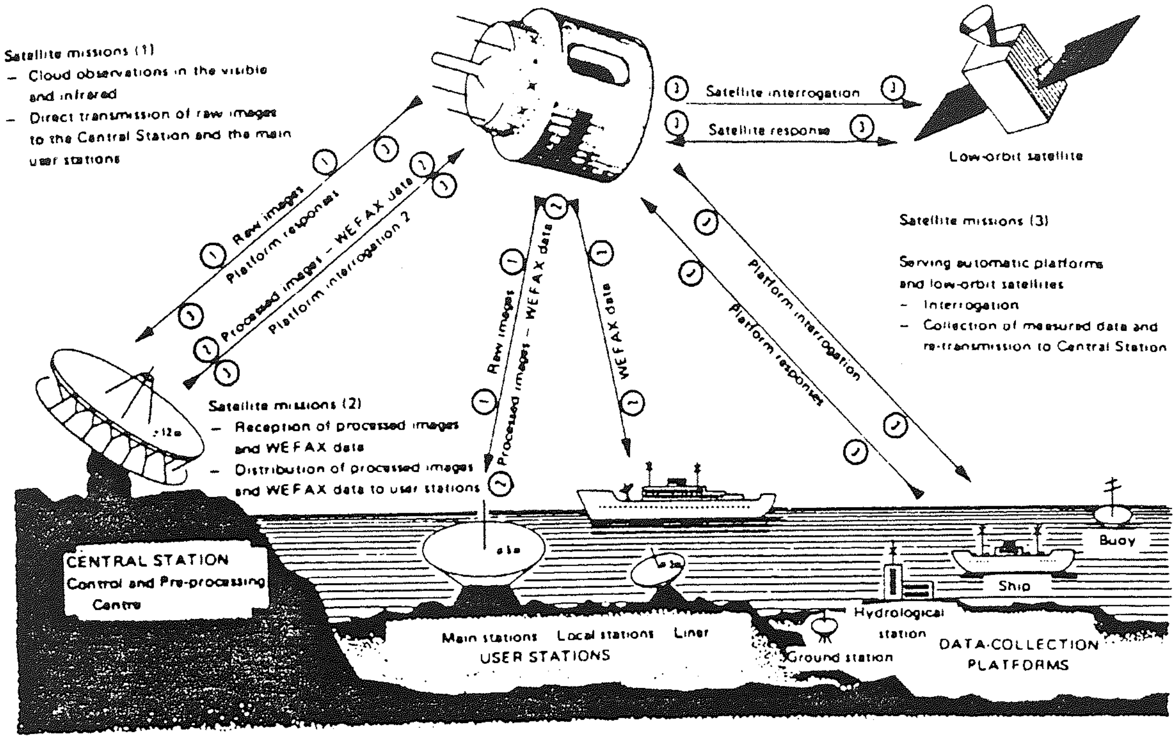


Figure 4.3 Dissemination and reception of METEOSAT system

4.4 Primary Data User Station (PDUS)

METEOSAT High Resolution transmissions can be received by a PDUS system, which in the most minimal form consist of :

- a parabolic antenna
- a low noise amplifier
- a down converter
- a receiver with modulator
- a bit and frame synchroniser
- an image processor

Some of the possible features of a PDUS are:

- high resolution hard copy unit
- colour display (for adding false colours)
- computer for processing of meteorological data.

The image data transmitted is in the full raw data resolution of 2500 lines and 2500 picture elements (pixels) with a spatial resolution of 5 km. at the subsatellite point for the infrared and water vapour images and 5000 lines and 5000 pixels (when water vapour is switced off) with 2.5 km. resolution at the subsatellite point for the visible.

The visible and water vapour images are coded in 64 grey-levels, the infrared image in 256 levels. After pre-processing the 64 grey-level visible and water vapour are expanded to 256 levels.

The images transmitted for user reception are in two formats:

4.4.1 A-format

The A format represents the whole earth-disc as seen by METEOSAT's visible, infrared or water vapour, as depicted by Figure 4.4.

4.4.2 B-format

Format B represents the European, North-Africa and Middle-Eastern regions as seen by METEOSAT's visible, infrared and water vapour sensors and is depicted by Figure 4.4.

The transmission of these formats are as follows :

A format every hour (infrared)

B format every half hour (both infrared and visible during daylight hours)

Typical dissemination schedule for METEOSAT is depicted on Table 4.1. Further information relating to HR digital data and its transmission format can be obtained from METEOSAT system guide- volume 9[42].

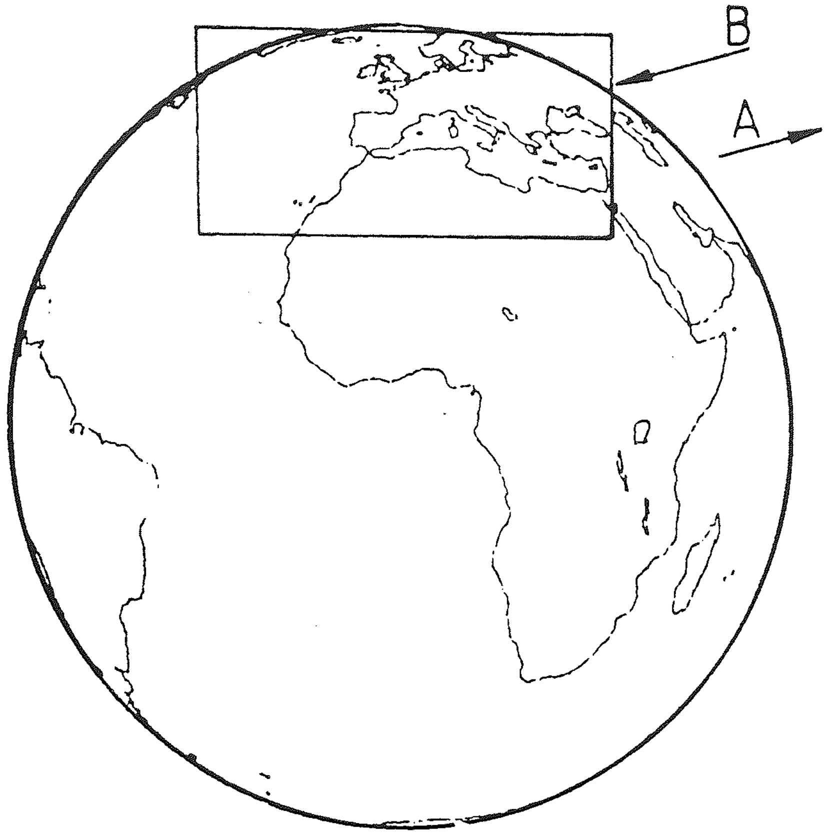


Figure 4.4 Format for PDUS dissemination

4.5 Secondary Data User Station (SDUS)

METEOSAT analogue transmissions can be received by a SDUS systems, which in most general form consist of :

- a parabolic antenna
- a down converter
- a receiver with some form of recording.

The SDUS are generally used as display stations giving a rapid visual update of weather developing with no form of computer attachment. Although this is generally the case, it will be shown in chapter 5 that such a station can be interfaced to a micrcomputer with provision for image processing capability that is normally associated with the PDUS systems.

The WEFAX transmission programme is concerned with the relay of image data from METEOSAT and GOES-E (not utilised in this project) satellites, and also

GMT HR.	00 CH A1	03	06	09
MIN.				
2	E3		E3	C7D
6		CTH		CTH
10	D2	D2	D2	D2
14	D1	D1	C02	C02
18	D3	D3	C03	C03
22	D4	D4	D1	D1
26	D5	D5	D3	D3
30	D6	D6	D4	D4
34	D7	D7	D5	D5
38	D8	D8	D6	D6
42	D2	D2	D2	D2
46	D9	D9	C02	C02
50	D1	D1	C03	C03
54	D3	D3	C3D	C8D
58			C2D	C9D
	01	04	07	10
2			C1D	
6				
10	D2	D2	D2	D2
14	D1	D1	C02	C02
18	D3	D3	C03	C03
22		E1	D7	D7
26		E2	D8	D8
30		E3	D9	D9
34		E4	D3	D3
38		E5		
42	D2	D2	D2	D2
46	D1	D1	C02	C02
50	D3	D3	C03	C03
54		E6		
58		E7	D3	D3

Table 4.1 Typical dissemination schedule for METEOSAT SDUS

includes:

- transmission of conventional meteorological charts (unreliable transmission).
- meteorological parameters extracted from the basic image at MGCS (cloud top height - intermittent).
- administrive messages sent in WEFAX image format.

Each transmitted WEFAX-format consist of 800 lines transmitted with a rate of 4 lines per second plus standard start and stop signals, and phasing signal. The total dissemination time of a WEFAX format is 3 minutes and 43 seconds, although a 4 minute slot is assigned to each transmission.

As indicated earlier, the images are sectored into formats. There are two types of sectorisation of the three spectral band images and these are:

4.5.1 C-format

The C-formats cover approximately 90% of the earth-disc as observed by the visible sensor of METEOSAT. The visible image is divided into 24 sub-formats (C01 to C24) as depicted by Figure 4.5.

The C02 & C03 formats are available every half an hour during daylight. The U.K. region is transmitted over the two frames and this requires a glue operation carried out by the computer (chapter 7) prior to any image processing.

4.5.2 D-format

The D-formats cover nearly the whole earth-disc as observed by the infrared sensor of the METEOSAT. The image is divided in nine sub-formats (D1 to D9) as depicted by Figure 4.6.

The D2 format are available every half hour for the full 24 hour period. The region of interest is contained within the D2 format.

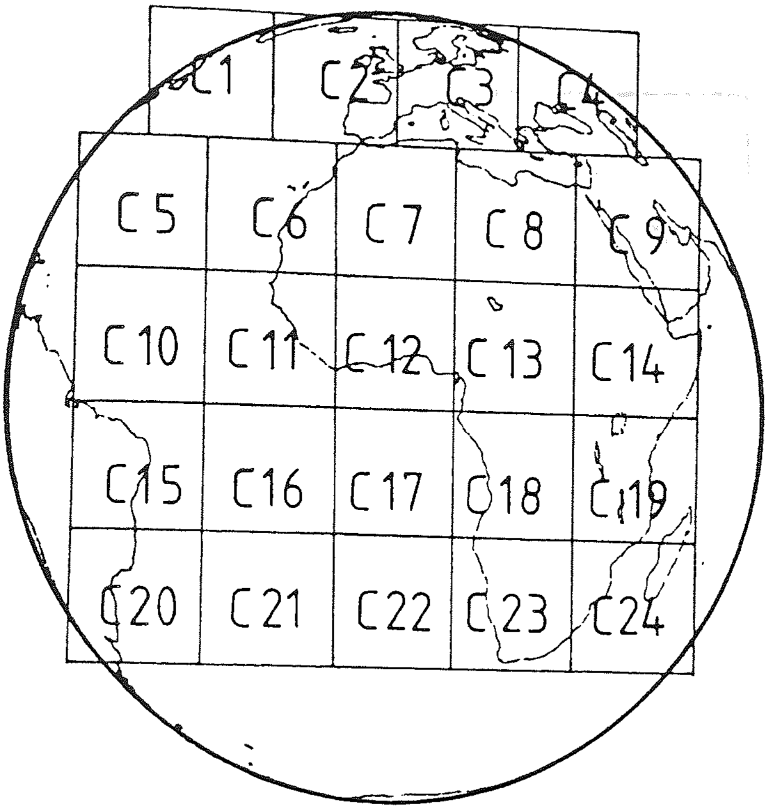


Figure 4.5 Format for SDUS visible dissemination

4.5.3 E-format

The E-formats cover the same area as the infrared D-Formats in nine sub-formats (E1 to E9). The information observed from the water vapour sensor of the METEOSAT is as depicted by Figure 4.6.

The E-Format transmission rate is only 6 E2 frames during the 24 hour period (typically at 3 hours interval).

Further information related to WEFAX transmission can be obtained from METEOSAT WEFAX TRANSMISSIONs[43].

4.6 SDUS for nowcasting

Commercially available satellite receivers can be purchased for receiving image data from a number of satellites in orbit. In the main, two types of SDUS satellite receivers exist: microcomputer controlled receivers and manually (The manual receiver is half the price of a micrcomputer controlled receiver) operated receivers. Major advantages of the

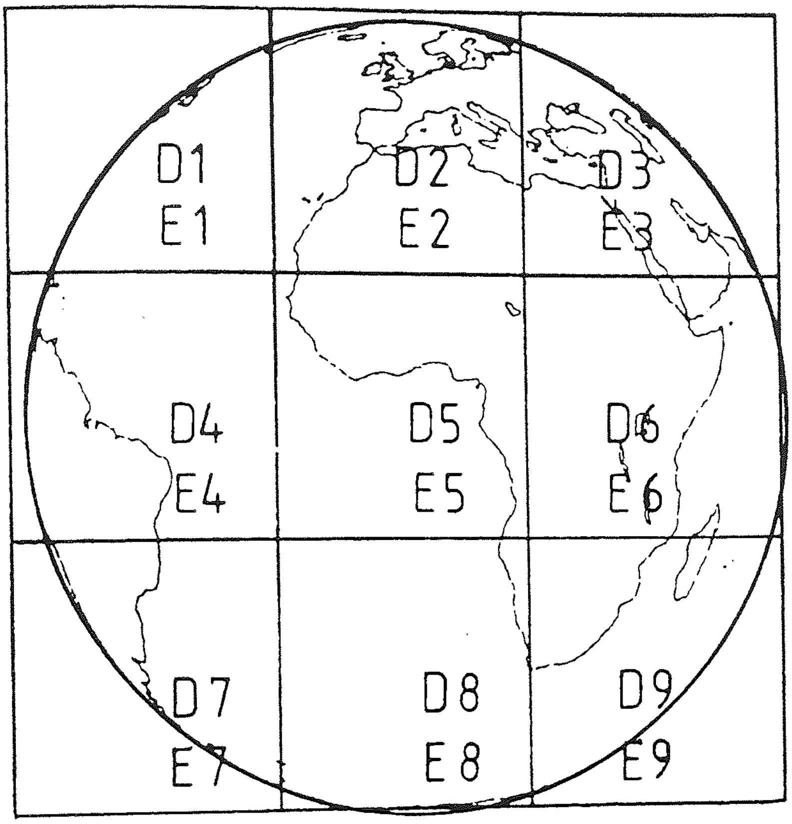


Figure 4.6 Format for SDUS infrared and water-vapour dissemination

microcomputer controlled receiver includes:

- Automatic reception and storage of images without the presence of an operator.
- Provision for storing a large number of images.
- Slightly higher resolution then obtained with a manual receiver.
- Images within the microcomputer environment can be processed for parameter extraction from images (wind field, cloud type, etc.), zooming of selected areas, animation, pseudo colouring, etc.

A microcomputer controlled receiver in general captures images with higher resolution than a manually operated receiver, of the original transmitted (0-255 grey levels) via METEOSAT. These images require a computer environment for processing. However, the trends is towards display systems with restricted processing capabilities; zooming of selected geographical locations, pseudo colouring, animation, etc. with no provision for implementing image processing algorithms for parameter extraction; such as cloud classification, and wind motion vector definition etc.

Since the requirements of a stand alone nowcasting system in terms of image processing was outside the capabilities offered by any commercially available microcomputer controlled receiver, it was decided to opt for a manually operated receiver with a view of modifying the receiver in-house for micrcomputer control, with facilities for image capture at the full resolution of 0-255 grey levels and image processing capabilities (Chapter 5). The receiver purchased is capable of receiving data from the METEOSAT geo-stationary satellite and also from the NOAA polar orbiting satellites and GOES-E geo-stationary satellite.

FIgure 4.7 depicts in diagramatical form the principal parts of the satellite receiving system. There are two antennas; a parabolic dish antenna for the S-band and a helical antenna for VHF reception. Each of these antenna has its own head amplifier, with output connected into a down-converter unit, which converts the S-band signal into a VHF signal. The incoming signal to the receiver unit is switch controlled to enable either the down-converted S-band signal (now at VHF) or the unconverted VHF signal (polar orbiting satellites) from the helical antenna to be passed.

Front panel controls allow selection of a particular type of reception. A notable difference in transmission formats is; METEOSAT images are transmitted with the South boundary first while GOES-E images are transmitted with the North boundary first. Care must be taken to select the appropriate switches for correct reception.

The manually operated receiver is also restricted to displaying (only 256 lines each of 256 pixels of the 800 lines of each 600 pixels transmitted by DATTS). Again switches are provided for selection of the appropriate geographical location of interest, with any data prior to the area of interest being ignored and the selected region displayed as it is being captured. The display memory is capable of holding three images of 256 * 256 pixels, allowing a simple animation of three images.

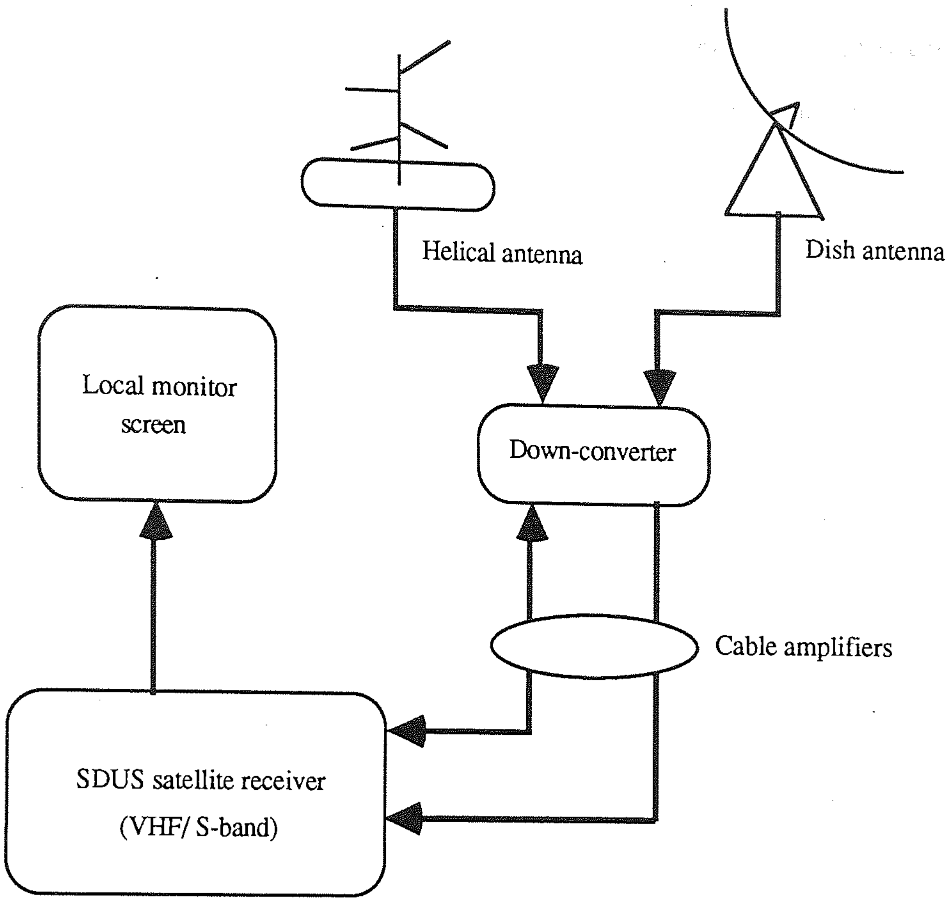


Figure 4.7 Basic SDUS system

After its successful synchronisation and locking for reception the original analogue signal is converted into a digital format. This digital data is 6 bits wide and is used to access an EPROM for grey scaling giving an output only 4 bits wide. This processed data is sent to the display memory. Two consecutive nibbles are packed into a byte for the final display. The resolution of the display being 16 grey levels.

The basic manually operated satellite system is restricted to displaying low resolution images for visual interpretation, and requires the presence of an operator. These restrictions can be alleviated by interfacing a microcomputer to the basic system. Signals currently controlled using toggle switches on the front panel are also provided in parallel for computer control. These lines are utilised (Chapter 5) for operating the receiver in automatic mode.

4.7 Conclusion

Major contributions of weather satellites are their effectivenesss in providing information, routinely and dependently, in areas where conventional data are sparse and absent The overall view of the Earth and atmospheric features reveal large-scale organisation and structure of clouds and sea ice distribution.

The major applications of weather satellites have been in weather analysis and forecasting services. Weather service offices throughout the world use satellite images as daily guidance for preparing routine public forecasts.

Polar orbiting satellites fall short of providing comprehensive data due to their intermittent coverage - twice daily in most places; these satellites do not provide a satisfactory sample of weather observations for local forecasts of a few hours ahead. This deficiency of the polar-orbiting satellites are made good by the use of geo-stationary satellites, providing quasi-continuous coverage of the area within the field of their view.

Chapter 5

5.0 Integration of the real-time nowcasting system

5.1 Introduction

The design of a low cost, real-time nowcasting system for localised weather has been made possible by the rapid advancement in personal computer (PC) design. The ability to handle vast amounts of data, with advances in software, has opened up many new and exciting opportunities in the deployment of personal computers in many fields which were only available to main frames in the not-so-distant past .

IBM personnel computers have become the standard in PC system design and are used throughout the world in many differing fields. Today, IBM PC compatibles are produced by many manufacturers; offering advantages over IBM in terms of cost effectiveness, hardware expansion capabilities, etc.

In selecting a PC, consideration must be given to the necessary hardware expansion required to cater for the special needs of a particular application. In the case of the real-time nowcasting system for localised weather; the fundamental requirements are: i) capturing real-time data arising from two sources, ii) the ability to analyse this atmospheric data for their future state prediction, and iii) the display of their dynamical changes for visual interpretation. A basic PC does not incorporate the necessary hardware or software and must be adopted to suit these individual requirements.

In view of all these factors, the PC utilised for the real-time nowcasting system for localised weather is an IBM - AT. At the heart of the machine is the Intel 16 -bit 80286 microprocessor. The operating system environment is the standard Disk Operating System (DOS), version 3.3. The PC is upgraded to include a 30Mb capacity hard disk to cater for the large image files (264 Kb per image). Figure 5.1 depicts the major hardware components of the system.

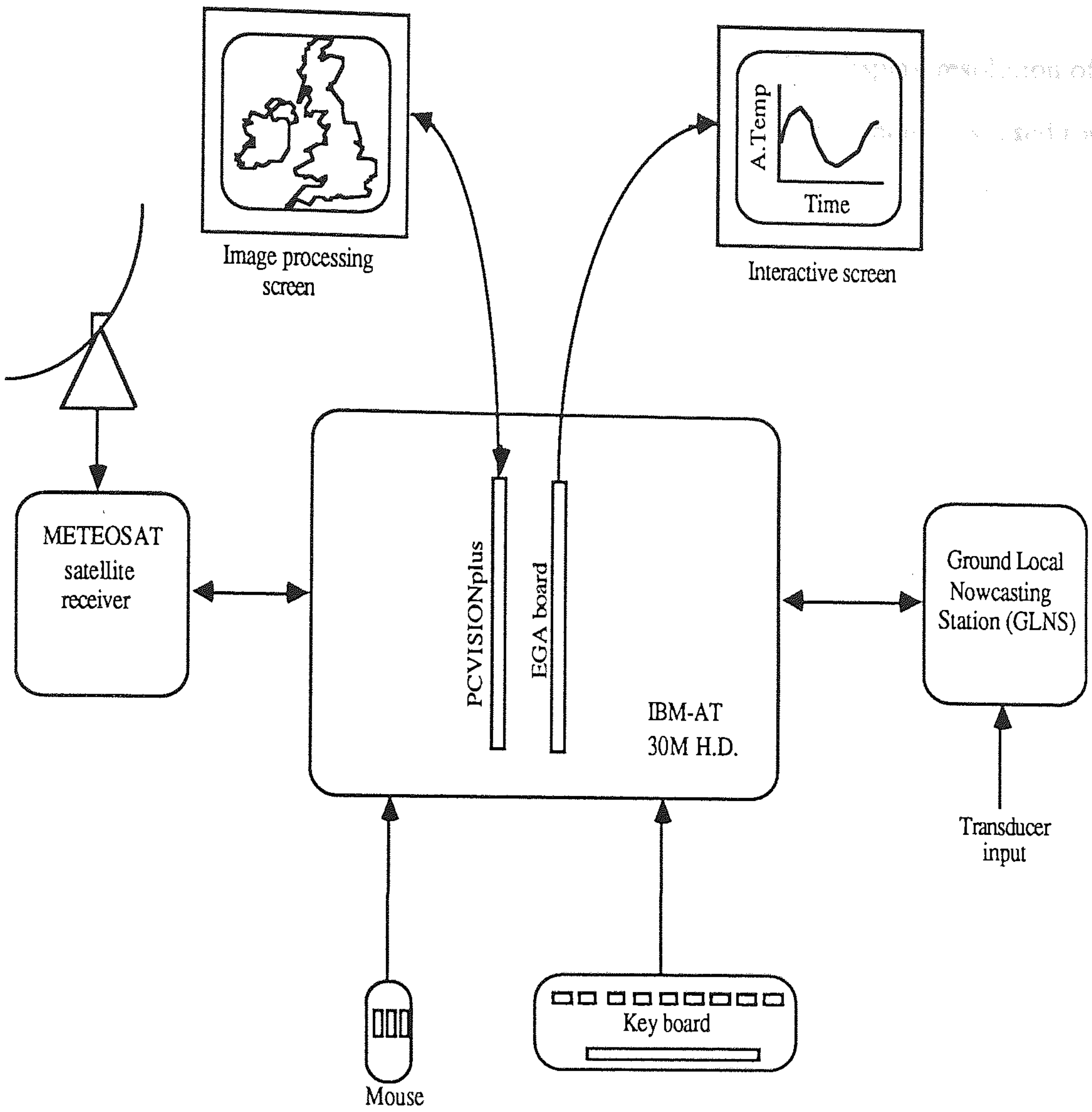


Figure 5.1 Real time nowcasting system for localised weather

The rapid growth in information technology has created new demands for presenting information in the most simple and economic form. The old adage of :

" ***A picture paints a thousand words*** "

is certainly being put to practice with great effect using high resolution colour graphics that are capable of displaying images on computer screens never seen before. The presentation of what seems meaningless information in raw format to its presentation in graphical format to various degree of sophistication. Thus there is no point in presenting raw data when it can be displayed in a sophisticated graphical form.

The interactive screen of the real-time nowcasting system for localised weather is an enhanced colour display which is driven by an EGA board. The display resolution of the EGA is 350 lines by 640 pixels. This, along with keyboard and mouse, is used for interactive communication with the PC. The graphical facilities are used for the comparison of modelled ground data with the actual observed by individual transducers, the real-time display in various formats for the ground data (as shown in chapter 6).

5.2 Image processing hardware

The basic graphical boards provide an environment for displaying information with little capability for processing. The boards designed for image processing offer various degree of sophistication; higher resolution (1024 * 1024 and higher), onboard hardware processing facilities (zoom, pan , scroll, angular rotation , etc.), ease of data manipulation, etc., albeit with added cost.

The image processing board selected for the real-time nowcasting system for localised weather is the 'PCVISIONplus' real-time frame grabber. It is a single board that plugs directly into an expansion slot on the IBM - AT. The 'PCVISIONplus' is a video digitiser with frame memory capable of digitising standard video input and storing the digitised image to the onboard frame memory. The stored image can be simultaneously displayed on a video monitor. It digitises the incoming signal into eight bits of accuracy at rate of 30 frames per second. It requires a single contiguous block of 64k bytes of the PC RAM memory, and contains 0.5 M bytes of onboard memory for image storage. The host is able to access to only 1/8 of this memory at any one time.

The board is concerned with receiving an analogue video signal, converting it to digital format and storing the digitised data to frame memory. It also reconverts back to analogue the frame memory's digitised data for video display on an external monitor. Figure 5.2 depicts in block diagram form its main functions.

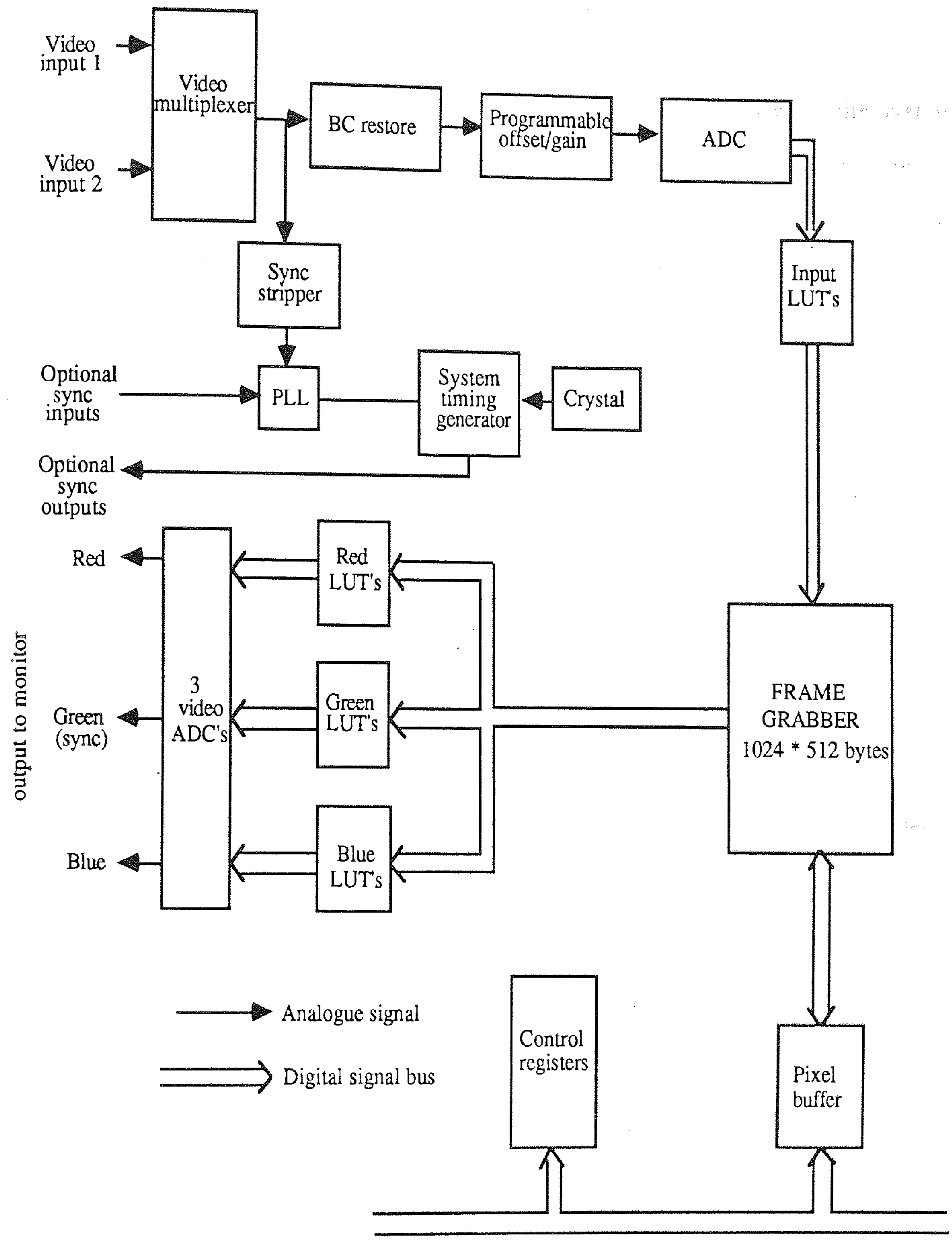


Figure 5.2 PCVISIONplus components

5.2.1 The host interface

'PCVISIONplus' real-time frame grabber is directly compatible with the IBM-AT's bus structure, and has two interfaces to the PC :

5.2.1.1 Control register interface

The 'PCVISIONplus' requires a block of sixteen contiguous bytes in the system I/O memory space for its control registers. Of the sixteen, only twelve are currently used. The base address is hardware selectable to any sixteen byte boundary in the I/O memory space.

5.2.1.2 Frame memory interface

The useful resolution of an image processing system is defined by several factors controlled by the system's components. The number of pixels that are displayed on a CRT defines the resolution of the CRT. The number of pixels transferred to or from frame memory in one frame defines the display resolution. The 'PCVISIONplus' has 1024 * 512 * 8 - bit frame memory which is partitioned into eight equally sized blocks of 64k bytes as depicted by Figure 5.3. Using the memory block select bits in the control register, allows access to one of the eight individual blocks. The frame memory is enabled on the PC system bus by a board select (BDSEL) bit in the control register.

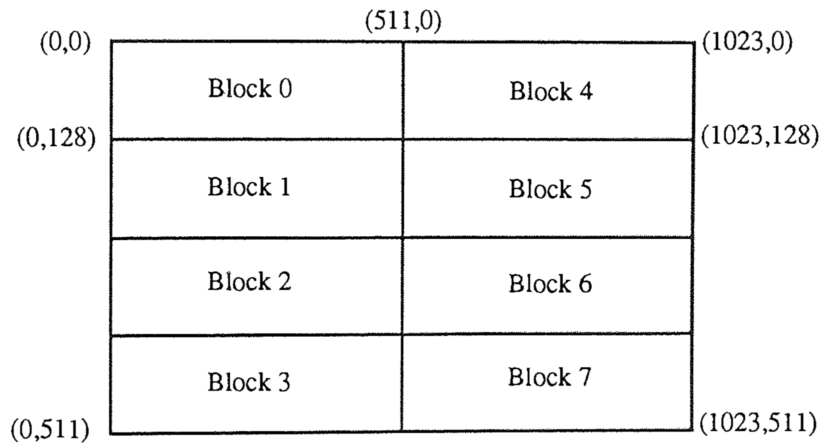


Figure 5.3 PCVISIONplus memory configuration

This effectively allows the mapping of upto three 'PCVISIONplus' boards to the same 64k block of PC memory. Three board configuration is mainly used for true colour image processing systems.

The 'PCVISIONplus' board can be configured to provide two 512 * 512 display screens, effectively allowing two images to be stored on the board consecutively (This mode is used for the real-time nowcasting system for localised weather).

5.2.2 Frame memory access mode

'PCVISIONplus' has a frame memory architecture which includes a pixel buffer to speed up host access to pixel data. The pixel buffer is a storage register that buffers eight 8 - bit pixels. All the data tranferred to and from frame memory passes through the pixel buffer. Access to the pixel buffer is provided via a pixel buffer register. The pixel buffer contents are loaded from or written to frame memory by executing a single host memory access cycle. It has two different pixel access modes for powerful data manipulation :

- Z-mode access : Each host memory cycle accesses a single 8 - bit pixel.The pixel buffer is FIFO with an internal counter, called the pixel counter. A frame memory write operation resets the counter to one. It also assumes that the pixel buffer already contains pixels that the user wishes to store in the frame memory. When the pixel buffer is enabled (PBEN = 1), the next write operation transfers the contents of the pixel buffer (as determined by the pixel counter) into consequtive locations of frame memory. Single pixels can be transferred. It is in this mode that the 'PCVISIONplus' is utilised for capturing of real-time satellite data.

- X-mode access : Each host memory cycle accesses eight horizontally adjacent bits from a specific bit - plane[44].

5.2.3 Look-up tables

A look-up table is simply a list or table of values used to transform pixel intensities. LUT's are programmed to modify the pixel data on the bases of values contained within the table. The pixel value is used as a table address and the corresponding value found in the LUT is used as the transformed pixel. The output value is dependent upon the value of the incoming pixel and the transformation formulae of the LUT.

Two form of LUT operations are provided by the 'PCVISIONplus' board:

- Input look-up tables
- Output look-up tables.

5.2.3.1 Input look-up tables

The incoming 8-bit data (256 possible levels) is used as a table address for the new data vlaue. The transformed pixel is stored to frame memory and simultaneously displayed. Eight input LUT's are available for transforming the image data. These LUT's are programmable through the PC bus interface.

5.2.3.2 Output look-up tables

There are eight LUT's for each of the primary clours (red, green, and blue). Each LUT can have a different transform, and are selected as a "bank" during the display process. The same numbered LUT is simultaneously selected from each of the primary colours; thus, selecting LUT 0 for red will also select LUT 0 for the other two colours and use their transformation to display the pixel to the video screen.

In output LUT manipulations, transforms are implemented without modifying the original image data stored within the frame memory. This minimises data transfer between the host computer and the display memory and also provides extremely rapid interactive image manipulation capacity. The transformation is implemented on every readout of the display memory so that the results of any new transformation are viewed immediately on the display screen.

The three output channels provide access for programming seperate transformation of the primary colours for density slicing, the transformation of monochrome images to pseudo coloured images.

5.3 Satellite reception

The standard satellite receiving system comprised a manually operated receiver (chapter 4) requiring the presence of an operator for selecting reception of multispectral band images using manually operated switches on the front panel of the receiver. These manually operated satellite receivers are available as low resolution display systems for visually interpreting dynamical changes in cloud morpohology as observed by the METEOSAT geo-stationary satellite. The commercial receiver purchased did not provide facilities for processing the received images, due to lack of a computer. However, it does allow simple image enhancement in the form of pseudo colouring of the low resolution images using maually operated switches available on the raster memory module.

The basic receiver did have facilities for accessing signals working in parallel with the manually operated switches for computer control. Figure 5.4 depicts in block diagram form the basic flow of the incoming signal and its conversion within the manually operated receiver. Conversion to digital format is carried out on the decoder module which produces a 6-bit decoded but not grey-scale processed data. This data is also offered in parallel for computer capture and also input to EPROM for further processing. Output from the EPROM is 4-bit grey-scale processed data for display on the satellite video screen and computer capture. Besides the image data, other signals are available for controlling the receiver and also for indirect transfer of image data.

The 6-bit data can be processed to 64 grey-levels, offering considerable improvement to the 16 grey-levels from the 4-bit data. Although, 6-bit data offers better resolution it still falls short of the original information transmitted from the METEOSAT satellite; e.g. the infrared image data contains 256 grey-levels which are being transformed to only 64 grey-levels. Considerable information is being lost in such transformation and needs to be remedied.

Investigation was conducted to determine what hardware changes were required to extract the full resolution image data. The receiver manufacturer was unable to give the required information.

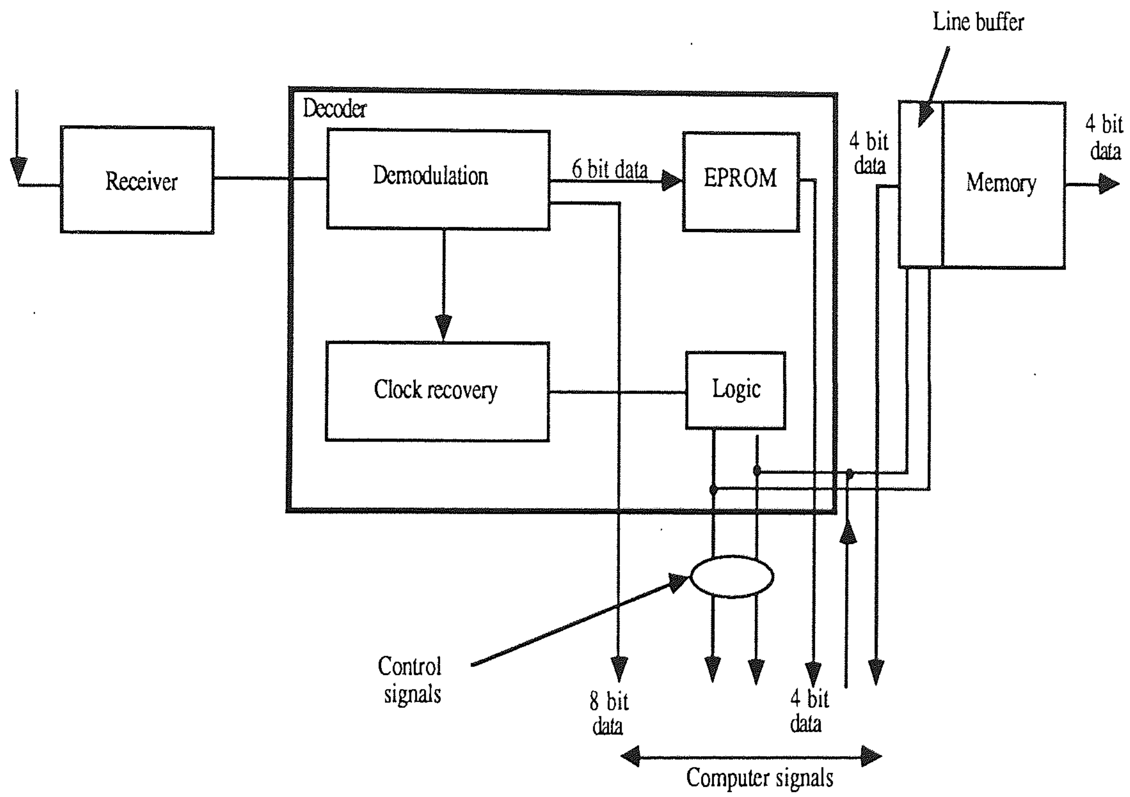


Figure 5.4 Satellite data preperation

Circuit diagrams for the basic receiver were provided for the individual plug-in modules. The analogue-to-digital conversion of the received signal is carried out on the decoder module. It was discovered that the 8-bit conversion was being carried out but the two least significant bits were dropped, and the most significant six bits buffered and offered as parallel output for computer capture, and to the EPROM for grey-scale processing to 4 bits. The task of extracting full resolution image data requires;

buffering of the two least significant bits and combining it to the 6-bits available to give the full resolution image data. The receiver had to be completely stripped to gain access to these two least significant bits and consequently connecting them to the receiver bus.

An interface module is available for accessing signals for computer control and reception. The signals available are:

- Select VHF (for polar orbiting satellites) or S-band (geo-stationary satellites).
- Select the VHF or S-band channel.
- Select OPERATE or HALT.
- Select PRIME.
- Check whether S-band is being received.
- Check if FORWARD or REVERSE is selected.
- Set FORWARD (for north-first) or REVERSE (or south-first).
- Select memory (capable of holding three low resolution images).
- Read LWB (Line Write Begin signal) from the decoder.
- Read 6-bit image data.
- Read DINSTR (Data Input Strobe for picture memory, clocks each pixel).
- Read 4-bit grey-scale image data.
- Disable the grey-scale EPROM.

The standard board available from the manufacturer to access signals for computer control is designed for dual port interface. In order to accommodate a large number of functions on a dual port interface, one of the two ports is multiplexed. The concerned port has bits 0-3 multiplexed according to the setting of bits 6-7, and bits 0-3 may be used for input or ouptput. The two control bits gives rise to four modes as depicted by Table 5.1.

Bit 6	Bit 7	Mode	Status
0	0	0	read/write
1	0	1	write only
0	1	2	write only
1	1	3	write only

Table 5.1 Modes selected

5.3.1 Mode 0

In this mode of operation, the control bits are set to 00, this allows the capture of the 4-bit grey-scale image data, with bits 0-3 containing the image data. The byte format is as :

00XXDDDD Where DDDD is the image data.

If the EPROM is disabled, then 4-bits of data can be written to the receiver memory for display on its video screen.

5.3.2 Mode 1

In this mode of operation, the control bits are set to 01. The data bits now allow the selection of channels for VHF or S-band reception. There are 1-5 channels. The byte format is:

01XXXCCC Where CCC is the channel select.

5.3.3 Mode 2

In this mode of operation, the control bits are set to 10, bit 2 allows the selection of the 'REVERSE' or 'FORWARD' option and bits 0-1, selecting one of the display memory channels on the receiver. The byte format is:

10XXXRMM Where R is for FORWARD or REVERSE and MM for memory.

5.3.4 Mode 3

In this mode of operation, the control bits are set to 11 allowing selection of several options. The options are selected using bits 0-2 with the setting of bit 3. The byte format is :

11XXSCCC

According to the state of bit 3 (S) command one or the other of the two mutually exclusive states are selected as shown by table 5.2.

MODE 3 COMMANDS			
COMMAND	Byte vlaue		COMMAND
	binary	decimal	
0	11xx0000	192	PRIME
0	11xx1000	200	NOT PRIME
1	11xx0001	193	HALT
1	11xx1001	201	OPERATE
2	11xx0010	194	VHF
2	11xx1010	202	S-BAND
3	11xx0011	195	CHANNEL 1
3	11xx1011	203	CHANNEL 2
4	11xx0100	196	STANDARD
4	11xx1100	204	GMS
5	11xx0101	197	EPROM OFF
5	11xx1101	205	EPROM ON
6	11xxx110		not used
7	11xxx111		not used

Table 5.2 Mode 3 operations

5.4 Satellite interface

The module for interfacing the satellite receiver must be capable of accepting signals from the receiver for computer control. The 8255A Programmable Peripheral Interface (PPI) is a general purpose I/O device for interfacing peripheral equipment to the microcomputer bus. It offers a wide range of functional configuration under the control of microcomputer system software. It requires no external logic to interface peripheral devices, and contains three 8 -bits ports (A,B,and C). These can be configured to a wide variety of functional characteristics.

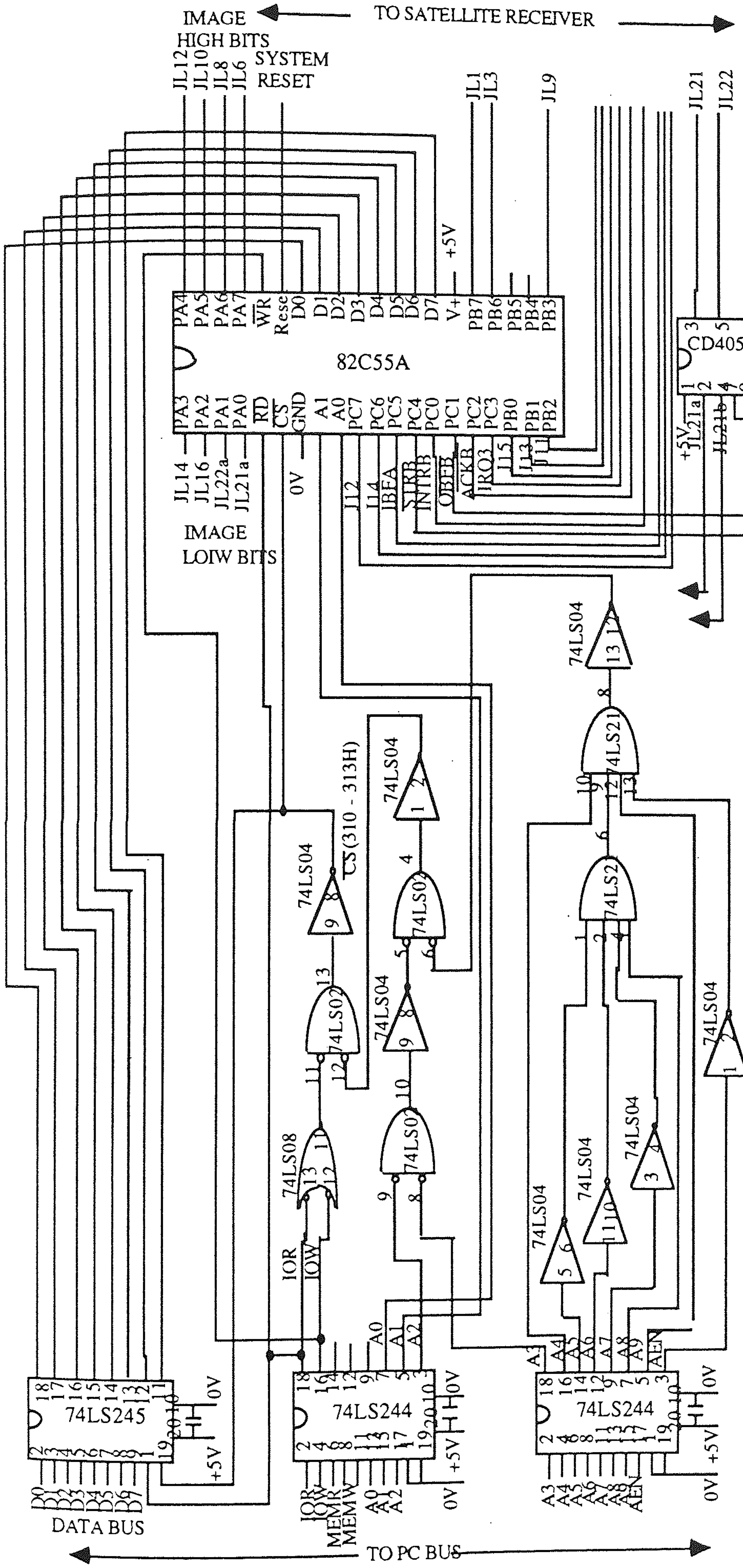
They are essentially three basic modes[45] in which the PPI can be operated:

- Mode 0 : basic input/output.
- Mode 1 : strobed input/output.
- Mode 2 : bi-directional bus.

In mode 1 configuration, the transferring of I/O data to or from the specified port is in conjunction with strobe or 'handshaking' signals. In this mode, port A and B use the lines on port C to generate or accept these 'handshaking' signals. This is the required mode for capturing of the satellite multispectral band image data.

The complete circuit diagram for the satellite receiver interface is depicted on Figure 5.5. This board is mapped on the IBM-AT I/O memory space at address locations 310-313H (hexadecimals). The incoming signals from the satellite receiver consists of high resolution image data with control signals for its capture. The out going signals from the IBM-AT select appropriate option controls. Care must be taken to ensure that the following manually operated switches are in the out position :

- All VHF channel switches
- S-band/VHF.
- S-band channel.
- OPERATE/HALT.
- FORWARD/REVERSE.
- All memory switches.



JL ARE THE CONNECTIONS FROM THE SATELLITE RECEIVER
PORT RESET IS CONNECTED TO THE SYSTEM RESET
IRQ3 INTERRUPT LINE IS USED FOR SATELLITE RECEIVER

Figure 5.5 Satellite receiver interface

5.4.1 Satellite receiver under computer control

As the satellite receiver is able to receive remote information from several different satellites, any software for controlling the basic receiver must essentially select the signal settings for the appropriate satellite. Initially, reception from the METEOSAT geo-stationary satellite is of immediate interest but optional software control can easily be provided for reception from other satellites. The software written selects those options for receiving METEOSAT images. The module is written using Microsoft C language, version 5.0 . All the neccessary initialising for 'PCVISIONplus' board and the PPI are included within this module.

5.4.2 Capturing of satellite image data

It was highlighted in chapter 4, that the METEOSAT geo-stationary satellite transmits multispectral band images at specified times. The METEOSAT transmission include several formats and not all are of interest. This requires some form of selective capture scheme. The IBM-AT system is designed for single user interactive operation. Its operating kernel devotes most of its time to servicing interactive commands or waiting for their arrival. As the incoming data is non-repetitive it must be captured in real-time, and requires precedence in its capture to any other process currently in execution. This type of request is handled using interrupts. The 80286 processor has two hardware interrupts; a non-maskable interrupt (NMI) used by the operating system for catastrophic events and a maskable interrupt (INTR) for use with internal or external vectored interrupts. The INTR line on its own is of no use and is restrictive to a single task if used in a straight forward manner. However, IBM-AT uses in conjunction with the INTR two Progammable Interrupt Controllers (PIC's) with each capable of providing 8 prioritised interrupt lines. It employs vector tables to determine the source of the external interrupt, providing an opportunity for several devices to interrupt the system. The assignments of external devices to specific interrupt levels is done by the manufacturer of the computer system and/or the manufacturer of the peripheral device. The IBM-AT has all its interrupts reserved for system use, offering no readily available interrupt line for capturing of the multispectral image data. However, not all the reserved lines are currently in operation and can be re-assigned for personel use. The interrupt lines reserved for peripheral and system use with decreasing priorities as follows :

- IRQ0 : 8254 timer 0
- IRQ1 : keyboard controller for interactive communication.
- IRQ2 : slave interrupt controller (redirected to IRQ9 for slave int. controller).
- IRQ3 : serial communication line 2.
- IRQ4 : serial communication line 1.
- IRQ5 : parallel printer 2.
- IRQ6 : diskette controller.
- IRQ7 : parallel printer 1.
- IRQ8 : real-time clock.
- IRQ9 : LAN adapter1 (redirected from IRQ2).
- IRQ10 : reserved.
- IRQ11 : reserved.
- IRQ12 : reserved.
- IRQ13 : 80287 error.
- IRQ14 : fixed disk controller.
- IRQ15 : reserved.

The chosen interrupt line for the satellite receiver must have the highest possible priority to ensure when data arrives the system relinquishes any processes currently executing and gives attention to the satellite image data. The first three interrupt lines must remain intact if the system is to function correctly. The best interrupt line available for use is that assigned to the serial communication 2 and can be re-assigned to the satellite receiver interface.

5.4.3 Mapping of pixel image data to the 'PCVISIONplus'

The 'PCVISIONplus' board is mainly designed for accepting analogue video signals and converting them to digital format for storage to frame memory. However, the 'PCVISIONplus' is also capable of mapping digital data direct to the frame memory under the host computer control. The frame memory is divided into contiguous blocks and needs to be addressed seperately.

The incoming digital image data from the satellite receiver consists of 800 lines of 600 bytes length. To capture the complete frame would require the setting of the 'PCVISIONplus' board to a single frame of size 512 lines of 1024 pixels each. The remaining (800 -512) lines transmitted from the satellite receiver must be ignored. Only 600 pixels of the 1024 would be occupied with the remaining pixels containing arbitary values. An alternative option is to configure the 'PCVISIONplus' for dual storage of 512 * 512 and to capture only the most appropriate 512 * 512 pixels of the 800 * 600 frame. The basic receiver allows selection of geographical locations by specifying co-ordinates using front panel switches and these are utilised to select the required portion of the incoming image data. The detail of information contained in a frame size of 512 * 512 is more then sufficient to cover the required geographical location.

Access to frame memory is as depicted on Figure 5.6 with the pixel displayed in the top left corner of the video screen residing at location 0000H and incrementing as shown by the arrows.

The board is designed to map any data to frame memory from left to right and top-down. Unfortunatly, METEOSAT transmits its image data in complete reverse with the south-side of the image being transmitted first and builds up from right to left as seen on the video screen. The necessary software for capturing this data must handle this and also to control the mapping of this data for correct display on the video screen.

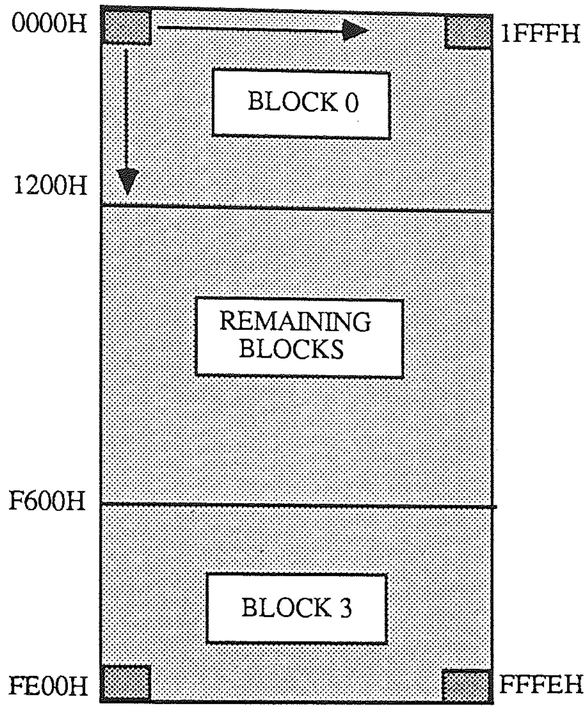


Figure 5.6 Pixel access

5.4.4 Satellite interrupt handler

The interrupt handler is invoked by the arrival of an interrrupt, taking immediate action, and then returning control to the original process that was suspended. In this case the handler captures a byte (pixel) of multispectral image data and maps it to the 'PCVISIONplus' board with the LUT's programmed for linear transformation.

The development of interrupt handlers has traditionally been considered one of the most arcane programming tasks. In reality, writing interrupt handler is, in itself, quite straightforward. The key to the success is to program defensively and to cover all the bases. The difficulty arises in writing interrupt handlers is that they are difficult to debug when they contain obscure errors.

As interrupts can occur asynchronously, that is; they are caused by external events without regard to the state of a currently executing process, any bugs within the interrupt handler can cause the system to behave quite unpredictably and in most cases; the system 'locks - up' ! Interrupt handlers must be written to be concise and efficient as possible, and as a result most of them are written in assembly language to eliminate all possible overhead and to ensure that the handler's routine runs as quickly as possible.

The interrupt handler designed for capturing the multispectral band satellite image data is written in 80286 assembly language. All necessary adjustments for mapping pixels to correct locations in frame memory on the 'PCVISIONplus' board are carried out within the interrupt handler. The interrupt handler captures the incoming pixel and immediately maps it to frame memory.

Plates 5.1 to 5.4 depict the full resolution multispectral band images captured by the real-time nowcasting system for localised weather.

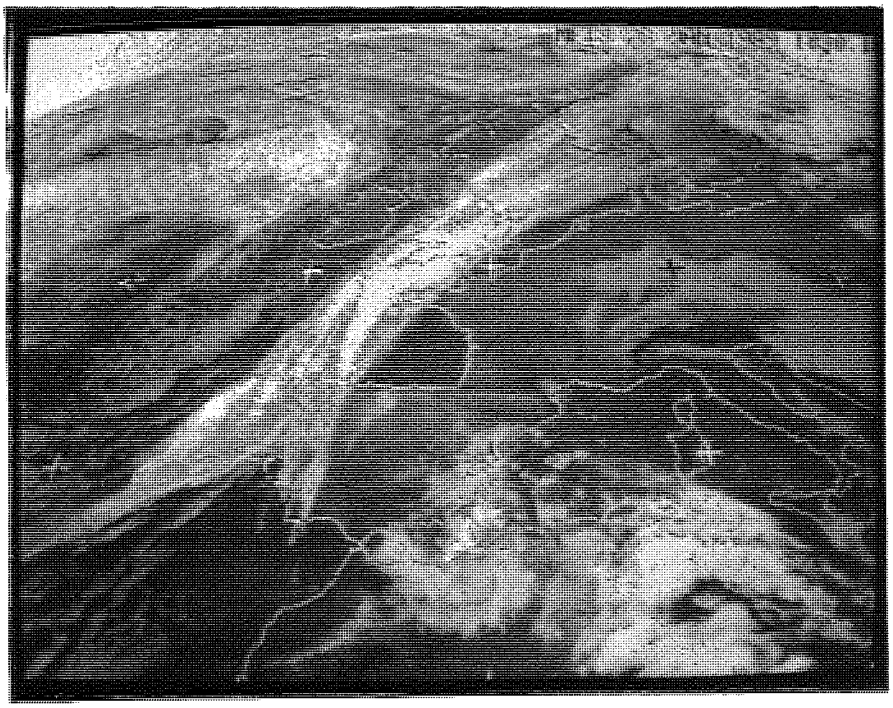


Plate 5.1 Infrared D2 format image captured by the system

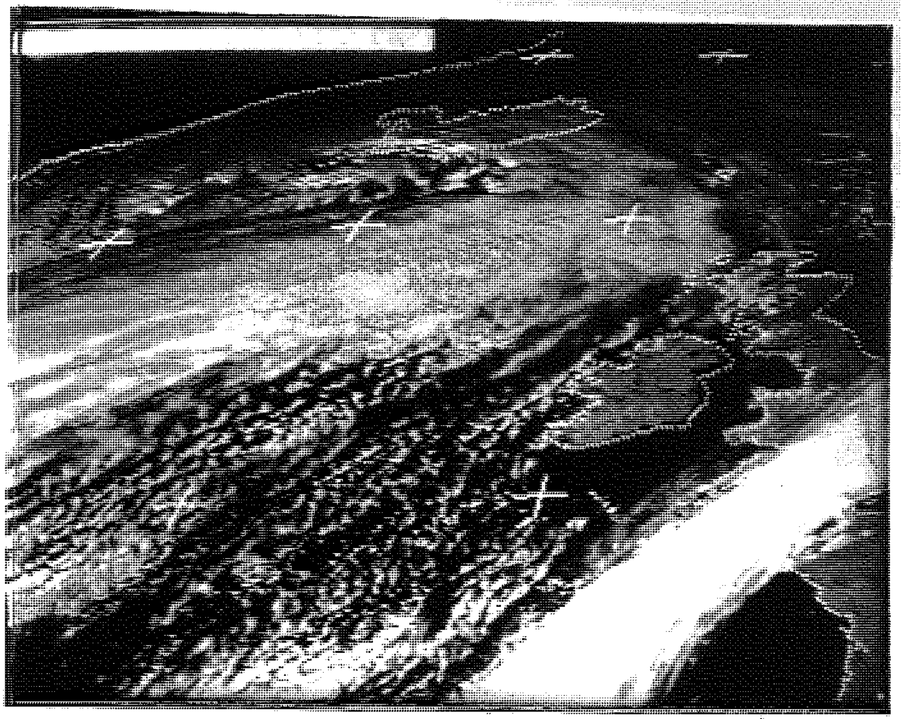


Plate 5.2 Visible C02 format image captured by the system

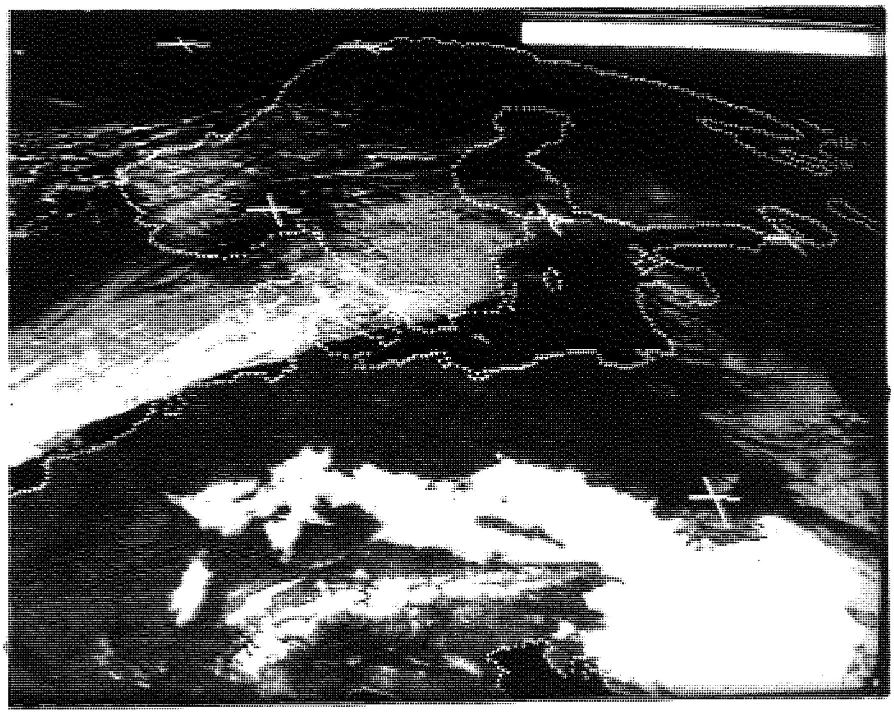


Plate 5.3 Visible C03 format image captured by the system

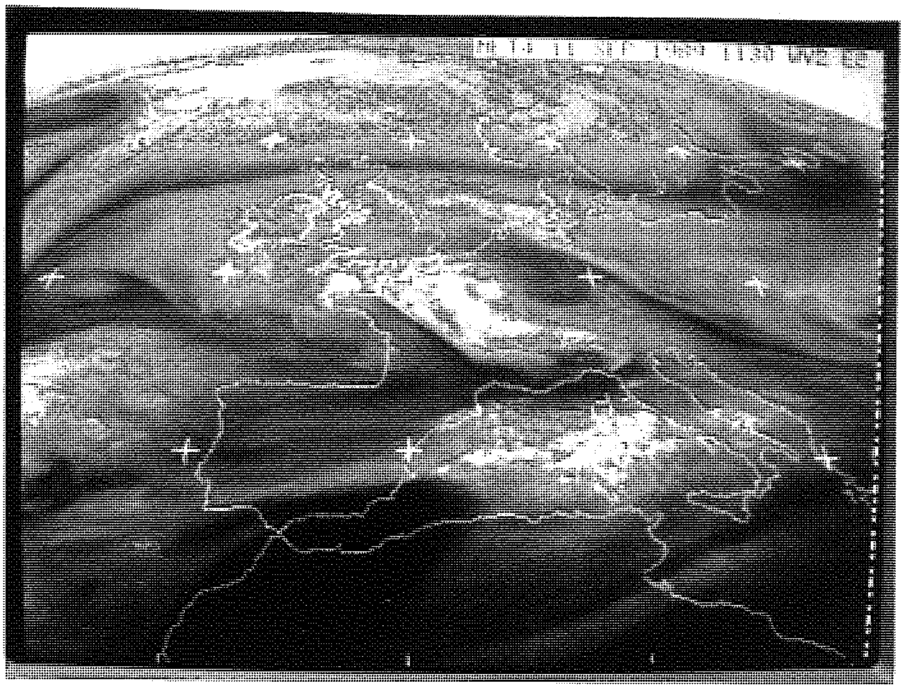


Plate 5.4 Water-vapour E2 format image captured by the system

5.5 GLNS reception

The GLNS samples atmospheric elements regularly at one minute intervals and stores the reading from each transducer in its rolling onboard local archive. The GLNS is dedicated to monitoring these atmospheric elements and to conditioning their inputs for computer capture. The GLNS transmits to the PC the last five samples of each transducer (every five minutes). These signals are in raw format (hexadecimal) . The IBM-AT must capture these local dynamic changes in weather elements for correlation with the remote observations for real-time local weather analysis.

An interface circuit designed to capture this data is depicted on Figure 5.7. At the heart of the circuit is the Programmable Peripheral Interface (PPI), utilised in mode 1 operation. The incoming GLNS data are strobed, with handshaking to ensure that each byte is captured by the PC system. There is also an embedded time out within the GLNS software to cater for the PC being non-responsive, allowing the GLNS to continue its main task of monitoring the tranducers. The interface board is mapped to the PC I/O memory space at address locations 314-317H.

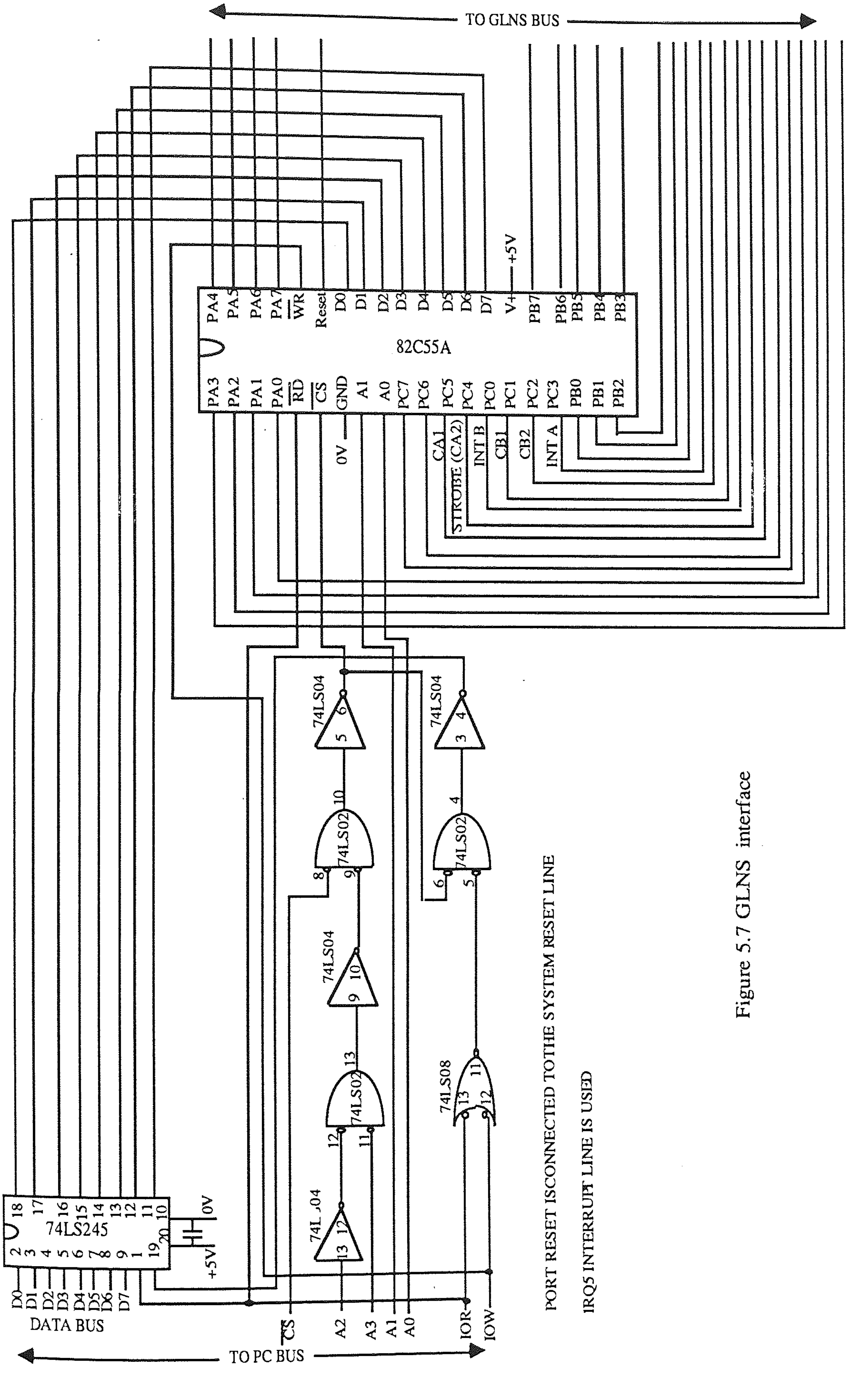


Figure 5.7 GLNS interface

5.5.1 GLNS interrupt handler

As indicated in section 5.4.2, in order to maintain the integrity of the operating environment, only those interrupts are utilised which do not hinder the operation of the system. The system interrupts are listed on page 102 in descending order of priority. Of these, IRQ3 is used for satellite reception. It is likely that future expansion will utilise serial comunication for serial data transfer. Therefore the next available interrupt is IRQ5, it is used for capturing the GLNS data.

The interrupt handler is written in 80286 assembly language. The major task of the handler is capturing the incoming atmospheric ground level data and placing it in the handler's buffer . The incoming data consists of the past-to-present five minutes sample from each transducer and also, current maxima and minima readings of each transducer; it is possible that all or some of these samples will contain corrupt data. As indicated earlier, these data need to be converted to physical values for their interpretation.

5.5.2 Conversion software

The raw GLNS data contained within the interupt handler's buffer must be converted to physical units for visual interpretation of the individual transducer value and consequently for analysis. The conversion software (written in C) handles the individual byte values and transforms these to physical units (^{o}C, ms^{-1}, mb's, % r.h., etc.). The major tasks of the conversion modules is :

- to retrieve raw data from the interrupt handler's buffer.
- to convert the raw data to physical units with averaging, checking for data integrity, and sign etc.
- to write each individual transducer value in pre-formatted form to its rolling archive file on the hard disk.

Each transducer has its own module for carrying out these data handling and manipulation tasks. The raw transducer data are in two seperate forms; the digital transducers provide a single byte per sample and the analogue transducers provide two bytes per sample with additional information of sign and overflow. The incoming transducer signals are conditioned to ensure minimum processing at conversion time. Each transducer value is converted, and written to its own rolling archive where it persists for 24 hours before it is overwritten. The format of the rolling archive files within the PC system are depicted on Figure 5.9. All files have the same format with the exception of the rain and precipitation file. This contains information relating to both of the transducers, with the centre column indicating whether it is precipitating or not and the third column showing the amount of rainfall for the previous five minute period.

5.6 Automation of data capture

The discussions so far have been confined to the necessary hardware and software for capture of both atmospheric data; satellite multispectral band image data and local ground level transducer data from the GLNS. The software modules exist in discrete form and can be executed interactively by a user for capturing the differing source of data. The interrupt handlers must be assigned to their interrupt lines and need to be resident within the operating system environment prior to their invocation by the external devices.

The arrival of a signal from the satellite receiver indicates the presence of an image pixel from the METEOSAT geo-stationary satellite. This invokes the satellite interrupt handler which consequently captures the individual pixels as they arrive. These pixels are immediately mapped onto the 'PCVISIONplus' frame memory board, overwriting the current pixels, and are also displayed on the image processing screen.

Similarly, information arriving from the GLNS invokes its interrrupt handler which inputs each byte of data to its buffer for later retrieval. During the period in which

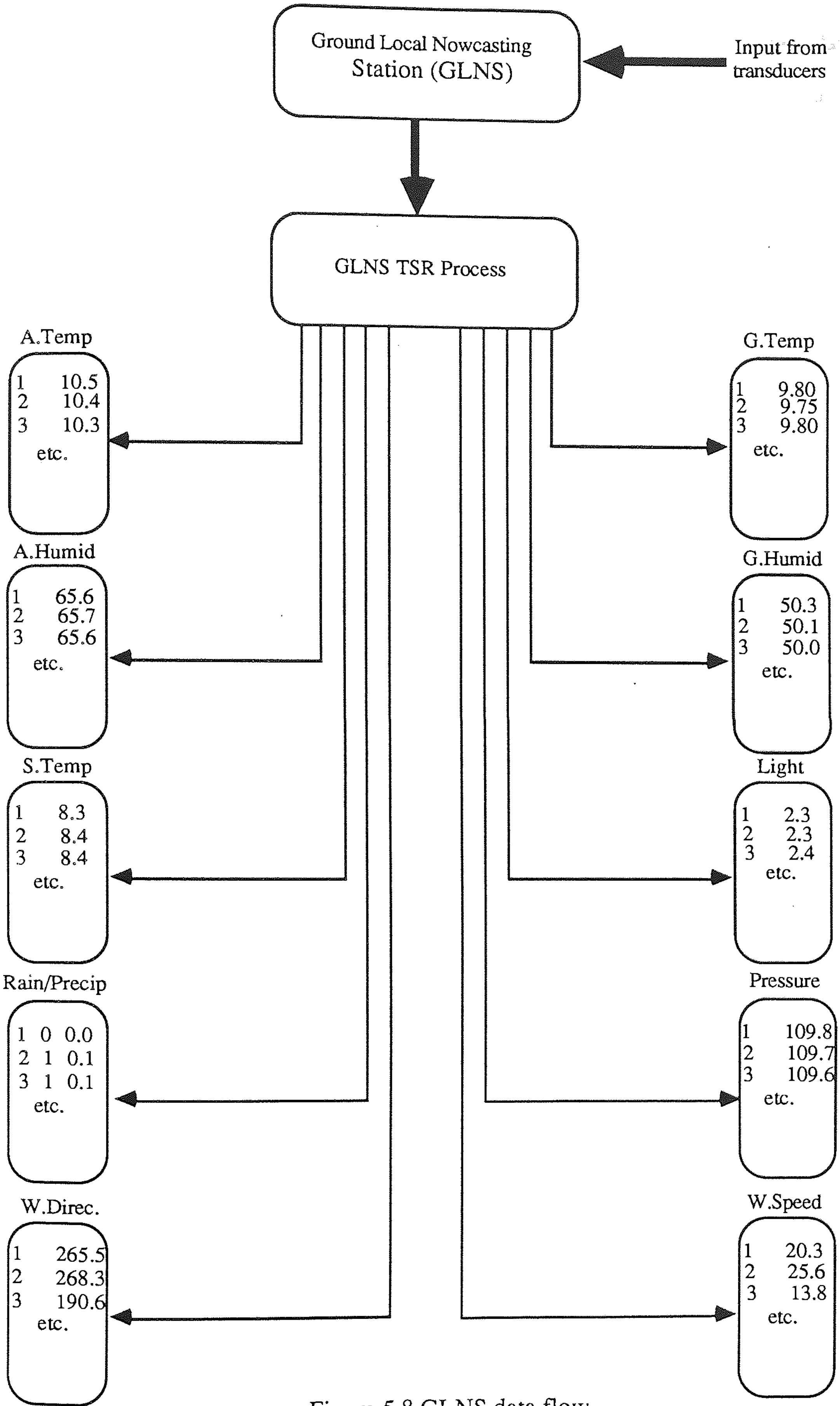


Figure 5.8 GLNS data flow

external devices are communicating with the PC system, any foreground process being executed is relinquished until such time as these devices have completed their transfer, after which the execution of the foreground process is resumed.

Loading the interrupthandlers in the manner indicated above is very primitive. The operating system is not aware of their presence, and they could easily corrupt existing system software. Furthermore this software provides no facility for data management (preperation, storage, analysis) as their objective is one of capturing data and their design needs to be concise and efficient as possible {section 5.4.4}. As METEOSAT is continually transmitting image data, any data management software in the case of the satellite receiver needs to be aware of the type of image being captured by the system and its storage to the appropriate rolling archive. Each image occupies 264 Kb of storage. The system cannot capture every image transmitted from the satellite and store on the hard disk. The incoming GLNS data is in raw format and needs to be converted to physical units prior to storage to rolling data files on the hard disk. The handling and management of atmospheric data is thus a non-trivial and yet fundamental task for the system.

To automate data handling and management in order to make it readily accessible for visual interpretation and analysis requires software which can be embedded within the operating system environment and which should be invoked as and when new data arrives from the external sources. This ensures that at any time, the most up-to-date data is readily available for analysis. The following sections describe the automation procedure.

5.6.1 Terminate and Stay Resident processes (TSR's)

The structure of a normal DOS process is that it is loaded into memory by DOS with all memory managment handled by DOS after which DOS transfers control to it. Once the process starts executing, it works under the assumption that it has all rights to the system. It may just wait idly without doing anything and can continue to hog the system for ever, until it decides to exit and pass control back to DOS. As control is passed back to DOS, all memory that the process was occupying is released back to the system. During the period of its execution, it can relinquish control to DOS when it wishes DOS to do something; such as read or write a record of data to or from a file. The control is returned to the process as DOS completes the assigned task.

The entire structure for a TSR process is different. In the beginning the TSR is like any other process to the operating system. Like any other process it is loaded by DOS, after which DOS transfers' control to the TSR. The TSR initialises itself and then permanently relinquishes control back to DOS, but in such a way that its executable code is preserved as part of the system without releasing its memory and such that the operating system will load any further process without destroying the TSR process. The TSR process will continue to reside as part of the operating environment but does nothing until it is invoked through interrupts, after which it springs into action, performs its task and then slips back into the shadows of the operating environment until it is invoked again.

One of the requirements for the real-time nowcasting system is that of capturing atmospheric data and preparing the data for interpretation. In order to accomplish this task without any effort from the user implies that any software must be loaded into the operating environment as a TSR process. This active TSR is then invoked by interrupt as and when external sources need to communicate with the system for data transfer.

5.6.2 Relocatable software

Any executable process is loaded into the system memory by DOS prior to passing control to it. All memory management is carried out by DOS (such as the absolute memory addresses into which the process is loaded, the amount of space it is given, etc.). The absolute addresses of the memory allocated to a process is not known prior to DOS loading that process. Any reference to an absolute physical address (as is the case with an interrrupt handler, being part of a code within a TSR process) can lead to conflict. Interrupt handling requires the storage of absolute addresses in their vector table . This can be achieved using a relocatable TSR. The task of passing the interrupt handler's absolute address to the appropriate interrupt vector table is carried out within a TSR process prior to it relinquishing control back to DOS.This also ensures that the software is independent of any phsyical memory space and can easily be transported to another system without any modification.

5.6.3 Single tasking system

The DOS operating system is designed for a single user environment. If a single process is being executed, another process cannot be executed concurrently; the second process must wait until the first process relinquishes control to DOS after its completion before it can be loaded and consequently executed. This non-reentrancy to DOS is linked with the way DOS uses a fixed internal stack and variables for all its operation. When a call is made to DOS, the current system operational stack pointers are saved, and a new stack inside the DOS code area is set up clearing any previous contents. This stack area is used for all internal operations. When a DOS call terminates, the original stack pointers are restored prior to returning control to the calling process.

The arrival of another call to DOS while one is already in progress results in the contents of the calling process's stack pointers being destroyed, as each DOS call creates a new stack, overwriting the first process's stack. This will either crash the system upon completion of the DOS call or the system will misbehave as it cannot return to the calling process whose stack pointer contents are destroyed.

As external sources could interrupt the system asynchronously prior knowledge of what is being executed by the system when a TSR is invoked is impossible. The TSR could conceivably attempt to gain control of the system while another process is being executed, and the inherent single user, single tasking design could result in the system crashing. Because of this limitation, a mechanism exists for determining whether DOS is in the process of executing a call so as to prevent it being called again at the present time. This mechanism makes use of an undocumented DOS call which returns the address of an internal variable, called the DOSIN flag. This flag is set to one when DOS is carrying out another call and resets to zero upon completion of the call. The DOSIN flag can be inspected at any time to determine DOS's current recursion level.

Unfortunately, this does not totally solve the problem of safe reentrancy. For example, when DOS is waiting for interactive input, the DOSIN flag is set indicating a call to DOS is in progess. This is a keyboard busy loop in which an interrupt is generated (INT 28H) which simply points to an interrupt return instruction. This interrupt in only generated while DOS is awaiting for interactive input. It is also known what DOS function calls can be safely executed without crashing the system(any DOS function calls other than keyboard calls). The system allows execution of any calls other then those it expects from the user without crashing the system. This provides an opportunity of invoking a TSR process while DOS is awaiting for interactive input. The TSR is invoked using the INT 28H internal interrupt.

If a foreground process is being executed at a time when a TSR process needs to be invoked, it must wait until the foreground process relinquishes control back to DOS. While the system is executing a foreground process, the keyboard busy loop interrupt is not generated and the TSR cannot be invoked using the INT 28H. As there is no prior knowledge of the foreground process's execution time, the current data may be lost if the time exceeds that of the next transmission. The system must be able to invoke the TSR process as soon as any current DOS call is complete. This can be achieved by using the timer ticker interrupt (INT 1CH, generated 18.2 times per second) to determine the state of the DOSIn flag prior to invoking the TSR in the event of a foreground process being executed. This provides the system with two ways of invoking the TSR and is diagramatically depicted in Figure 5.9.

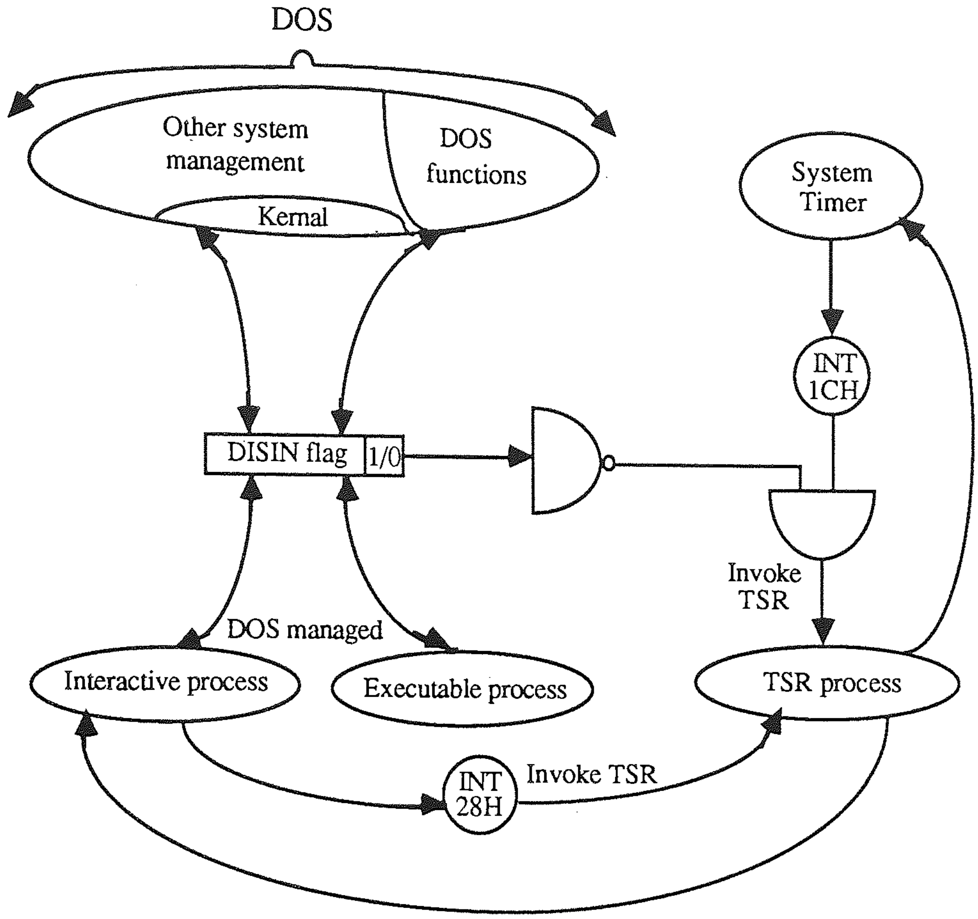


Figure 5.9 Invoking TSR process for safe operation

The safe execution of any TSR process would require the use of these factors to enable safe reentrancy to the operating environment without crashing the system. The software required to capture and manipulate the two sources of weather data, must be capable of providing this level of supervision to avoid crashing the system.

5.6.4 C language reentrancy

As software was designed to cater for the inherent deficiencies in the operating sytem environment, it was discovered that the langauge being utilised (C version 4.0) had deficiencies and was not capable of handling TSR processes. Its update, version 5.0, was designed to overcome this deficiency and was consequently acquired. The software developed on version 4.0 was tested on the new version but failed to run. This was later discovered to be caused by some of the library functions being non-reentrant and ways of removing these from the software did not provide a straightforward solution. The critical library functions were implemented using non-structured methods to achieve the required goal.

5.6.5 Satellite data scheduling

As highlighted in chapter 4, images are transmitted continuously from the METEOSAT geo-stationary satellite. These images in the main are from three spectral bands of the METEOSAT scanner covering its field of view, and are transmitted under strict timing schedule (page 80). These can be captured by a satellite receiving system. Not all of these images are of interest for the real-time nowcasting system for localised weather. Some form of strategy must be devised to capture only those images of interest. This is achieved using a real-time scheduler, capable of overcoming the inherent deficiencies of the operating environment (single tasking) to provide a fail safe system.

The multispectral band images of immediate interest with their transmission times are depicted on table 5.3. Only the infrared images (D2 formats) are transmitted during day and night, while visible transmissions are available during day light hours. Other formats of interest are:

- C2D :These are visible images obtained using a single channel , having the same format and resolution as the D2 format.
- E2 : These are images of air moisture as seen by METEOSAT with the same format and resolution as the D2 format.

HH	00	03	06	09	12	15	18	21
MM								
10	D2	D2	D2	D2	D2	D2	D2	D2
14			C02	C02	C02	C02		
18			C03	C03	C03	C03	C03	C03
42	D2	D2	D2	D2	D2	D2	D2	D2
46			C02	C02	C02	C02		
50			C03	C03	C03	C03		
58			C2D	C2D	C2D	C2D		
	01	04	07	10	13	16	19	22
10	D2	D2	D2	D2	D2	D2	D2	D2
14			C02	C02	C02	C02		
18			C03	C03	C03	C03		
26		E2					E2	
42	D2	D2	D2	D2	D2	D2	D2	D2
46			C02	C02	C02	C02		
50			C03	C03	C03	C03		
	02	05	08	11	14	17	20	23
10	D2	D2	D2	D2	D2	D2	D2	D2
14			C02	C02	C02	C02		
18			C03	C03	C03	C03		
42	D2	D2	D2	D2	D2	D2	D2	D2
46			C02	C02	C02			
50			C03	C03	C03			
58		E2		E2		E2		E2

Table 5.3 Satellite reception for nowcasting

5.6.5.1 Scheduling strategy

With transmissions from METEOSAT available for most of the 24 hour period, the task of the scheduler must be to capture only those images of interest to the real-time nowcasting system for localised weather and ignore all other transmissions. Figure 5.10 depicts in block diagram form. The real-time scheduler for capturing METEOSAT's multispectral band image data.

The real-time scheduler forms an integral part of the satellite TSR process. The two timing schedules; 'ON' and 'OFF', are necessary to inform the overall supervisor of the times for which reception is required from the satellite receiver. The PC's real-time system clock (RTC as shown on Figure 5.10) has an alarm facility with its own internal interrupt. This interrupt is generated by the precise setting of alarm times. The 'ON' and 'OFF' schedule routine modules are part of the supervisor control for handling satellite reception in a fail safe manner.

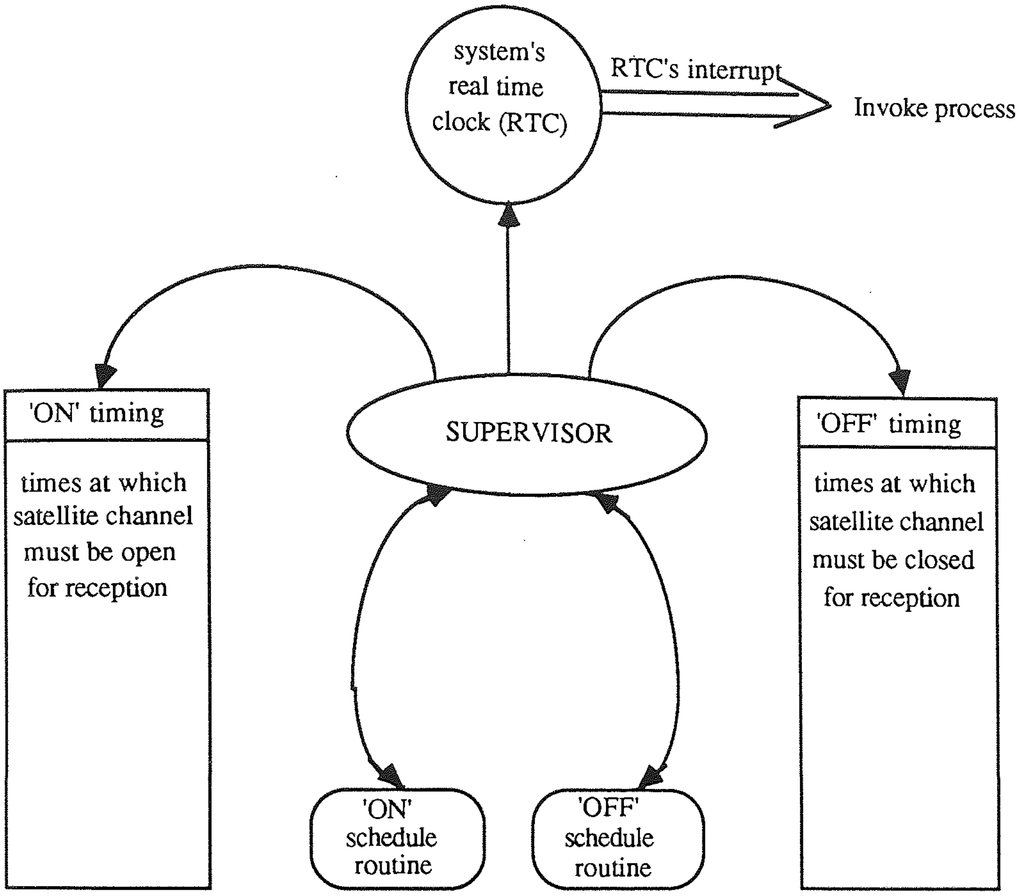


Figure 5.10 Real time scheduler

The real-time scheduler is represented here using pseudo code. At power up, the 'ON' timing schedule is interrogated for the next required image timing information. This information is used to set an alarm on the RTC. The interrupt vector of the RTC is loaded to point to the 'ON' schedule routine. At the time of alarm, the RTC interrupt is generated, and any current foreground process relinquishes control to the 'ON' schedule routine. The action of the real-time scheduler is explained in the proceeding sections.

The 'ON' schedule routines must first enable the satellite reception interrupt line. From the timing schedule, identity of the next multispectral band image is known. This information is used to pass a code to the spectral type flag which can be interrogated by the image save routine. This reduces the possibility of storing the current image to an incorrect sequence on the hard disk. The corresponding 'OFF' timing schedule is also interrogated for the next required image, to access the turning off time for the incoming image. This timing information is passed to the satellite's interrupt handler to set alarm conditions for disabling the interrupt line after image reception. The alarm for this condition is set upon the arrival of the first incoming image pixel, which also sets an imagein flag. The RTC interrupt vector is set at the arrival of the first pixel to point to the 'OFF' schedule routine. As this routine is invoked under interrupt, the last statement of this routine is a return from interrupt.

The 'OFF' schedule routine is invoked after the capture of a recent multispectral band image. Its first task is to disable the satellite's interrupt line to ensure that no further images can be captured until the current image in 'PCVISIONplus' board is dealt with. The corresponding 'ON' timing schedule is interrogated to extract the time of the next multispectral band image and the RTC is alarmed. The RTC interrupt vector is set to point to the 'ON' schedule routine for capturing of the next image. As both of the external sources transmit their data under interrupt, the corresponding TSR process needs to be invoked by the same internal mechanisms. This is achieved by chaining of the internal interrupt lines without conflict; as both external sources will never transmit data at the same time.These internal interrupts can safely be chained for the two external sources. When the internal interrupts are used for satellite reception; the GLNS vector addresses are preserved and restored after the completion of the satellite's TSR process. As this routine is invoked under interrupt, the last statement of this routine is a return from interrupt.

The save image routine is the only module of the satellite's TSR process that calls DOS. The internal mechanisms described in the preceeding sections are used to invoke this module. Prior to saving of the current multispectral band image in the 'PCVISIONplus' frame memory, its spectral identity (infrared, visible, moisture, or others) must be determined by interrogating the spectral type flag. Once the image's identity is known, it is stored to its corresponding sequence on the hard disk. The image sequence is updated by removing the first image to maintain a set image sequence. The last task before control is returned to the foreground process interrupted is to initialise the interrupt handler's pointers for the capture of the next image. Once again, as this routine is interrupt driven, its last statement is a return from interrupt.

```
procedure (real-time scheduler)
begin
    begin
        extract next image time from 'ON' timing schedule;
        set alarm interrupt vector to 'ON' schedule routine;
        set alarm for next image capture;
    end;

    begin ('ON' schedule) {executed by RTC}
        enable satellite reception interrupt for image capture;
        set spectral type flag;
        extract corresponding turning off time from the 'OFF' timing schedule;
        pass the above to the interrupt handler for setting alarm;
        return from interrupt;
    end; {'ON' schedule}

    begin ('OFF' schedule) {executed by RTC}
        disable satellite reception interrupt line;
        extract next image time from the 'ON' timing schedule;
        set alarm interrupt vector to point to the 'ON' schedule routine;
        set alarm for next image;
        save current internal vectors for reentrancy;
        chain new vector pointers for satellite images;
        return from interrupt;
    end; {'OFF' schedule}

    begin (save image) {executed after checking DOSIN flag}
        extract the spectral type of the current image;
        inspect imagein flag for its status;
        if (imagein == yes)
            begin
                reset imagein flag;
                store current image to its spectral sequence;
                remove the first image of the sequence;
                update the new image sequence;
            end;
        else
            do nothing;
```

```
            initialise interrupt handler's pointers;
            chain back to original vector addresses;
            return from interrupt;
    end; {save image}
end; {real-time scheduler}
```

5.6.6 GLNS sheduling

The amount of data arriving from GLNS every five minute intervals is only a small fraction of that arriving from the METEOSAT geo-stationary satellite per image. The transmission from the GLNS is software controlled and can be altered to suit, which is not the case of the satellite's transmission. The GLNS is programmed to transmit its data for capture by the PC without any conflict with data being transmitted from the METEOSAT geo-stationary satellite.

The TSR process for the GLNS consists of an interrupt handler that safe capture of the local atmospheric ground data and consequently storing it to its buffer, and finally software modules for converting the raw data arriving from the GLNS. Each transducer has its own module for preparing the data for storage to its 24 hour rolling file on the hard disk.

The raw data can be captured by the PC under interrupt at any time without any form of supervision, however, date manipulation interms of file handling etc. must be carried out under strict supervision as has been highlighted. This is done using the internal interrupt mechanisms described earlier. The vectors of these internal interrupts for safe reentrancy are initially assigned to the GLNS TSR process and the satellite's TSR chains them when it requires them without confliction.

The flow of the incoming GLNS data is depicted by Figure 5.9. Every five minutes, GLNS transmits its past and present samples of the atmospheric elements to be captured by the PC. This incoming data is initially stored within the interrupt handler's code area buffer. When all the data is captured, a DATAIN flag is raised to indicate that the data manipulation part of the TSR process can be executed when safe to do so. The individual tranducers samples after being converted are stored to their 24 hour rolling archive, overwriting previous day sample of the same time. The 24 hour data file of each transducer is maintained.

5.7.0 Conclusion

The collection of meteorological data is generally associated with large computer systems due to their large volume. However, it has been shown, this need not apply to collecting of data from a local site for single station observation. The data is captured by the real-time nowcasting system for localised weather from two differing sources. The multispectral band images from the METEOSAT geo-stationary satellite showing cloud morphology that can be interpreted visually by observing animated sequence of particular spectral images. The immediate display of these images is only made possible by pre-processing the vast amount of raw data from the METEOSAT at a ground station (chapter 4) prior to its dissemination to users. The GLNS captures and stores local transducer measurements in raw format and these cannot be presented immediately for visual interpretation. Considerable processing must be carried out on this raw local data. The handling and preparation is an important process in any real-time system without which these systems become helpless.

The capture and consequent preparation of atmospheric data is an important element of the real-time nowcasting system for localised weather. Any microcomputer deployed must be capable of satisfying this requirement. The current philosophy behind microcomputer design is towards a single system, capable of executing a single task without any form of concurrency. These restrictions imposed on the PC design inhibit the PC's for concurrent real-time operations. It has been shown how these deficiencies can be removed to handle the atmospheric data in real-time.

The software developed for real-time operation is designed as a TSR process and is automatically embedded as part of the operating environment.

Chapter 6

6.0 ARIMA modelling of GLNS data

6.1 Introduction

The greatest stimulus to the study of weather has undoubtedly been the desire to forecast changes in the weather. In principle the problem is very simple, for all we need to know are, firstly, the state of the atmosphere at any given moment and, secondly, the physical laws which govern the changes of the state. When an answer is sought in practice, however, two difficulties immediately become apparent: (i) not enough information is available to describe adequately the state of the atmosphere in detail, and also, the mathematical equations expressing the physical laws are too complex for an exact solution[46] unless simplification are made. However, continuous research has resulted in improvement of atmospheric modelling by including those physical processes of importance in the behaviour of the atmosphere. An equally significant development has taken place in the design of procedures used for numerical integration[47] of the complicated equations that describe large scale atmosphere dynamics and thermo-dynamics. At the same time, large and faster computers have allowed the meteorologist to incorporate more physical processes and better numerical methods into their models.

The atmospheric models[47,48,49,50,51], referred to as Numerical weather Prediction (NWP) models, attempt to view the atmosphere as a 3 dimensional space and are constructed on global aswell as regional (country) bases. These models are implemented on large computers (CRAY-1[52], CYBER 205[53]) with model execution times of several hours to produce forecasts. The input parameters to these models are collected, transmitted and compiled on global scale and the models are run at set times every day[53].

Inspite of these advances, the complexity of atmospheric variations are not fully understood; the factors making up the atmosphere are disturbed in an indescribably complex way that full solution of its future behaviour still eludes us.

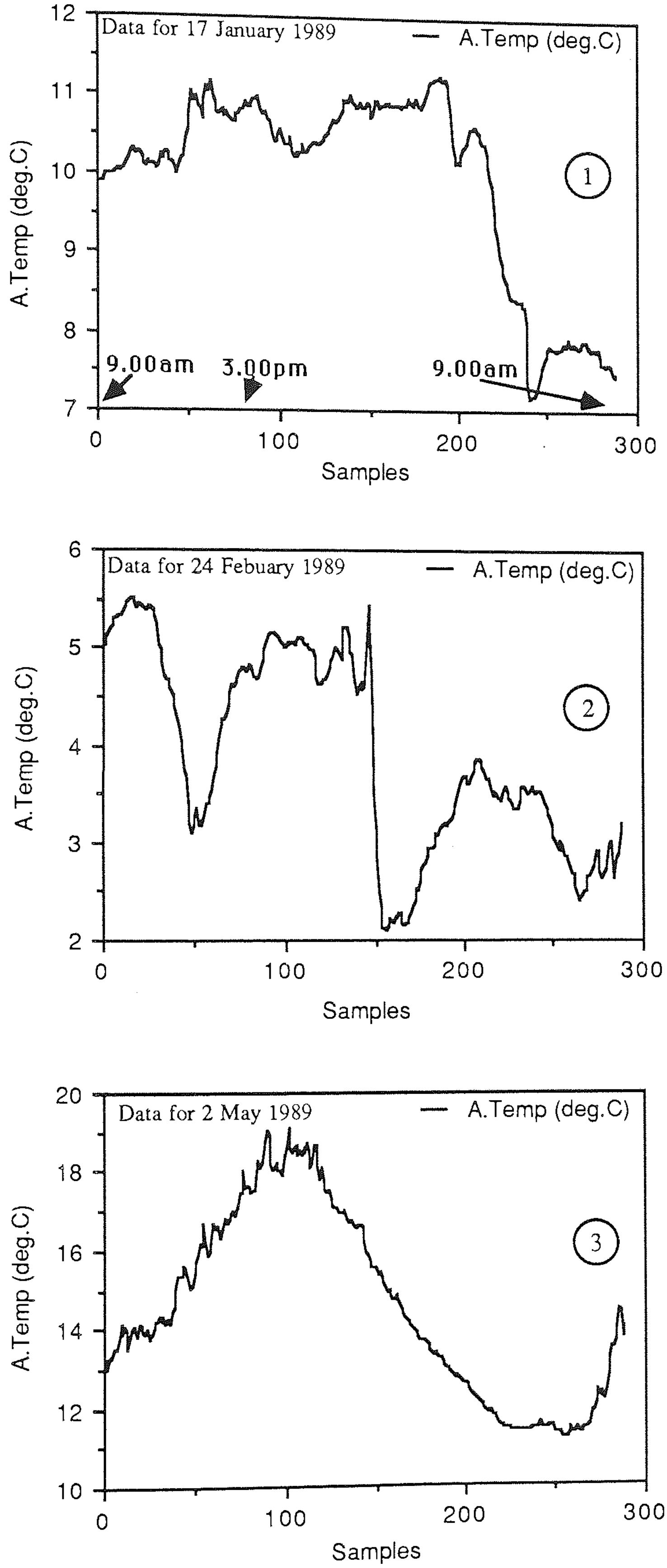
Miller et. el[54] conducted an experiment on single station forecasting, using hourly observations of weather elements. The model used employs the principle of multivariate regression in a Markov process. In his findings, he concluded that regression was superior to Persistance (simple assumption: a front moving at a speed will continue to do so with the same weather accompanying it) over a period of 3 hours.

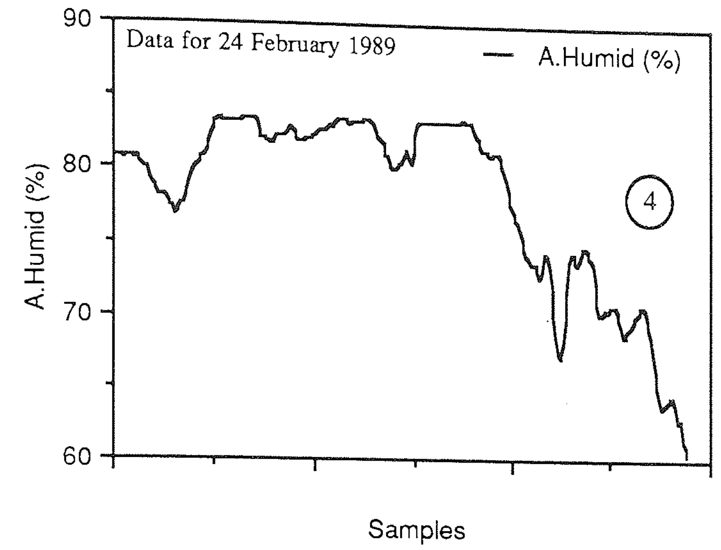
Extensive literature search failed to show any work being carried out related to simple extrapolation of weather elements for nowcasting using statistical models or otherwise. Yao[55] and Gates et.el[56] fitted autoregressive time series models to rain data for long-range forecasting. The novel approach adopted in this thesis is one of constructing simple statistical models using site-specific data to predict future changes of weather elements based on their past and present variations.

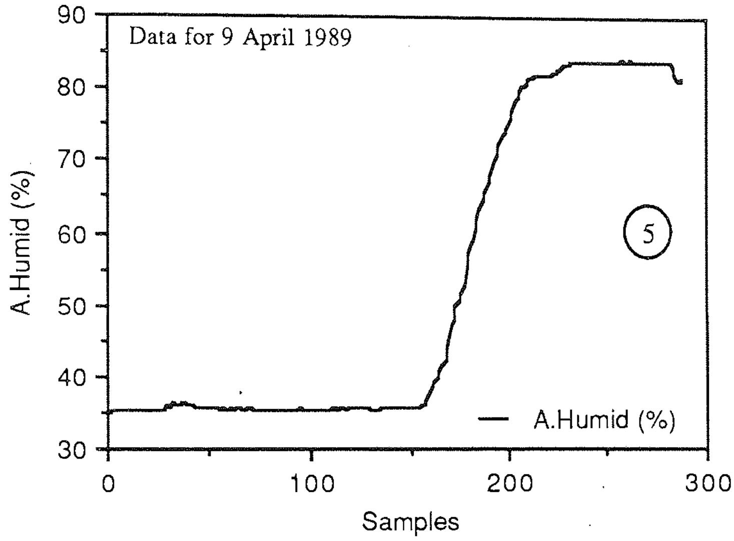
6.2 Site-specific data variations

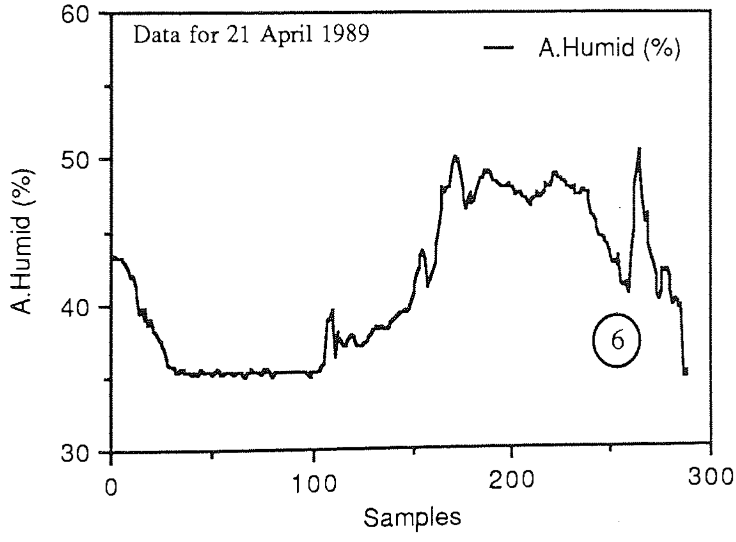
Fundamental to the development of any model building is an appreciation of how the data varies. In the case of data containing only small samples, its variation can readily be appreciated by observing the data itself, however, when data consists of large samples, the simplest form of presentation is by displaying it graphically for visual appreciation. Each GLNS transducer file consists of 288 samples of 24 hour past and present data (each sample being an average of five 1 minute samples). Graphs 1-15 depict the transducer variations for different days . Each graph presents a transducer variation of 24 hours from 9.00am to 9.00am (the following day). From the graphs for different days, it can be appreciated that weather elements do not vary consistently from one time period to the next within the same day and similarly from one day to the next. The 3 hour snap shots of each transducer as depicted by graphs 16-20, clearly highlight the feasability of modelling this data for nowcasting. These snap shots show that weather elements (except for wind speed,wind direction) in the main do not fluctuate abruptly and lend themselves to linear extraploation.

24 hour transducer profile

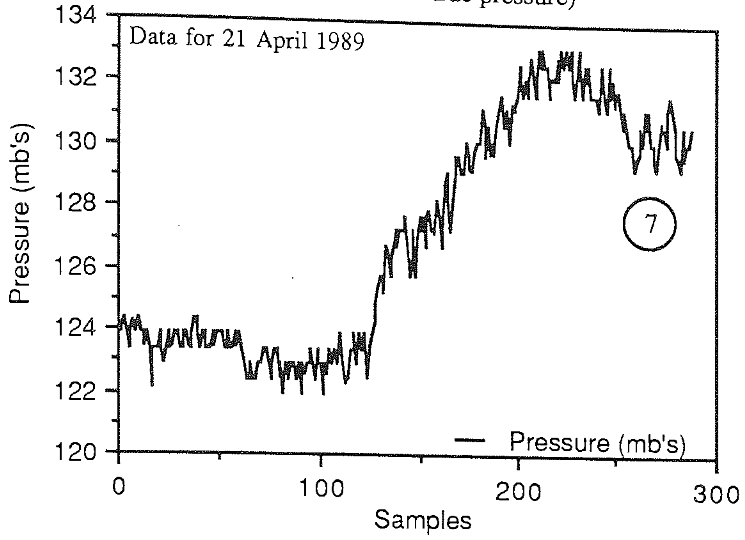


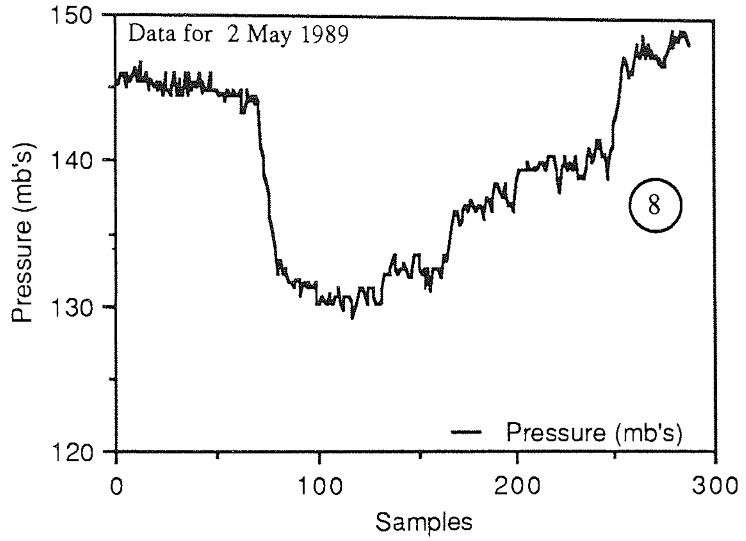

Data for 24 February 1989
A.Humid (%)
4
90
80
70
60
A.Humid (%)
Samples

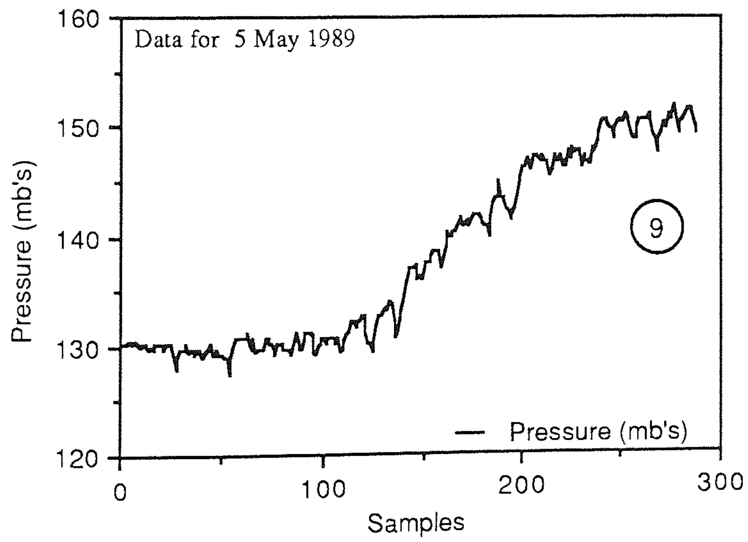

Data for 9 April 1989
A.Humid (%)
5
90
80
70
60
50
40
30
A.Humid (%)
0
100
200
300
Samples

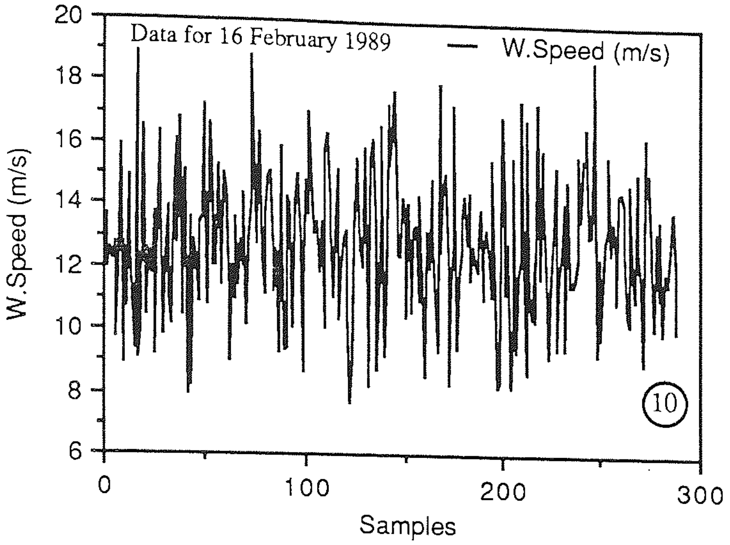

Data for 21 April 1989
A.Humid (%)
6
60
50
40
30
A.Humid (%)
0
100
200
300
Samples

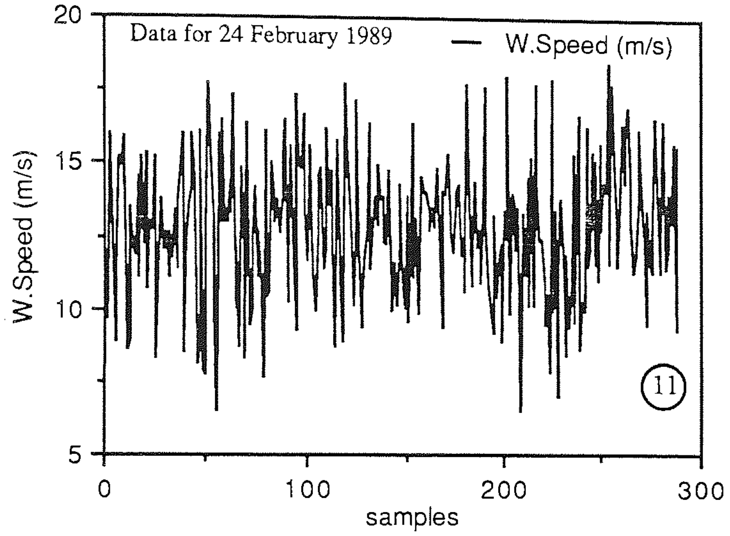
(Note: Add 900 for true pressure)

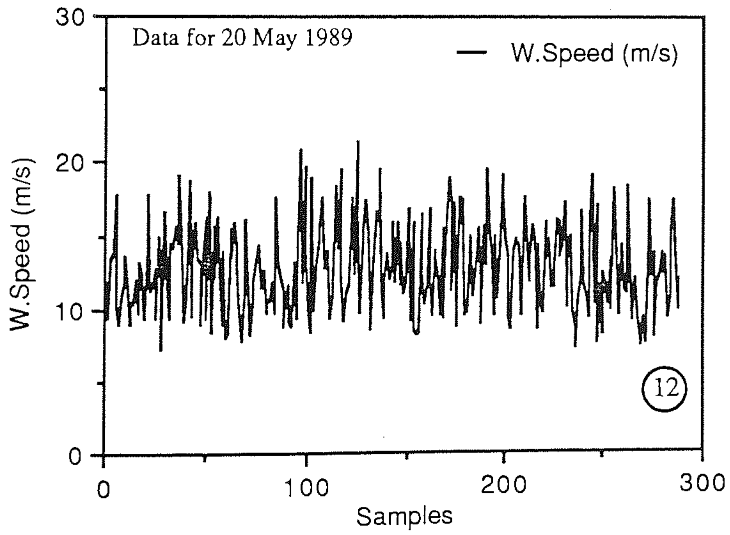


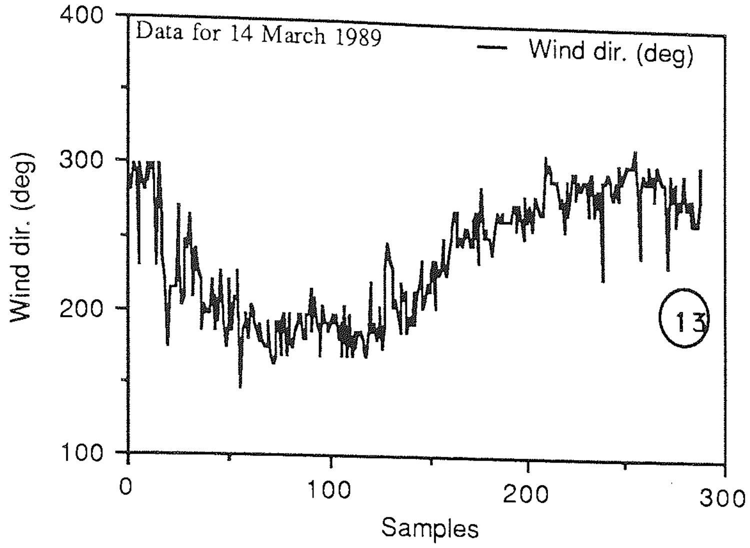


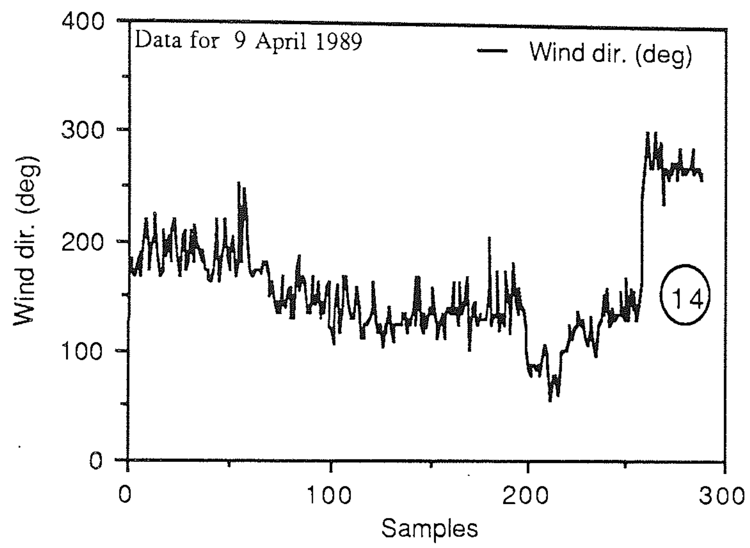


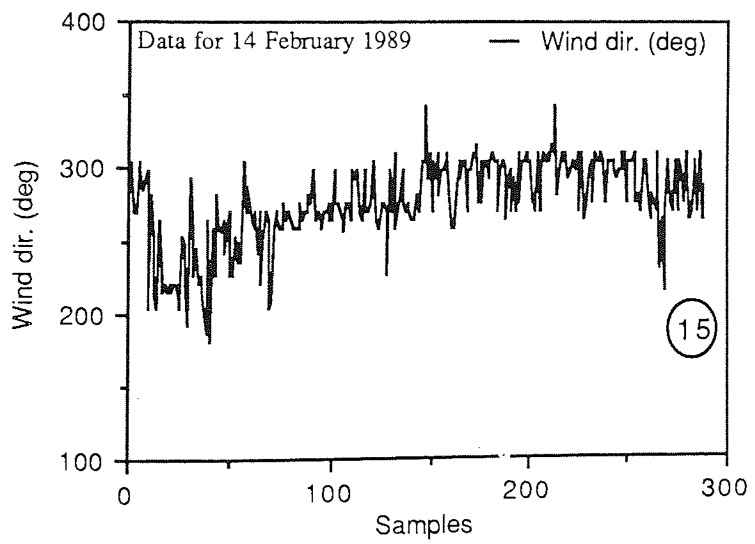

Data for 16 February 1989
W.Speed (m/s)
W.Speed (m/s)
Samples
20
18
16
14
12
10
8
6
0
100
200
300
10


Data for 24 February 1989
W.Speed (m/s)
W.Speed (m/s)
samples
20
15
10
5
0
100
200
300
11

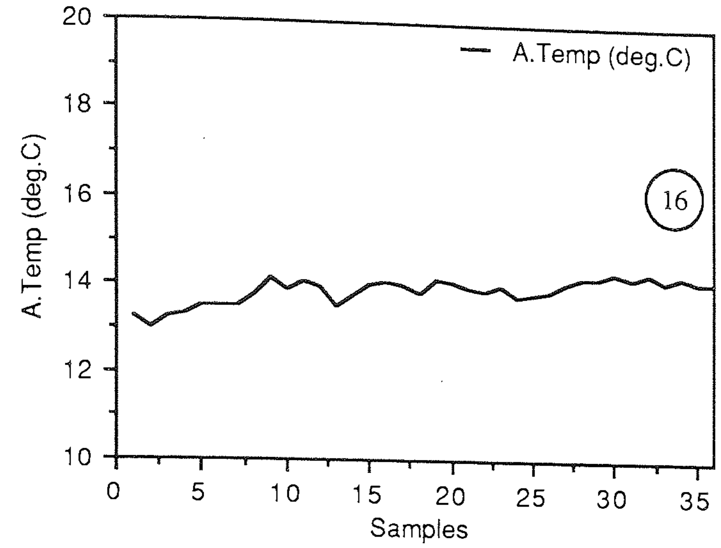

Data for 20 May 1989
W.Speed (m/s)
W.Speed (m/s)
Samples
30
20
10
0
0
100
200
300
12

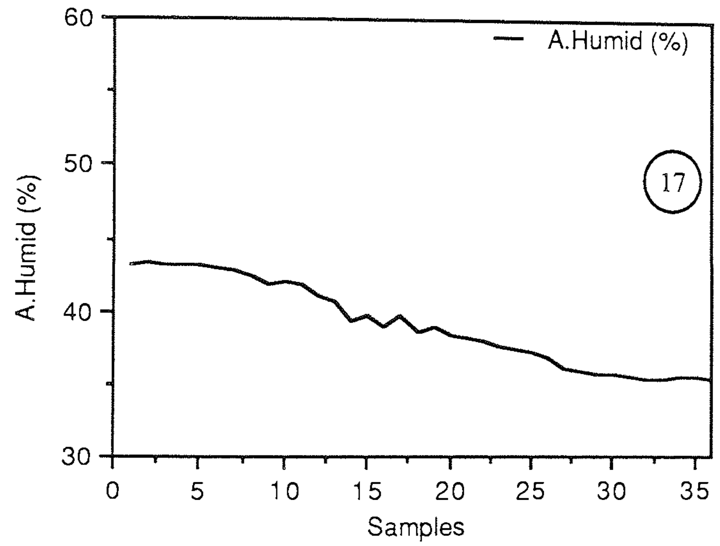

Data for 14 March 1989
Wind dir. (deg)
Wind dir. (deg)
Samples
13

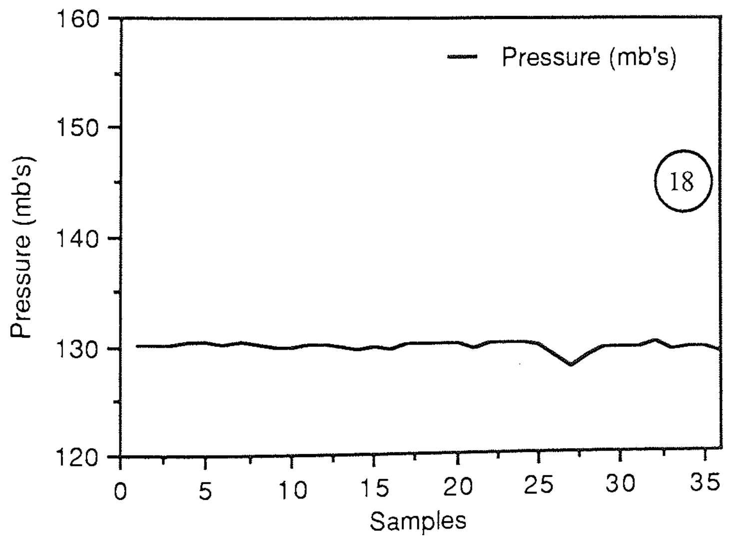

Data for 9 April 1989
Wind dir. (deg)
Wind dir. (deg)
Samples
14

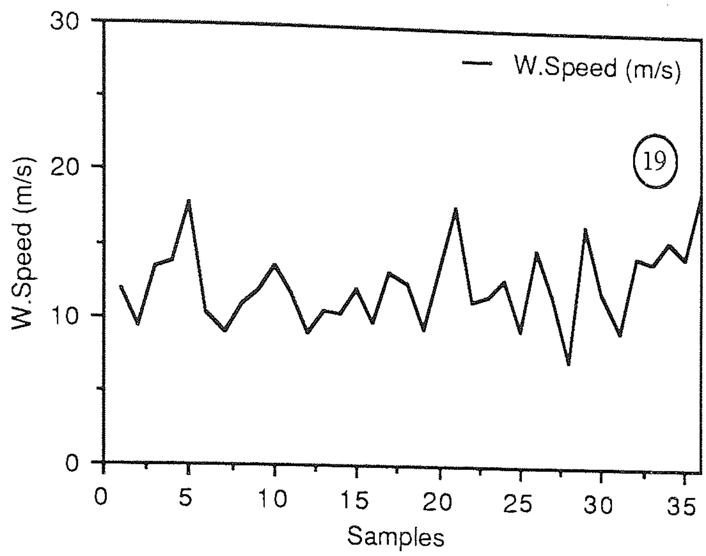

Data for 14 February 1989
Wind dir. (deg)
Wind dir. (deg)
Samples
15

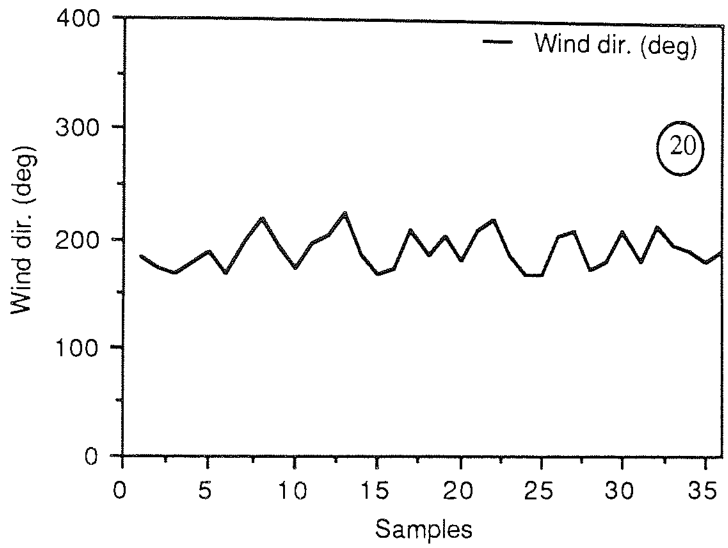
Three hour snap shot of transducers











6.3 Modelling techniques

If an exact solution of a phenomenon can be presented in the form of a mathematical model then such a phenomenon is totally deterministic. As highlighted in the earlier sections of this chapter, atmospheric phenomena are not deterministic and lends itself to modelling, using probability models or stochastic models. The models derived for each atmospheric element can be used to calculate the probability of a future value lying between two specified limits.

The weather element data is in the form of discrete samples recorded at equispaced times. This type of data lend itself to time series analysis.

6.3.1 Curve fitting techniques

The curve fitting techniques determine the best way to draw any predetermined polynomial[57] through the data series under analysis. Once a curve is found which fits the data series adequately, any forecasts are simply an extension of the curve. Curve fitting does not assume any theory behind the variation of the data. When a curve fits well this is a straightforward method of short-term forecasting.

This technique will not work with meteorological data as there is no straightforward method of finding a curve.

6.3.2 Exponential smoothing

Exponential smoothing combines the data series observed mean, its trend, and 'seasonality' with added weight given to the more recent observations to make a forecast. This is best used for short-term forecasting, or what is known as 'one-step-ahead' or 'one-period-ahead' forecasts. When correct parameter values are chosen for the series, it extracts a lot of useful information from the most recent observation, somewhat less from the next-most-recent, and so on, and usually makes a good forecast for a single period. As it moves into the future, however, making 'several-steps-ahead' forecasts, it quickly runs out of recent information on which it bases these forecasts. The tendency is to level to the 'one-step-ahead' forecast.

Several tests were conducted at building exponential smoothing models. It was discovered that with all the transducers data showing no trend, seasonality and purely relying on weighting of past and most recent observations, the weighting factor found was close to unity indicating that any future forecasts of the series were totally dependent on the more recent observation. For single period forecast it was the appropriate model to use; however, it was of no use for the time scale envisaged for nowcasting.

6.3.3 AutoRegressive Integrated Moving Average (ARIMA) models

The ARIMA models provide a wide class of stationary and nonstationary models which can adequately represent many of the time series met in practice[58]. These stochastic models are based on the idea that successive values are highly dependent and can be regarded as generated from a series of independent 'shocks' a_t. ARIMA models combine as many as three types of processes[58]: autoregression (AR); differencing to strip of the integration (I) of the series; and moving average (MA). All three are based on the concept of random disturbances or 'shocks'. These disturbances can be mathematically described by ARIMA models. Each of the three types of process has its own characteristic way of responding to these shocks.

6.3.3.1 Autoregressive (AR) process

In an autoregressive (AR) process each value in a series is a linear function of the preceding value or values. In a first-order AR process the current value is a function of the preceding value, which is a function of the one preceding it, and so on. The general AR process is expressed as :

$$\hat{z}_t = \phi_1 \hat{z}_{t-1} + \phi_2 \hat{z}_{t-2} + ... + \phi_p \hat{z}_{t-p} + a_t \quad .... \quad 6.1$$

where μ = mean of the series
$\hat{z}_t$ = value of the series at time t
$\hat{z}$ = zt $-\mu$ (deviation from the mean).

The general AR process in equation 6.1 is an autoregressive process of order p, and contains p+2 unknowns, $\mu, \phi_1, \phi_2, ..., \phi_p$, and σ_a^2 which have to estimated from the data. Where σ_a^2 is the variance of the white noise process a_t

6.3.3.2 Moving Average (MA) process

In a moving average (MA) process, each value is determined by the average of the current disturbance (shock) and one or more previous disturbances. The order of the MA specifies how many previous disturbances are averaged into the new value. The general MA process is expressed as :

$$\hat{z}_t = a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \ldots\ldots - \theta_q a_{t-q} \quad \ldots\ldots\ldots \quad 6.2$$

The general MA process in equation 6.2 is a moving average process of order q, and contains q+2 unknowns, $\mu, \theta_1, \theta_2, \ldots, \theta_q$, and σ_a^2 which have to estimated from the data.

6.3.3.3 Stationary and nonstationary proces

A series that varies about a constant mean level is called a stationary series (process). The autoregressive-moving average models rely on the series to be stationary. When a series wonders, and has no natural mean level is called a nonstationary series . It is these latter series that are generally met in practice. However, such a wondering series have small differences from one observation to the next and thus the differences of even a wondering series remain constant. This steadiness or 'stationarity' of the differences is highly desirable for autoregressive-moving average processes.

A series that measures the cumulative effect of something is called 'integrated' (I)[58]. In the long term, the average level of an integrated series might not change, but in the short term values can wander quite far from the mean level. The differencing of such a series leads to its differences being steady or stationary for stochastic modelling.

6.3.3.4 ARIMA process

The three processes mentioned in the preceding sections are combined to formulate an ARIMA model. The ARIMA models give greater flexibility in fitting actual time series. The general ARIMA process can be expressed as:

$$w_t = \phi_1 w_{t-1} + ...+\phi_p w_{t-p} + a_t - \theta_1 a_{t-1} - ....- \theta_q a_{t-q} \quad .... \quad 6.3$$

where $w_t = z_t - z_{t-1}$ (difference)

The ARIMA model assumes that the d^{th} difference of the series can be represented by a stationary ARMA process. This model can be regarded as transforming the highly dependent, and possible nonstationary process z_t, to a sequence of uncorrelated random variables a_t; that is transforming the process to white noise. If the autoregressive process is of order p, and the moving average process of order q, the d^{th} difference is taken, then we have an ARIMA(p,d,q) process.

6.4 ARIMA modelling

The three types of random processes in ARIMA models are closely related.There is no computer algorithm that can determine the correct model for a given time series.Instead, Box and Jenkins[58] describe an iterative approach to model building. This approach is adopted to construct the best possible model. Figure 6.1 summarisethe iterative approach which basically consists of three main steps, identification, estimation, and diagnoses, which are repeated until the model is satisfactory.

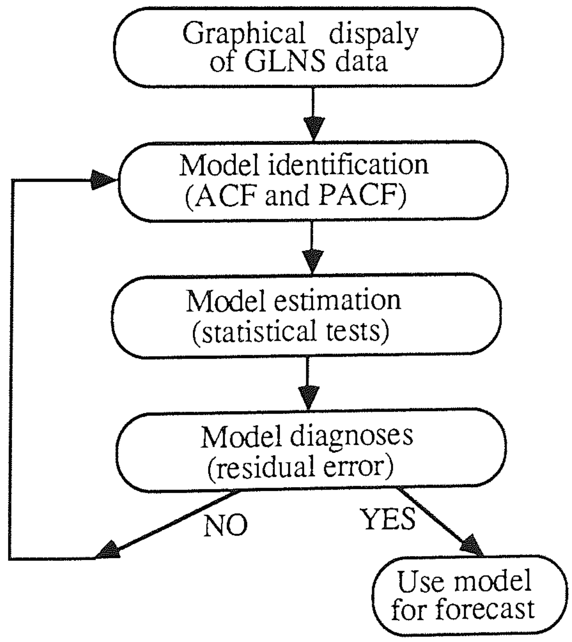


Figure 6.1 ARIMA modelling approach

6.4.1 Model identification

Identification methods are rough procedures applied to a set of data to indicate the kind of representational model which is worthy of further investigation.

To identify the process underlying a series, it must be determined from the data whether or not the series is stationary, since the identification of the AR and MA components require the series to be stationary. The stationarity of the series is determined by plotting the autocorrelation function (ACF) for the series. If the ACF 'die out' quickly for moderate and large lags, the series is stationary, however, if the ACF does not die out quickly and falls away slowly and linearly is taken as an indication that the series is nonstationary and needs to be transformed by differencing.

After determining the degree of differencing, the study of the ACF and partial autocorrelation function (PACF) is made to determine the choice of the order of AR(p) and MA(q). The ACF of an AR process of order p tails off, while its PACF has a cut off at lag p. Conversely, the ACF of the MA process of order q has a cut off after lag q, while its PACF tails off. If both the ACF and PACF tail off, a mixed process is suggested.

6.4.2 Model estimation

After identifying the model, efficient estimates of the model parameters must be made. Box and Jenkins[58] have suggested several statistical tests for the correct estimation of the model parameters, minimum sum of squares, least squares, the maximum likelihood and the residual variance. The idea is to estimate the minimum sum of squares, which is the least squres estimate and (on the assumption of Normality) a close approximation to the maximum likelihood estimate. Other goodness-of-fit statistics have been suggested. They are the Akaike Information Criterian (AIC)[59] and the Schwartz Bayesian Criterion (SBC)[60]. They measure how well the model fits the series, the model with the lowest AIC or SBC is the best.

6.4.3 Model diagnoses

A question, after a model has been identified and estimated is whether the model is adequate. If the form of the model is correct and the ϕ and Θ parameters are known, based on the results of Anderson[61], the estimated ACF of the a's (error residuals) would be uncorrelated and distributed approximately Normal about the zero. To check the residuals, both the ACF and PACF of the residuals are plotted and they must be randomly distributed ('white noise'), with only a few scattered correlations exceeding the confidence limits.

6.5.0 Forecasting

The concept of forecasting is straightforward, given an observation (z_t) at time t, forecasts are made for various lead times. Forecasts are needed for several lead times in nowcasting, where the lead times are restrained by the accuracy of the forecasts. The accuracy of the forecasts may be expressed by calculating probability limits on either side of each forecast. These limits may be calculated for any convenient set of probabilities, for example 50%, 95%,etc.. They are such that the realized value of the time series, when it occurs, will be included within these limits with the stated probability.

6.6 Modelling atmospheric elements

The methods employed to solve for the parameters of ARIMA models require quite intensive computation. Software packages are available with time series analysis routines for constructing ARIMA models. These packages were originally available for main frames due to their requirements for large memory space, but have recently (1988) been offered for small systems. The real-time nowcasting system is based around a PC, one of the fundamental requirement was that an analysis package with ARIMA time series must be capable of running within the PC environment. One such package marketed is the SPSS/PC+[62] suitable for IBM PC/XT/AT and PS/2 systems. The complete SPSS/PC+ package contains a wide range of statistical analysis routines with the complete package occupying 11.4 Mb of hard disk space. However, it does provides the user with options for installing only those routines of interest, consequently, reducing the required hard disk space. The time series routines occupy around 5 Mb of hard disk space.

The SPSS/PC+ package incorporates full ARIMA modelling strategy as described by Box and Jenkins[58].

The SPSS/PC+ supports several data formatting schemes for transporting data into its environment for analysis. The two column atmospheric elements data was easily transported into the SPSS/PC+ environment using its FREE format command.

One immediate difficulty arose with the presentation of atmospheric data in graphical form within SPSS/PC+. The graphical display routine provided with SPSS/PC+ offers a poor resolution display (presented as characters) with capability of dispaying 68 points on a single screen, consequently, the full atmospheric data file occupies several screens. This was overcome by using an in-house developed weather window display package[64] which is capable of displaying upto 9 transducers and their models in full resolution on a single screen {see section 6.6.7.1}.

Several months of GLNS data was available for analysis, from which random samples were selected for constructing univariate models. The selected transducers have provided continuous observations over several months, while others (mainly ground level) are awaiting appropriate site for their installation.The following sections show the range of ARIMA univariate models fitted to the individual atmospheric elements.

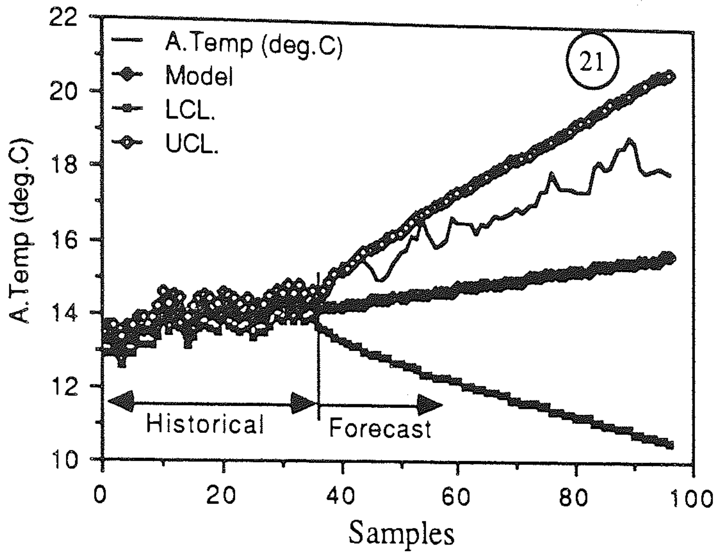
6.6.1 Air temperature

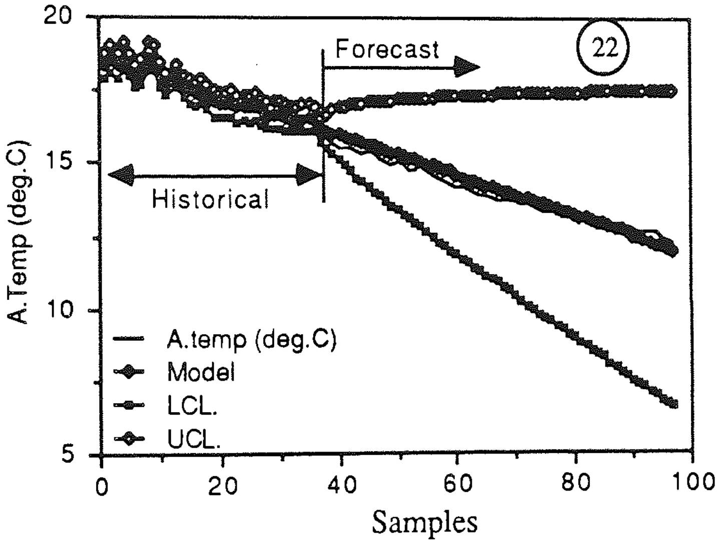
The air temperature profile of 2nd May, 1989 provided a rare diurnal variation of this atmospheric element and was selected for initial ARIMA model determination. The ACF plot of the data showed a constant level for several lags indicitive of a nonstationary process. The ACF plot indicated the data series should be transformed to achieve stationarity prior to determining the ARMA parameters. Differencing the data resulted in the ACF and PACF plot behaving as white noise (random distribution). When differencing a series reduces it to white noise the ARIMA modelling procedure is complete and the resulting model is simply an ARIMA (0,1,0) model. The series was differenced once more to see what changes may result in the tentative ARIMA (0,1,0) model. The ACF and PACF of this tranformation inferred a different plot indicating that the series contained a first order moving average parameter, the resulting model being an ARIMA (0,2,1) model. Both of the tentative models will be analysed to determine the correct model for air temperature.

Estimating the validity of the model is achieved within SPSS/PC+ by providing the tentative model with historical data to extend this into forecasts. Forecast lead times were unknown; as evident from the 24 hour transducer graphs 1-15, too longer lead times could easily result in inaccurate forecasts. One of the important factors in the analysis of GLNS data is the determination of forecast lead times for individual transducers. This has been achieved empirically using historical data of the transducers and the resulting model of these data sets. SPSS/PC+ contains all the necessary parameters to determine the appropriate model for the data series. Any model output is accompanied by user defined upper (UCL) and lower (LCL) confidence limits and these were set to 95%.

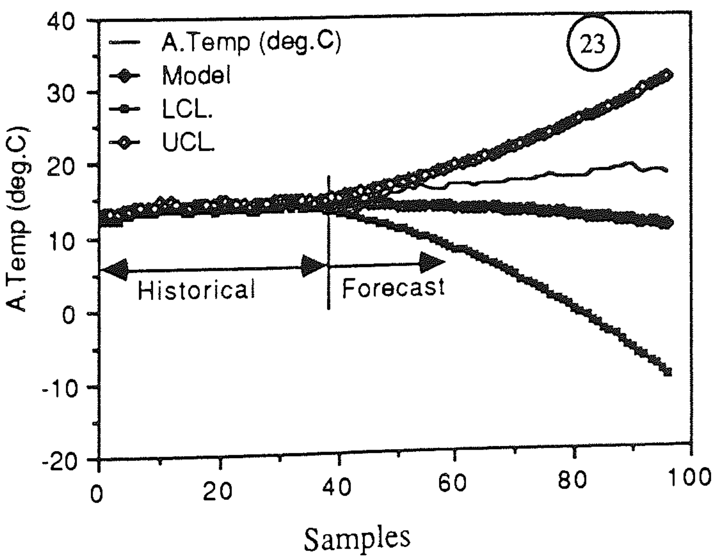
Graphs 21-24 depict the result of the two tentative models for different observation time periods, where the historical region (3 hours) is the bases on which forecasts for lead times of 5 hours are made. The ARIMA (0,2,1) model shows a tendency of sloping away as lead times are extended while ARIMA (0,1,0) model tends to track the actual data quite well. Table 6.1 depicts the best-fit model statistics for both of the

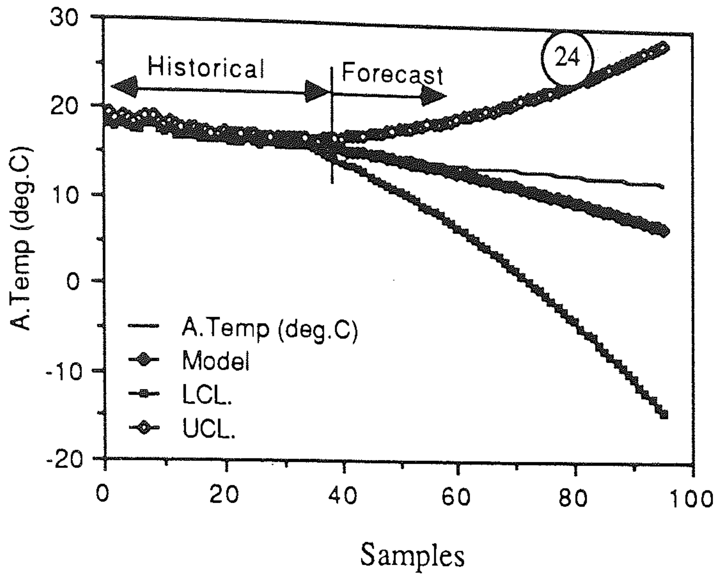
ARIMA (0,1,0)





ARIMA (0,2,1)





Air temperature			
Period	Statistical tests	ARIMA (0,1,1)	ARIMA (0,2,1)
12:00 - 5:00 pm	ASOS	1.30	1.43
	AIC	-13.84	-7.12
	SBC	-12.3	-4.06
	RV	0.0383	0.0404
	MA1	-	0.9995
	CONSTANT	0.026	-0.0018
9:00pm - 2:00am	ASOS	1.53	1.71
	AIC	-8.97	-2.37
	SBC	-7.39	0.74
	RV	0.044	0.047
	MA1	-	0.9998
	CONSTANT	0.069	-0.0018

Table 6.1 Best-fit model results for air temperature

tentative models. It can be seen from the statistical tests that an ARIMA (0,1,0) model performs well on all the best-fit test criterion.

In diagnosing the tentative models, their residual variance (RV) plots indicated that both of these had been reduced to white noise, however, as ARIMA (0,1,0) performed well and was selected for nowcasting.

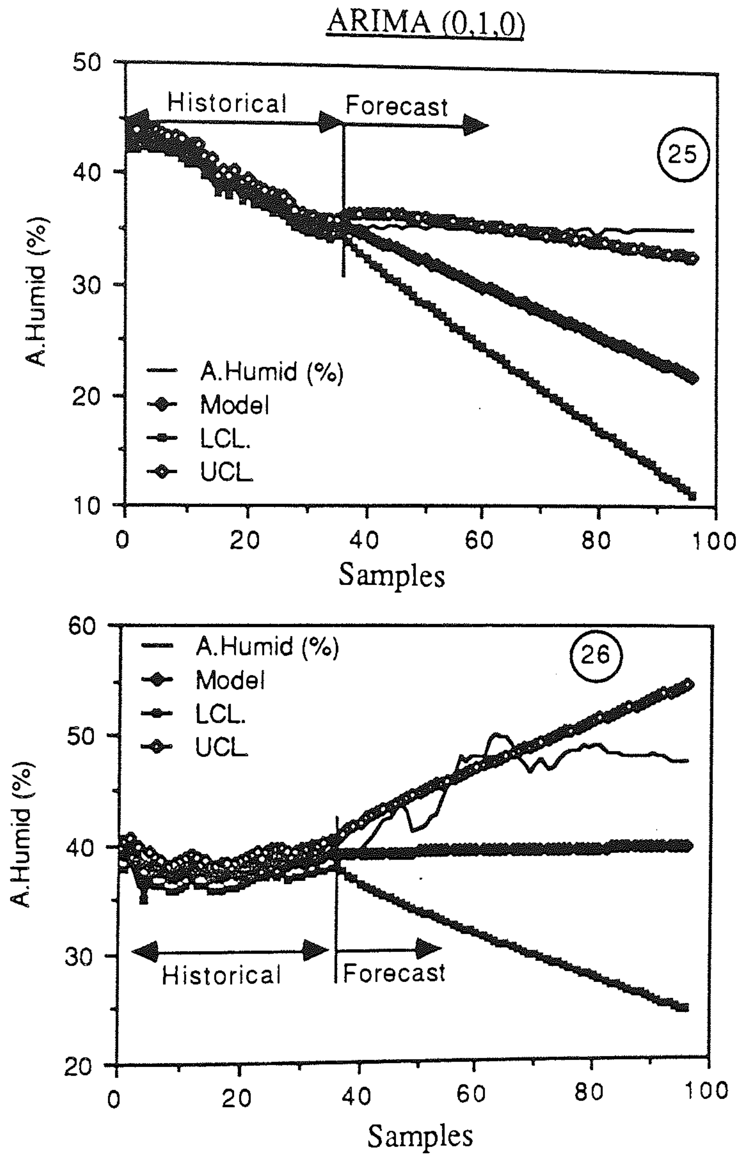
These preceding tests were conducted on randomly selected air temperature data of several months to validate the ARIMA (0,1,0) model as the correct model. It was discovered that the chosen ARIMA (0,1,0) model performed well on the data tested. As depicted by graphs 1-3, air temperature does not behave in a well defined manner and forecast lead times cannot be too long. It was discovered that lead time of 2 hours was sufficient in most cases and occasionally this could be extented on a stable day. However, on an unstable day, local variations change at a much faster rate and the model was found to be in error for longer lead times. In such situations, the model needs to be executed every half an hour with any drastic divergence from the current forecast corrected to incorporate the new developments.

6.6.2 Air humidity

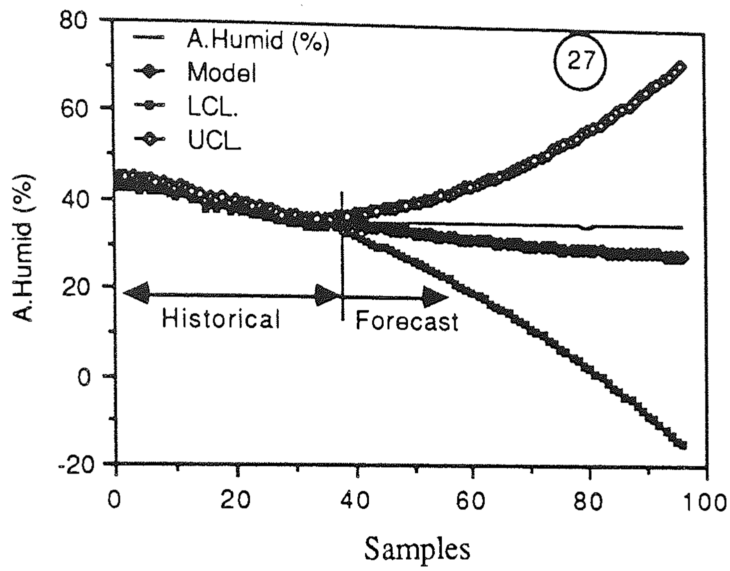
The air humidity profile of 21st April 1989 provided a reasonable variation for its selection for initial trials. The ACF plots of this series indicated a nonstationary behaviour in the process. Differencing the series reduced it to almost white noise, without any ARMA parameters indicating a tentative ARIMA (0,1,0) model. Differencing the series twice showed a first order MA parameter. The two tentative models will be analysed to determine the correct model.

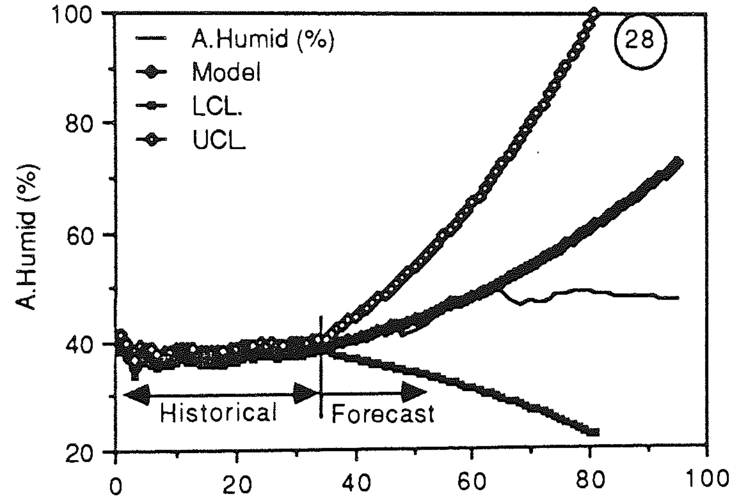
The estimation results of the two models for the same time periods as section 6.6.1 are depicted by graphs 25-28. An initial visual inspection shows the ARIMA (0,2,1) model tracking the actual data in the forecast region better than ARIMA (0,1,0) model. Table 6.2 depicts the best-fit model statistics for both of the tentative models. It can be seen from the statistical tests that an ARIMA (0,2,1) model performs well on all the best-fit test criterion.

Applying the same procedure as section 6.6.1 to determine the best model for nowcasting, showed that the ARIMA (0,2,1) model performed well and was confirmed by the best-fit statistic criteria. Validating the model by historical data confirmed that the model performed well. It can be concluded from graphs 4-6 that air humidity does not follow the same pattern as air temperature; nevertheless, it can change within a short period of time by the arrival of moist air. The model should then be executed on the same lines as air temperature of every half hour to ensure the integrity of the previous forecast.



ARIMA (0,2,1)





Air humidity			
Period	Statistical tests	ARIMA (0,1,1)	ARIMA (0,2,1)
12:00 - 5:00 pm	ASOS	6.49	5.87
	AIC	44.2	38.8
	SBC	47.3	40.4
	RV	0.183	0.173
	MA1	-	0.9998
	CONSTANT	0.0023	-0.223
9:00pm - 2:00am	ASOS	12.5	1.53
	AIC	67.2	63.8
	SBC	70.3	65.4
	RV	0.341	0.335
	MA1	-	0.9998
	CONSTANT	0.0113	0.0061

Table 6.2 best-fit model results for air humidity

6.6.3 Air pressure

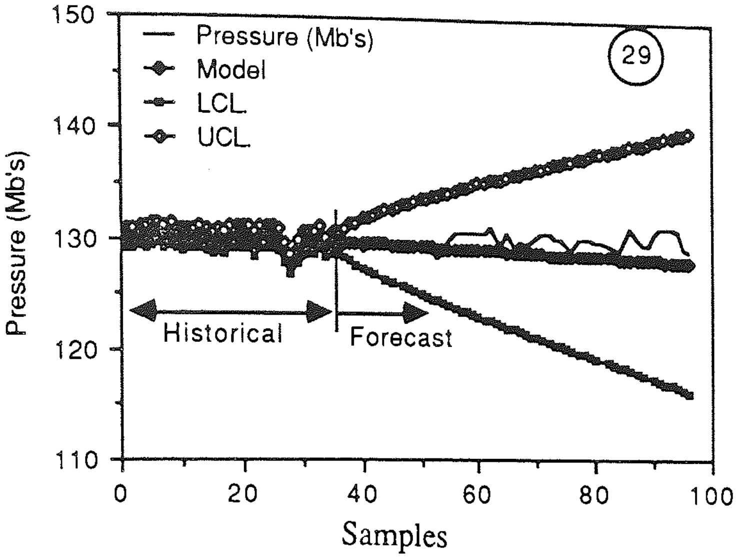
The pressure at a site does not obey any diurnal variation and shows no distinct pattern. The air pressure profile of 5th May 1989 was selected for initial modelling. Its ACF plots indicated a nonstationary behaviour in the process. Differencing the air pressure series reduced the ACF plots to white noise indicating the ARIMA (0,1,0) model. Differencing the series twice failed to indicate any ARMA parameters.

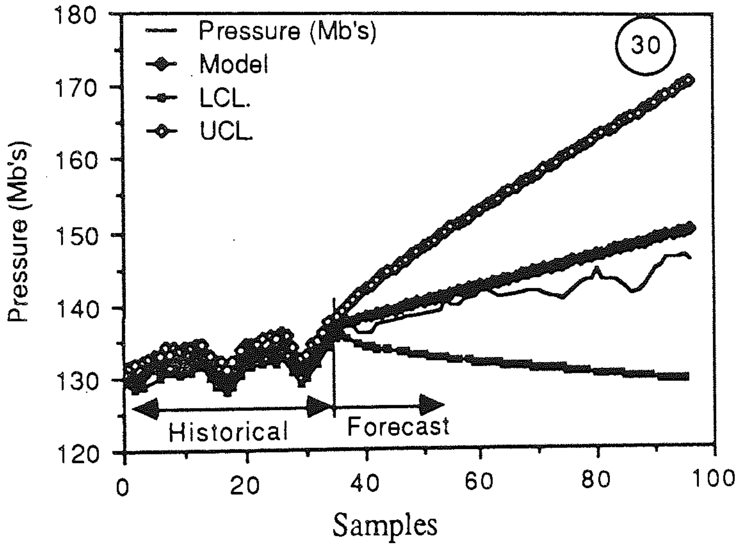
The estimation results of the ARIMA (0,1,0) model for the time periods of section 6.6.1 are depicted by graphs 29,30. It is evident that the model tracks the actual data well during the forecast region. Table 6.3 depicts the best-fit model statistics for the tentative model. From the statistical tests it can be seen that an ARIMA (0,1,0) model performs well on the data.

Applying the same procedure as section 6.6.1 in determining the correct model for nowcasting revealed that the ARIMA (0,1,0) model performed well on the data analysed using the best-fit statistical criteria.

The samples depicted by graphs 7-9 highlight its variation at a given site. Although the selected data profiles indicate that forecasts of longer lead times are possible with this atmospheric element, nevertheless, it can change rapidly by the arrival of a frontal system over a short-period of time. The common strategy of executing the model every half an hour must be adhered with the integrity of the previous forecast varified for forecast lead times of 2 hours.

ARIMA (0,1,0)





Air pressure		
Period	Statistical tests	ARIMA (0,1,0)
12:00 - 5:00 pm	ASOS	6.95
	AIC	44.7
	SBC	46.3
	RV	0.204
	MA1	-
	CONSTANT	-0.026
9:00pm - 2:00am	ASOS	8.34
	AIC	35.6
	SBC	36.9
	RV	0.41
	MA1	-
	CONSTANT	0.214

Table 6.3 best-fit model results for air pressure

6.6.4 Wind speed

It is evident from graphs 10-12 that this atmospheric element along with wind direction show greater fluctuations than the other elements. There is no clear indication of what future value the process will take. Box and Jenkins[58] stated that a series showing such random fluctuations should be subjected to logarithmic transformation.

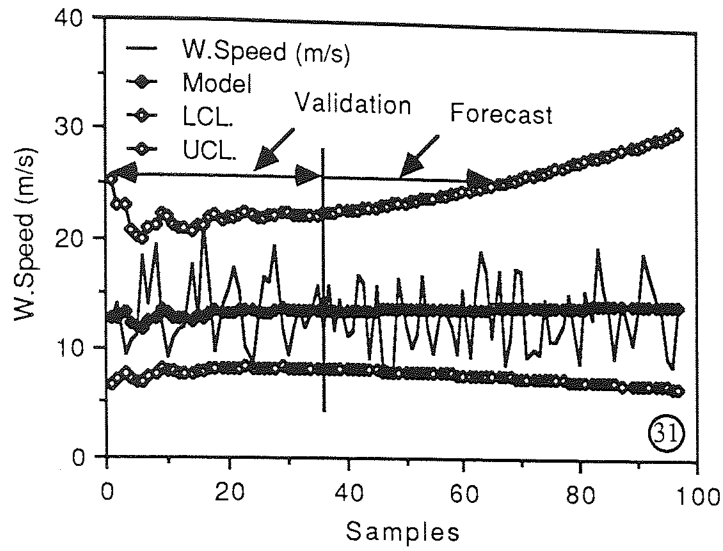
The ACF plot of 20th March 1989 indicated a nonstationary process. Differencing the series showed a first order MA parameter in the ACF and PACF plots. Further differencing failed to improve on the tentative ARIMA (0,1,1) model.

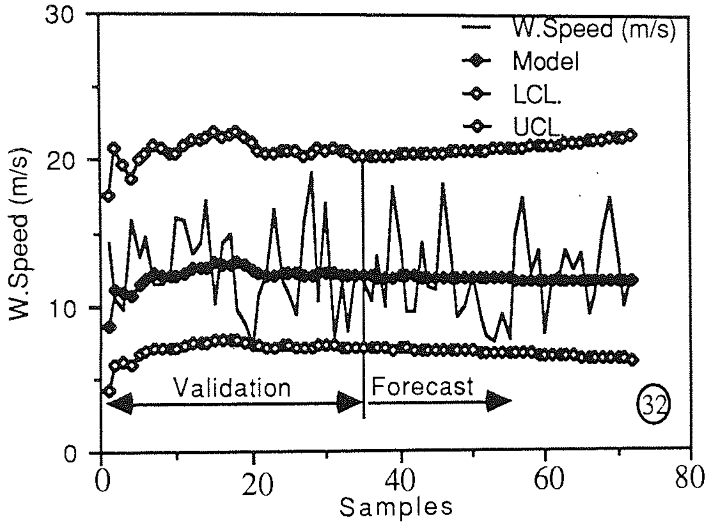
In estimating the ARIMA (0,1,1) revealed considerably large values of best-fit statistical tests. The residual variance plot of the ARIMA (0,1,1) model was similar to the series ACF plot indicating that the process's residual was not reduced to white noise and the model was inadequate. The ARIMA (0,1,1) model was subjected to logarithmic transformation with the results from both of the trials depicted in table 6.4. The best-fit statistical tests show the affect of log transformation. Graphical results from estimation for the time periods of section 6.6.1 are depicted by graphs 31-32, it is evident from visual inspection of these graphs that the model tracks the series mean level within the forecast region.

Diagnosing the tentative model by plotting its residual variance showed the plot as randomly distributed white noise validating the ARIMA (0,1,1) model with log transformation as the correct model.

Applying the procedures of section 6.6.1 on historical data confirmed that ARIMA (0,1,1) model with log transformation performed well for this element.

The best forcasts achievable for this atmospheric element are those of its mean variation and the model tracks this quite well. The common strategy of executing the model every half an hour should be followed.





Wind speed			
Period	Statistical tests	ARIMA (0,1,1)	ARIMA (0,1,1) log.
12:00 - 5:00 pm	ASOS	27684.8	0.47
	AIC	336.9	-47.5
	SBC	340.1	-44.4
	RV	822.1	0.014
	MA1	0.712	0.726
	CONSTANT	-2.10	-0.0082
9:00pm - 2:00am	ASOS	10637.4	0.143
	AIC	310.9	-92.9
	SBC	314.2	89.8
	RV	283.1	0.0038
	MA1	0.9999	0.9998
	CONSTANT	-0.338	-0.0012

Table 6.4 best-fit model results for wind speed

6.6.5 Wind direction

It is evident from graphs 13-15 that fluctuations of this atmospheric element is not as drastic as wind speed, nevertheless, it does fluctuate more than any other element but shows some trend in its variation.

The ACF plot for 14th February, 1989 indicated nonstationary behaviour in the process. Diffencing the series revealed a first order MA parameter in the ACF and PACF plots to give a tentative ARIMA (0,1,1) model. Further diffencing failed to improve the tentative model.

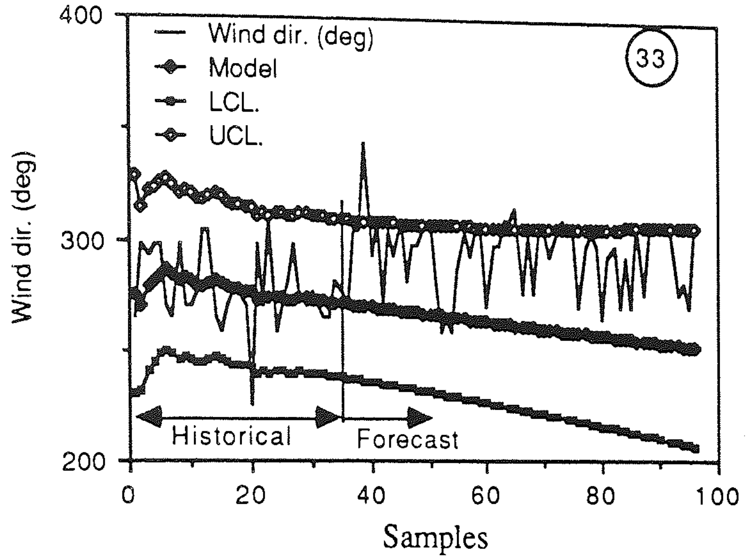
Estimating the ARIMA (0,1,1) revealed considerably large values of best-fit statistical tests. The residual variance plot of the ARIMA (0,1,1) model failed to reduce it to white noise indicating that the model was inadequate. The ARIMA (0,1,1) model was subjected to logarithmic transformation with the results from both of the trials depicted in table 6.4. The best-fit statistical tests show the affect of log transformation.

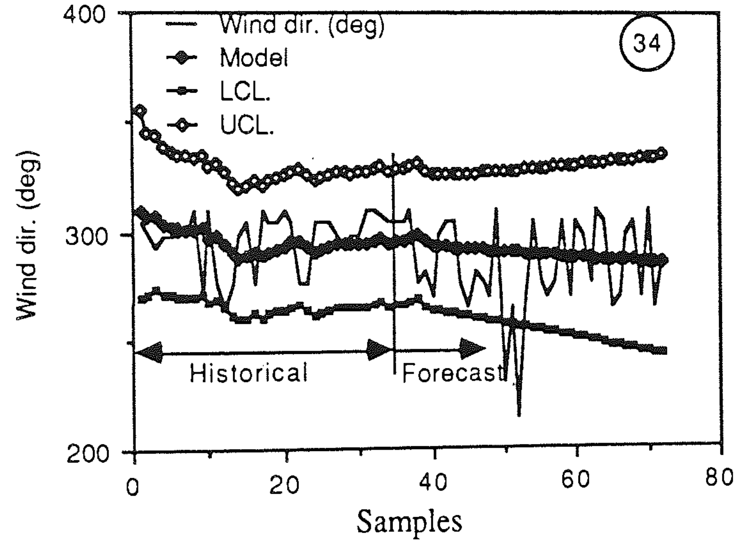
The results for the time periods of section 6.6.1 are depicted by graphs 33-34, it is evident from visual inspection that the model tracks the series mean level within the forecast region as is the case with wind speed.

Applying the procedures of section 6.6.1 on historical data in validating the ARIMA (0,1,1) model with log transformation confirmed it to be the correct model.

The best forcasts achievable for this atmospheric element are those of its mean variation and the model tracks this quite well. The common strategy of executing the model every half an hour should be followed.

ARIMA (0,1,1) log.





Wind direction			
Period	Statistical tests	ARIMA (0,1,1)	ARIMA (0,1,1) log.
12:00 - 5:00 pm	ASOS	1098.2	1.78
	AIC	223.9	-0.89
	SBC	227.1	2.21
	RV	30.05	0.049
	MA1	0.9996	0.9999
	CONSTANT	0.1519	0.0055
9:00pm - 2:00am	ASOS	1597.8	2.09
	AIC	242.7	3.75
	SBC	245.9	6.91
	RV	42.5	0.056
	MA1	0.9996	0.9999
	CONSTANT	0.0224	0.001

Table 6.5 best-fit model results for wind direction

6.6.7 GLNS data presentation

Extensive literature search revealed a lack in facilities for simple presentation of atmospheric data for visual interpretation which can be of use to forecasters (particularly at outerstations) and other parties interested in its dynamic variation. Considerable effort in this research has been directed towards the presentation of data in simple formats.

Working in this area was considered ideal for final year undergradute student projects, in particular the development of software tools for integrating into the real-time nowcasting system. These projects served two fold purposes: they provide an important practical exercise for the student in making a contribution as group members to an on-going project; similar to an industrial environment, and they also, provide tools for enhancing the real-time nowcasting system. These projects were closely monitored with regular discussions by all involved to provide an opportunity for members of the group to make their contribution.

The following sections details two such projects in the presentation of GLNS data.

6.6.7.1 Weather nowcast graphical display[63]

This software tool enables the nowcast system to present GLNS data in symbolic form that can easily be appreciated by non weather experts. The interactive display screen is divided into current transducer(s) value and the model forecast. Since all the transducer symbols could not be incorporated on a single display screen, the tool presents these as two screens which are switched by user defined intervals. As new data enters the system, previous values are updated.

6.6.7.2 Weather window graphics[64]

The software tool enables the nowcast system to present the GLNS data in graph form. The interactive screen is divided into user defined windows. Each window displays the past-to-present GLNS data for visual appreciation. Additional facility includes overlaying the output from the model with the actual outcome of each transducer to look at forecast integrity. This facility is user-selectable and can be switched off easily to display just the transducer values. A front end menu allows the user to select the options available, such as the number of transducers required for display (from 1 to 9) on a single screen. This tool can be executed continuously, and updates the display as new data enters the system.

6.8 Conclusion

The physical behaviour of the atmosphere is quite complex. Attempts at modelling the atmosphere as 3 dimensional space is carried out by the meteorolgical community throughout the world. These numerical models are complex in themselves and are implemented on large scale computer systems (CRAY, CYBER). These models represent the atmosphere on global and national scale and are executed at set times. On the national scale, forecasts from the model are distributed to a network (outerstations) of centres for local forecasting. The time scale of these forecasts are such that variations at a locality can persist without their detection.

Such local variations can be monitotred continuously using a simple on-site low cost real-time nowcasting system with their development reported in real-time. It has been shown in this research that variation in local atmospheric elements lend themselves to simple stochastic modelling for the derivation of nowcasts; being statements of local atmospheric elements and their short term (2 hours) forecasts. These models need to be executed at half hour intervals with any marked developments in the elements to their previous forecast being updated. The forecast lead time for each element was decided on the limit of error tolerable for the sensors invloved (e..g. 0.5 ^{o}C in the case of temperature sensors).

The univariate stochastic models derived for each atmospheric element assumes that they are a seperate entity without any interaction between them. In practice, interaction between atmospheric elements exists. The next stage of research would be to construct multivariate models for individual elements. Box and Jenkins[58] describe these as multifunction models and point out that their determination is more an art then science.

Considerable effort has been directed towards the presentation of atmospheric data in simple form for appreciation by both weather and non weather experts.

Chapter 7

7.0 Satellite image analysis for nowcasting

7.1 Introduction

The impact of geosynchronous satellites in the field of meteorology is often reported in the literature . The ability to observe weather features in remote regions which were previously void of observations have extended the capabilities of national weather forecasting offices throughout the world.

The real-time information presented in a form of multi-spectral images provides a forecaster not only with the overhead view of these amorphous cloud formations in the vicinity of interest but also enables him to view cloud formations on a global scale.

Extracting of information from these multi-spectral images for the purpose of weather forecasting in the main involves: identifying cloudy regions within the most recent image, associating the types of cloud present (cloud classification) and determining their individual motions (cloud motion vectors), and associating signatures such as raining and nonraining to enable their evolution to be predicted.

In manual operation, a trained meteorologist can view animated images to observe any development or decay in these clouds and their motions, to include in his forecast. Automating the procedure of extracting this information from multi-spectral images using computer algorithms is a non-trivial problem as these amorphous clouds evolve and are subjected to movement, growth, distortion, bifurcation, superposition (multi-layer clouds) or elimination.

Several objective techniques for extracting cloud information using computer algorithms from sucessive images have been proposed in the literature. Investigation indicated that extracting information automatically from satellite images split in to three distinct areas- 1) extracting wind motion vectors for clouds, 2) their classification, and 3) extracting rainfall information from them. Several techniques have been proposed for each category, each with certain pitfalls and with varying degrees of success. These techniques were individually analysed to select those worthy of further investigation for nowcasting.

It must be pointed out that previous research efforts have been directed towards analysing images for synoptic scale forecasting; which necessarily demand analysis of data covering large areas for which satellites with their wide aeriel coverage are well suited. Analysing this copious raw real-time data is a computationally intensive exercise requiring supercomputers. The images are analysed at synoptic times daily by national weather forecasting offices. The original research proposed here shows that multi-spectral image analysis for nowcasting does not require exceptional computing power and can be met by a modern, desk-top system.

Analysing multi-spectral images for nowcasting differs from those reported in the literature; where a weather feature is identified and tracked towards the vicinity of interest (normally for the whole country). The techniques for extracting cloud information automatically rely on the presence or identification of a weather feature. The novel approach presented for nowcasting relies on no previous conception of a weather feature being present on a global or country scale, only weather features present within the area of interest are of concern to the locality and need to be reported. For nowcasting, the area of interest is defined as depicted by Figure 7.1. The inner zone (black square) typically represents a square with side 20 km. (approx.) representing the local area. The next zone is a square with side 50 km. (approx.) which will contain weather features likely to become local weather within the next 30 minutes; the outer zone is a square with side 250 km. (approx.) and contains weather features which will become the local weather; or which will influence the local weather, within the next 3 hours. There is no attempt to identify global weather features or even the rest of the country.

The rest of this chapter concentrates on extracting cloud information from the real-time multi-spectral images captured by the real-time nowcast system from the METEOSAT 4 geo-stationary satellite.

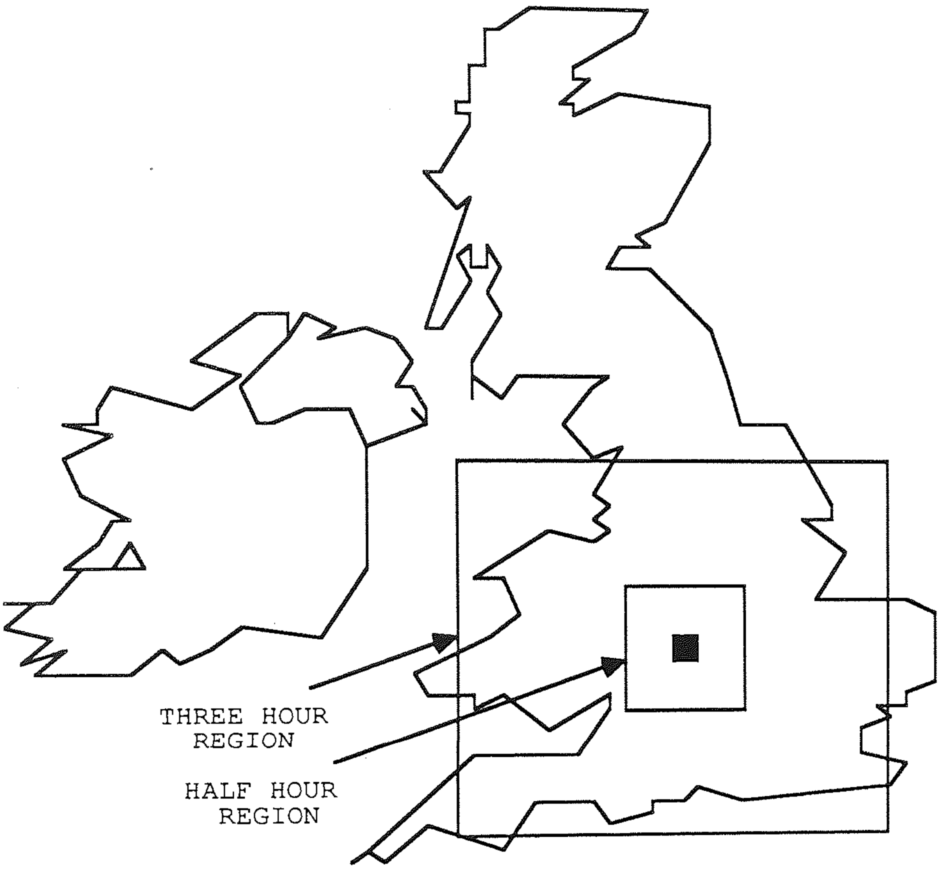


Figure 7.1 Highlights area for nowcasting

7.2 Image preparation

The incoming multi-spectral images are captured by the real-time nowcast system and mapped on to the image processing display screen. These images show weather features that can be appreciated visually by experts and non-experts alike. However, these images cannot be immediately analysed using computer algorithms as they are not in the form for direct analysis. Spurious information such as coastal lines help to identify geographical locations but need to be removed prior to any processing. The visible images being higher resolution are transmitted over two frames giving the same view as an infrared image with United Kingdom split between two frames, this require a digital cut-and-paste. The incoming raw image is not corrected for Earth's curvature and needs to be geometrically transformed.

Considerable computational effort must be expanded towards preparing the image prior to any processing using computer algorithms.

7.2.1 Image reconstruction

High resolution visible images {chapter 5} representing the same aeriel view as the infrared images are transmitted over two seperate frames CO2 and CO3 (two images). The split in the overall view is along the 0^{o} longitude line which effectively splits U.K. with Norfolk and East Anglia being transmitted in the CO3 frame. As this forms part of the nowcast region, the two frames must be captured and the image covering the U.K. reconstructed. The digital cut-and-paste is carried out by using the flexibility of the PCVISIONplus board. The board is configured to its full capacity of 1024 * 512, and the two consequtively received images representing the same view as infrared are mapped on to the board as a single image; effectively forming a single 1024 * 512 image. The central 512 * 512 pixels of the image are extracted and stored as the composite or constructed image. The visible images depicted by plates 5.2 and 5.3 in chapter 5 are constructed to form the composite image depicted by plate 7.1.

7.2.2 Removal of spurious information

The captured multi-spectral images have superimposed coast-lines which are added by the METEOSAT groundstation control centre as a visual aid for geographical locations. Unfortuanatly, their presence distort subsequent image processing and they must be removed. The coast-lines are removed by sliding a 3*3 window using a median filter.The coast-lines are superimposed with higher intensities then the reflectivity information from the sensors and can be treated as spurious noise.The

Plate 7.1 Visible C02 & C03 formats reconstructed to form a composite image

median filter regards them as noise and supresses them. This filtering operation also removes any extreme variations within the sliding window and acts as a deterrent for any transmission noise that may be embedded within the received signal and consequently removes it. The filter is not without side effects since it tends to degrade the natural extreme variations within the image. There was no visual depreciation of the received images after the implementation of this filtering operation. Plate 7.2 depicts an infrared image with coast-lines removed.

7.2.3 Image enhancement

Image enhancement consists of a collection of techniques[65] that seek to improve the visual appearance of an image, or to convert the image to a form better suited for computer analysis.

The grey-scale satellite images captured by the real-time nowcast system can be represented with pixel intensities between 0-255. However, the actual image received tends to cover the dynamic range between 80-220 (predominantly) and needs to be stretched to occupy

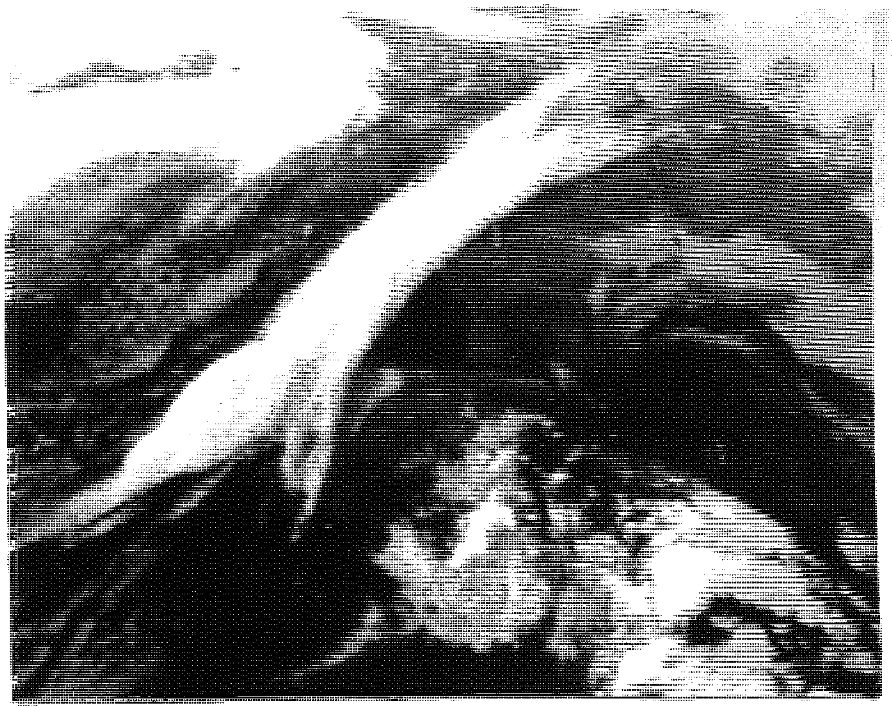


Plate 7.2 Infrared image with coastal lines removed

the full range. The histogram equalization technique[65] is applied to the dynamic image for enhancement. This has the effect of linearly stretching the dynamic range of the image from the 80-220 to 0-255.This has two fold advantages: the stretched image has tendency to show well defined cloud features for visual appreciation, and in turn eases motion vector identification. The adverse affect of stretching an image is that it corrupts the original reflectivity information and as such cannot be used in cloud classification; where clouds are classified according to their reflectivity given by the multi-spectral images. Plate 7.3 depicts an infrared image that has been stretched.

7.2.4 Geometric transformation

The multi-spectral images received from METEOSAT 4 are in raw form without any corrections for the Earth's curvature. The satellite simply views the Earth from a distance of 35,900 km. and presents reflectivity of its sensors in imagery form. In the accurate determination of cloud motion vectors, it is necessary to remove the curvature of the Earth in the received images.

Several geometric transformation (map projection) techniques are reported[66] that

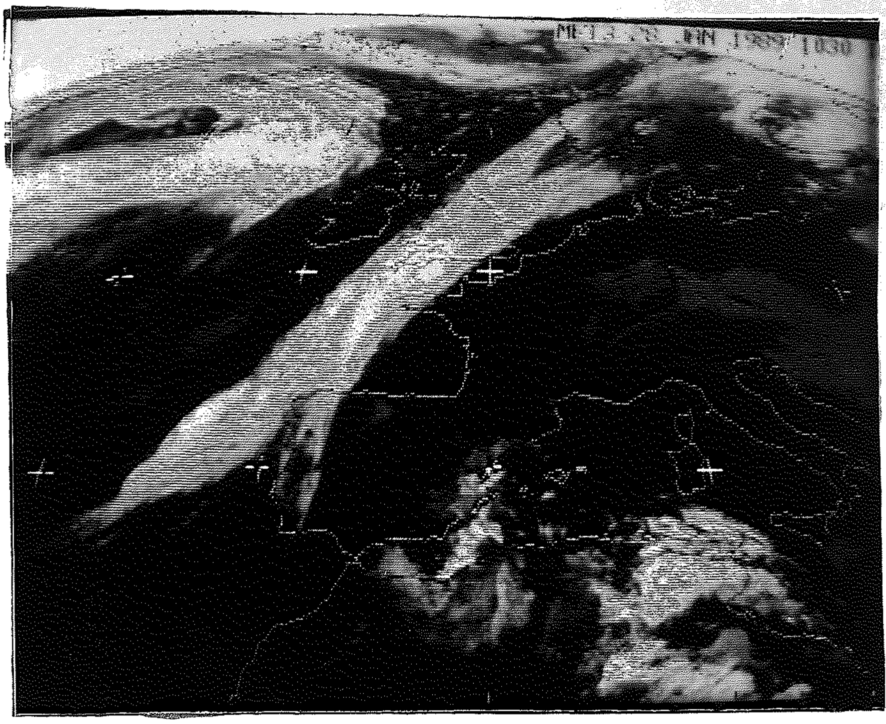


Plate 7.3 Infrared image enhanced using histogram equalization

stretch the Earth from a sphere to a flat plane. These projections deform the corrected area to some extent, and different map projections distort the area of interest in different ways. The way maps are distorted is used to classify the type of projections[66].

The Transverse Mercator map projection is favoured for land masses that extend predominantly North to South, such as Great Britain. The technique has previously been implemented[67] on ATS satellite images and was selected for implementation on the real-time nowcast system.

The implementation of the Transverse Mercator algorithm which is basically an output-to-input pixel mapping posed a classical problem for setting as a final year undergraduate project. This was assigned to a student and details of its implementation can be found in the technical report[68].

The area of interest (U.K.) is projected using this technique. Unfortunately, this is a computationally intensive task for implementation on a small desk-top real-time nowcast system without an additional co-processor. The initial software without any optimsation took 4 hours to transform the image. This was operationally impractical, bearing in mind that a new image is available every 30 minutes. Optimisation, using fixed point arithmetic and extensive look-up tables reduced the processing time to 6 minutes.

Although geometric transformation is vital in synoptic-scale, global forecasting, for a nowcast concerned with a small area of interest, the distortion across the image is small (no more than 5 percent in this work). It has been decided to ignore the effect at this stage. However, a software tool is available within the real-time nowcast system for removing Earth curvature from satellite images. Plate 7.4 depicts an infrared image projected using Transverse Mercator algorithm.

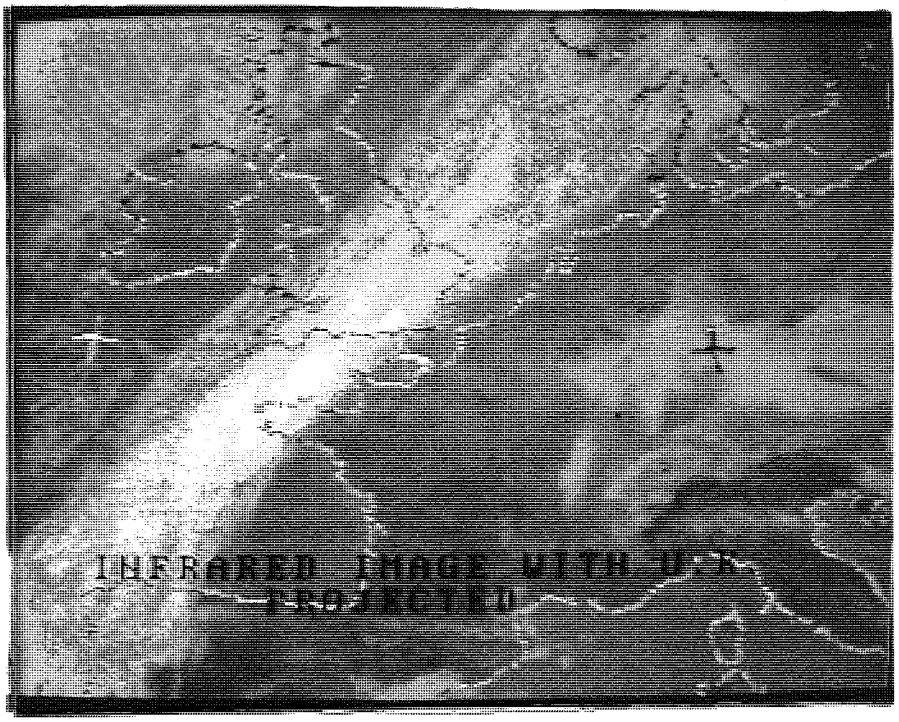


Plate 7.4 Infrared image geometrically projected

7.2.5 National grid overlay[69]

The multi-spectral images received from the METEOSAT 4 geo-stationary satellite have coast-lines added to highlight geographical locations on country bases without any internal references. For the real-time nowcast system, it was considered essential to provide a facility for dividing the image in to a set of known regions; where the real-time nowcast system will be able to highlight regions of interest on the monitor screen. This is provided by superimposing the national grid on the image.

The software tool is menu driven and interacts with the user for input to superimpose the national grid on a set of standard reference points taking into account the curvature of the Earth and the relative position of the geo-stationary satellite. Additional features include options for highlighting other major sites (cities and oil rigs in the North sea) on the image, and positioning grid with expanding and rotational capabilities.

7.2.6 Standard image processing

Although standard image processing algorithms such as : filtering, edge detection, image enhancement, degredation, bit-slicing, power spectrum analysis, etc. are implemented on the real-time nowcast system for direct application to the received dynamical satellite images, very rarely are these directly applicable for extracting information for nowcasting. In an interactive mode, such facilities can be used to manipulate the received images for highlighting certain features contained in the multi-spectral data or enhancing (density slicing, contrast stretching, etc.) for visual appreciation.

The availability of these standard algorithms on the real-time nowcast system increases the capabilites of the system to process images other than those received direct by the system from METEOSAT 4. The real-time nowcast system forming a test-bed for continuing research into image processing.

7.3 Automatic extraction of cloud motion vectors

The ability to determine cloud motion vectors from geo-stationary satellite images was first demonstrated with 'loop movies' by Fujita[70] shortly after this kind of information became available. It became clear that sequence of images can be used to extract direction and speed of cloud motions. The National Environment Satellite Centre conducted an operation experiment (1969) to determine cloud motion vectors manually from a sequence of ATS-I pictures. The cloud motion vectors were determined by viewing the loop movies and fixing the position of cloud elements at the beginning and end of the picture sequences. This proved a tedious exercise and it became clear at the outset of the need to duplicate these manual procedures by computer methods.

Several researchers(71,72,73,74,75) have proposed algorithms to process the raw satellite data for extracting cloud motion vectors. The data used in their experiments ranged from photographs to digital images received from geo-stationary satellites. The concept behind all the algorithms is the same: identify a cloud element within an image at one time and find its match in subsequent images. Complexities arise in finding matches between subsequent images as clouds are subjected to movement, growth, decay, bifurcation or superposition. In manual operation, an operator can detect these dynamic changes and is able to incorporate them in his decision making process. However, it is very difficult to detect these changes using computer algorithms. These techniques are all based on persistance (movement without changes). This limits their practical usefulness to short-term predictions; which is the task of the real-time nowcast system. Due to these changes perfect match is rarely possible and the algorithms seek to find the best match.

Wolf et.al[73], Endlich(71,76) have developed and improved their technique of automatic cloud motion vector extraction based on image recognition; similar to how a human recognises changes. Their algortihm initially searches for targets within the satellite image and identifies them as brightness centres that could be tracked as a function of time. These brightness centres are then matched in the subsequent images. Muench[74] proposed a binary covariance technique, which reduces the satellite images to binary values and computes covariance using logical arithmetic. Leese et. al.[72] proposed their technique based on cross correlation; where the cross correlation coefficient represents a measure of the relationship between the members in two sets of quantities. The latter technique has been implemented in various forms by many organisations (ESA, NESS, etc.). The technique has also been used by many researchers as a reference to test against their proposed techniques. The cross correlation technique was selected for further investigation for nowcasting.

7.3.1 Cross correlation

Cross correlation is a measure of similarity between two signals and can be calculated by shifting one signal with respect to the other. The test integral for calculating cross correlation of two continuous signals is given by :

$$R_{12}(\tau) = \int^{+\infty} f_1(t) * f_2(t + \tau)\, dt. \quad \text{-------} \; 7.1$$

where τ is a 'searching' or scanning parameter. Equation 7.1 expresses cross correlation of one dimensional signals. Similar expressions hold for two dimensions. If $f_1(x,y)$ and $f_2(x,y)$ are functions of continuous variables, their cross correlation is defined as follows:

$$R_{12}(m,n) = \int\int^{+\infty} f_1(\alpha, \beta) * f_2(x+\alpha), (y+\beta) \quad \text{--------} \; 7.2$$

The discrete equivalent for equation 7.2 is:

$$R_{12}(m,n) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f_1(x,y) * f_2(x+m, y+n) \quad \text{--------} \; 7.3$$

In digital image processing, the principle application of cross correlation is in the area of template matching, where the problem is to find the closest match for a given template over a predefined image (search window) region. One approach to this problem is to compute the cross correlation coefficient between the two images. The closest match can then be found by selecting the image area (within the search window) that yields the cross correlation coefficient with the largest value.

Given the region W(x,y) of size M*N on the satellite image at time t_1, determine if it contains a region which is similar to some template T(x,y) of size J*K of the satellite image at time t_0, where J<M and K<N. For any value of (m,n) inside W(x,y) as depicted by Figure 7.2, equation 7.3 is applied to compute one value of R. As m and n are varied, the template T(x,y) is scanned across the search window and a cross correlation coefficient R(m,n) is obtained. The maximum value of R(m,n) then indicates the position where T(x,y) best matched W(x,y).

Introduction of a normalisation factor in the denominator has a tendency to sharpen the peaks of R(m,n). The normalised cross correlation has a maximum value of unity that occurs if and only if the image function under the template exactly matches the template. Equation 7.4 expresses the normalised cross correlation function.

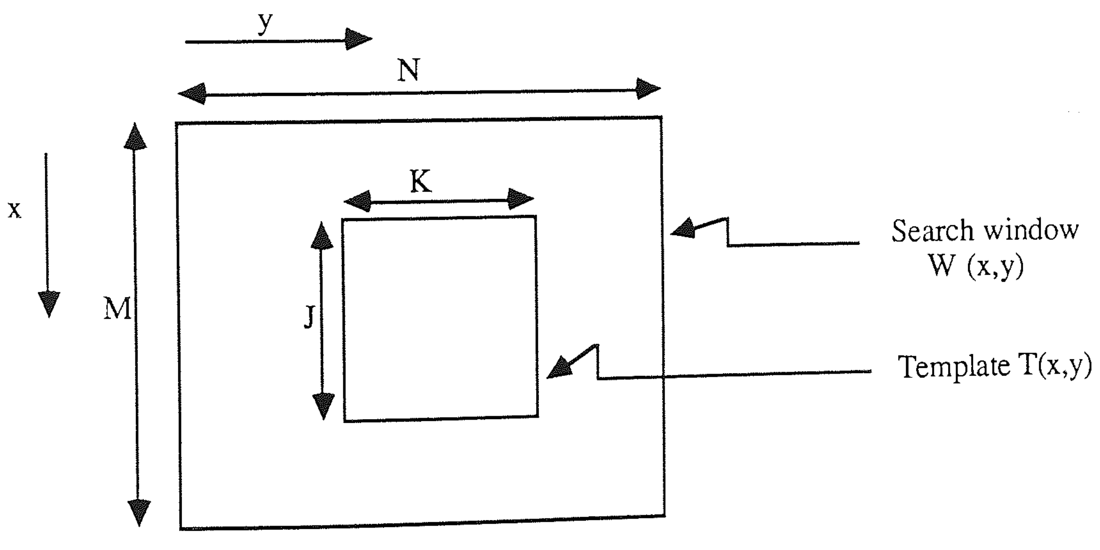


Figure 7.2 Search and template for cross correlation

$$R(m,n) = \frac{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} W(x,y) * T(x+m, y+n)}{\left[\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} W^2(x,y)\right]^{1/2}\left[\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} T^2(x+m, y+n)\right]^{1/2}} \qquad \text{------- 7.4}$$

The computation of cross correlation is effeciently carried out in the frequency domain using an FFT[77] algorithm to obtain the forward and reverse transforms.

The algorithm for computing cross correlation is :

(1) Compute the Fourier Transform for W(x,y) and T(x,y) to obtain W(u,v) and T(u,v) in the frequency domain.

(2) Compute $R(u,v) = W(u,v) * T^*(u,v)$, where * represent complex conjugate.

(3) Perform an inverse transform on R(u,v).

(4) Divide by the normalisation factor to obtain cross correlation matrix.

(5) Search for the highest cross correlation coefficient to compute cloud motion vector.

This algorithm has been implemented on the real-time nowcast system.

7.3.2 Extracting cloud motion vectors

The infrared images are selected for extracting cloud motion vectors due to their availability over day and night.

The initial template size selected for computing cloud motion vectors from METEOSAT geo-stationary satellite was a 10*10 pixel array. The search window must be selected to ensure that the template image is contained within it. This can simply be determined as follows :

1 pixel = 5 km. = 3.12 miles.

10 pixels = 50 km. = 31.2 miles.

Each sequence of image 30 minutes apart.

A displacement of 10 pixels corresponds to a movement of 62.14 miles or 124.3 m.p.h.

A displacement of 10 pixels within the subsequent image was sufficient to cater for most weather features. As the direction of the clouds are unknown; search must be conducted in all possible directions. The search array size must cope with 10 pixel displacement away from the template's initial position in all directions. The search window to cope with this is a 30*30 pixel array.

The overall array size (S) for cross correlation must be such that S >= K+N+1 (see Figure 7.2) and of power of 2[74]. The two arrays for cross correlation are 64*64 pixels with appending zeros.

The software tool for extracting cloud motion vectors was tested on synthetic samples to check for its correct operation and any problems removed.

7.3.2.1 Results of cloud motion vectors

Several sequences of images corresponding to differing weather situations were selected for extracting cloud motion vectors for nowcasting.

The initial tests were conducted on the received uncompressed images and the results failed to highlight a distinct single peak corresponding to a template match in the subsequent image's search window as was expected. Instead, numerous peaks were found. This was due to similarities with the template as it was scanned over the search window. Even with prior knowledge of cloud motion, it was impossible to decide from the cross correlation matrix which of the so many peaks corresponded to the particular cloud movement. It would be impractible to use a computer algorithm to select it.

The images were then subjected to various form of degradation (dilating, contrast stretching, manual thresholding) but failed to solve the problem satisfactorily such that a computer algorithm can detect a single peak within the cross correlation matrix to compute cloud motion vectors.

Simple texture and gradient measures {see section 7.4.2} of the arrays prior to computing their cross correlation failed to improve on the previous results. Several permutations of the above tests with texture and gradient were tried without much success.

The problem lies primarily in the nature of the weather which affects the United

Kingdom. A typical frontal system with horizontal extent in excess of 100 km, and generally being too smooth (with too small a dynamic range or grey scale values within a weather feature) and may also change size, distort, break-up, superimpose or be eliminated between images (convective showers). Furthermore, as the satellite is limited to a single view of reflectivity, multilayer clouds with their differing motions upset the cross correlation algorithm, adding complexity to finding a best match between subsequent images.

Previous publications have indicated some of these difficulties and offered some solutions by selecting single targets[73,76] to track their movement or using the techniques interactively[78]. Additional difficulties are presented with the approach for nowcasting, where weather feature within the area of interest is of immediate concern for extracting information and its future evolution, and other weather systems outside the area of interest can be ignored.

Plates 7.5 and 7.6 depict two differing weather features. In plate 7.5, multilayer clouds are shown over the area of interest. Animation of this sequence showed the brighter cloud region remaining stationary and increasing in its extent while a lower level cloud with very light precipitation is moving in the N-E direction. In plate 7.6, a high cloud prevailed with its extent over several kilometers. This is a single layer homogeneous cloud highlighting the difficulty of cross correlating small template to detect a peak. Increasing the template size to 32*32 pixels and computing the cross correlation coefficient for plate 7.6 provided a single peak (cross correlation coefficient of 0.97) with S-E direction and speed of 9.96 m.p.h.. However, such distinct weather features rarely occur and their extent is variable so a fixed template size cannot be set.

Cloud motion vectors using cross correlation can be obtained interactively by changing the template size to cater for the extent of the amorphous clouds; differing weather situations requiring differing template sizes. One drawback is that as array size increases, this also increases computation time.

Plate 7.5 Infrared image showing multilayer clouds

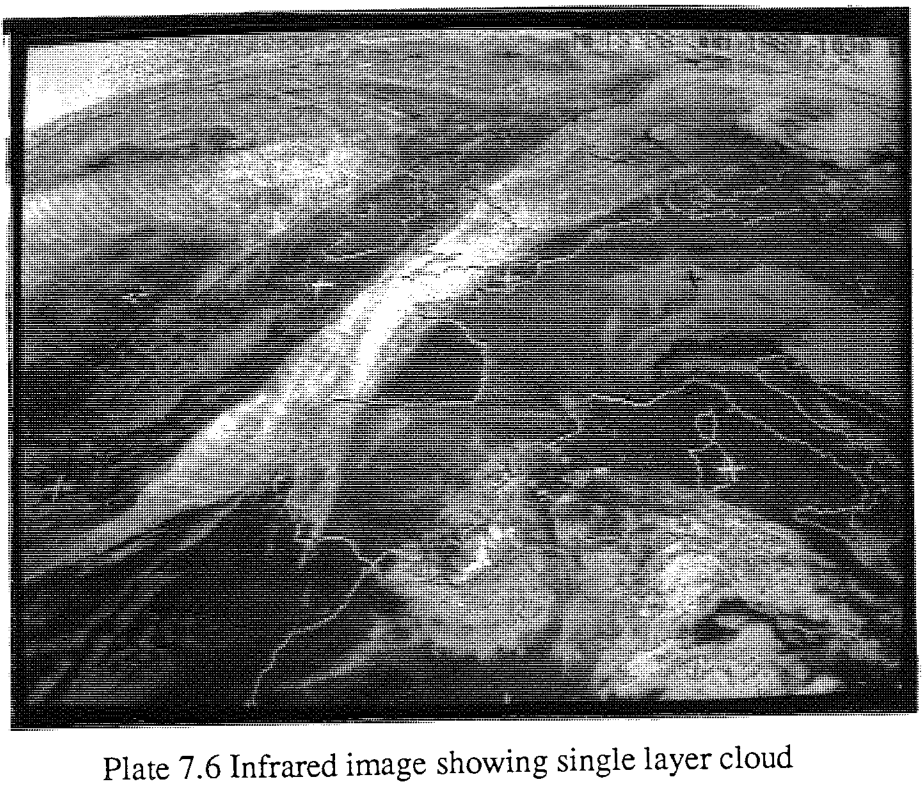


Plate 7.6 Infrared image showing single layer cloud

The most promising method for further investigation is based on correlation after segmentation. As classication {section 7.4} leads to the identification of upto 4 layers of clouds within the area of interest, thresholding based on the identified layers could result in individual layer being tracked seperately. This remains an area of future work.

7.4 Cloud classification

The automation of cloud classification from satellite images using computer algorithms is an important component for meteorological and hydrological organisations, which require estimates of parameters such as solar radiation, rainfall, moisture, and sea-surface temperature. Although a trained meteorologist can visually interpret some of the information from these multi-spectral band images, extracting this information using computer algorithms is exceedingly complex. Many contributory factors[79] are involved which make the interpretation using computer algorithms difficult.

Several researchers[(80,81,82)] have proposed differing techniques for classifying clouds automatically. In the main, classification is based on the detection and recognition of one or more objects or patterns within a window. In cloud classification, the information is dynamic without distinct shape or pattern. All the techniques proposed attempt to segment an image window into appropriate sub-regions (clusters). Segmentation of satellite multi-spectral data ordinarily seeks sub-regions homogeneous with respect to some imagery property such as texture or gray-level. Haralick[83] explain the reasons for and advantages of the clustering approach to multi-spectral analysis. After segmentation, classification of each segment is then based on their reflectivity, texture, peaks, etc.

Desbois et al.[80] proposed an extension to the technique currently in operation by the European Space Agency (ESA)[78], using 2-dimensional histograms of the multi-spectral band images to identify and classify the reflecting sources. They proposed using all three multi-spectral images (infrared, visible and moisture) to construct 3-dimensional histograms to classify differing reflectivity sources. The algorithm is implemented on the Cyber 750. Using an array size of 200*200 takes 55 second to compute. Parikh et al.[81] proposed their technique of classification based on the infrared imagery. They have shown that segmentation of this type of data using standard techniques such as thresholding, edge detection, and region growing proved difficult due to the complex nature of the atmosphere and the resulting amorphous clouds. Their segmentation is an adaptation of the W.D. Fisher clustering algorithm[84]. After sgementation, classification of these clusters is based on the reflectivity of the infrared data and its tonal and texural information using Robert's gradient. The technique is restricted to using only one of the multi-spectral band (infrared) data and classifying cloud catagories as low, mix, or Cumulonimbus. Hawkins[82] proposed a clustering technique for satellite imagery analysis. The technique clusters a window of 16*16 pixels using infrared data. These clusters were then subjected to manual classification, and a relatively comprehensive classification system was proposed giving upto 18 different catagories. The approach adopted by Hawkins[82] concerns categorising individual layers of clouds for local rather then global classification, and this was selected for further investigation for nowcasting.

The classification of METEOSAT geo-stationary satellite data is split in two seperate parts: 1) Segmentation of image data, and 2) classification of the resulting clusters.

7.4.1 Image segmentation using Hawkins[82] algorithm

The object of the automatic clustering algorithm is to separate satellite infrared data into mutually exclusive regions of similar reflective count values. These regions represent cloud layers (including clear areas). The size of the image selected for clustering is a 16*16 pixel array of infrared and a 32*32 pixel array of corresponding visible data. The area of interest for nowcasting can then be incorporated in to approximately 3*3 arrays of the infrared data and the corresponding visible data as depicted by Figure 7.3. Each array of data can be seperately clustered and classified to give regional information. This will necessarily involve loop operations within the classification software. For initial investigation, only a single 16*16 arrray of infrared data and its corresponding visible data was used.

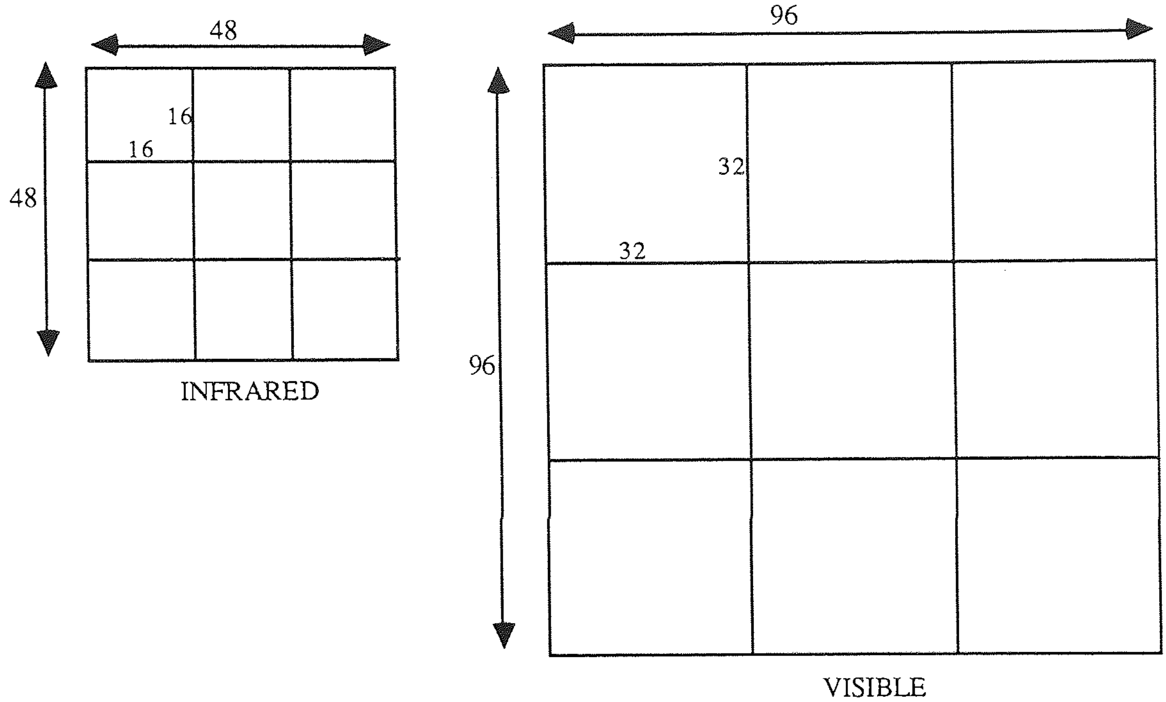


Figure 7.3 Infrared and visible data arrays for area of interest

The clustering operation starts with the sub-division of the 16*16 pixel infrared data into four quadrants of 64 values each. Histograms are obtained for each quadrant of sixteen intervals of this data (each interval representing a band of reflectivity values). These histograms are then transformed into four clusters (or less since upto three can be zero). At each interval transfers are made from quadrants having smaller frequencies to quadrants having a larger frequency. This seperates the infrared data into unique clusters completely consistent with the overall distribution of the whole area.

Hawkins[82] clustering algorithm is essentially sequential and can be expressed as a list of operations as described:

STEP1:

Subscript the infrared array by quadrants.

STEP2:

Set the width of each interval to 10 infrared counts within the range 65 to 205 recognised to include all or nearly all meteorologically significant data. Interval 1 includes the lower counts (0 to 65) and 16 the upper counts (206-255).

STEP3:

For each interval place the sum of all quadrant frequencies into the one having the largest value. If equals exist for "largest", leave for next step.

STEP4:

For those instances with two or more "largest" frequencies, place sum at that interval into quadrant having the largest sum in adjacent intervals.

STEP5:

If any quadrant (cluster) has less than thirteen points (5% of the total coverage) place it in nearest cluster. (note the quadrant data is being transformed into cluster data).

STEP6:

For any cluster consisting of two parts (one or more zero intervals between non-zero frequencies), seperate by putting one in a zero cluster if a zero cluster exists. If not put the one closest to another cluster into that cluster.

STEP7:

Combine close clusters. Clusters consisting of values at only one intervals and having a similar cluster one interval away are combined into one cluster.

STEP8:

Eliminate clusters with less then 13 points (5%). This is used a second time since the separation of multiple clusters could create a small cluster.

STEP9:

Summarise cluster information; histograms of clusters, number of clusters, and count levels which seperate clusters from one another (cut levels being the major results of the clustering algorithm).

The clustering algorithm was implemented on the nowcasting system. The algortihm was subjected to samples representing a wide variety of infrared data to verify the integrity of the software and the clustering algorithm. The following example shows the implementation of the clustering algorithm as applied to plate 7.5 over the inner zone shown by Figure 7.1.

RAW INFRARED DATA

159	157	160	167	159	160	171	176	179	181	191	195	199	199	199	199
160	158	167	171	169	176	183	179	187	195	199	197	200	198	199	195
159	161	167	177	186	185	183	193	196	199	199	203	201	198	195	195
175	179	179	189	193	192	191	196	199	199	196	195	193	198	199	191
176	179	187	195	195	197	202	199	195	195	195	194	189	194	191	187
186	189	192	195	191	195	195	194	195	195	191	191	185	187	182	179
190	193	195	195	195	197	196	191	189	183	191	188	187	183	186	179
192	195	198	199	198	195	195	188	186	183	176	175	183	178	179	175
199	199	193	196	195	195	191	186	187	175	174	175	175	177	172	175
195	198	199	197	192	191	184	179	174	169	172	171	173	171	171	167
195	199	196	198	185	175	169	161	157	164	167	178	171	165	164	163
198	195	195	186	183	171	163	152	155	166	173	175	171	166	167	163
193	193	188	179	170	157	155	155	161	168	175	174	171	165	166	165
194	187	179	172	155	155	158	157	155	159	168	166	159	163	159	160
191	181	182	171	163	159	159	159	159	158	161	159	162	163	171	163
189	188	179	168	163	162	165	163	167	159	159	158	163	169	179	164

IR CLUSTERED INTO FREU. COUNT

206-255	0	0	0	0
196-205	20	9	10	0
186-195	29	28	20	1
176-185	13	11	9	4
166-175	2	7	7	33
156-165	0	9	13	24
146-155	0	0	5	2
136-145	0	0	0	0
126-135	0	0	0	0
116-125	0	0	0	0
106-115	0	0	0	0
96-105	0	0	0	0
86-95	0	0	0	0
76-85	0	0	0	0
66-75	0	0	0	0
0-65	0	0	0	0

QUAD. WITH LARGEST VALUE GROUPED

0	0	0	0
39	0	0	0
78	0	0	0
37	0	0	0
0	0	0	49
0	0	0	46
0	0	7	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

IR DATA CLUSTERED

0	0	0	0
39	0	0	0
78	0	0	0
37	0	0	0
0	0	0	56
0	0	0	46
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

MAPPED CLUSTERED DATA

3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4
3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4
3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	3
4	4	4	4	4	4	4	4	4	3	3	3	3	4	3	3
4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3
4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3

7.4.2 Automatic cloud classification

Hawkins[82] applied the clustering algorithm to 102 satellite images covering a wide variety of cloud conditions. In manually classifying the clusters he proposed a relatively comprehensive classification system in which upto 18 different categories of clouds could be identified as depicted by Table 7.1. These include all the different formations of the fundamental categories of Cirrus, Stratus, and Cumulus.

CIRRUS	CUMULS	
1) THIN	8) SMALL SCAT.	12) STRATUS
2) MODERATE	9) SMALL	13) STRATOCUMULUS
3) THICK	10) MODERATE	14) ALTOCUMULUS
4) THIN OVER CU.	11) LARGE	15) ALTOSTRATUS
5) MOD. OVER CU.		16) NIMBOSTRATUS
6) THIN OVER ST.		17) CUMULONIMBUS
7) MOD. OVER ST.		18) CLEAR

Table 7.1 Cloud classification system

In classifying these clouds manually, the following information was used:

1) Mean of the infrared cluster.
2) Mean of the visible cluster.
3) Visual texture measure at three spatial scales.
4) Visual gradient measure at three spatial scales.

The texture measure is calculated by :

$$\text{Texture} = | 4V_o - (V_1+V_2+V_3+V_4) |$$

Where:

V_o = Visual count for the central grid-point.

$V_1 \text{to} V_4$ = Visual count values of the four surrounding orthognal points in the grid.

The gradient measure is the Robert's gradient and can be calculated by:

$$\text{Gradient} = |V_1 - V_2| + |V_3 - V_4|$$

Where the four points form the square and V_1 lies diagonally opposite V_2 and V_3 lies opposite V_4.

The results of the manual classification for the 102 samples of satellite data as given by Hawkins[82] are depicted by Table 7.2. For each classification catagory, means and standard deviations are given of the eight measures.

	CLOUD CLASS NO.	NO. CASES	INFRARED	VISUAL	TEXTURE1	TEXTURE2	TEXTURE3	GRD.1	GRD.2	GRD.3
CI. THIN	1	15	103.6 17.5	53.2 10.0	7.1 3.6	16.5 6.6	19.8 7.9	7.9 4.7	51.4 25.9	54.8 25.4
CI. MOD.	2	15	153.2 18.4	71.9 10.6	7.4 5.7	13.0 5.0	16.9 5.8	8.8 4.1	52.1 21.0	55.1 19.3
CI. THICK	3	15	181.8 10.5	83.1 6.0	6.2 3.2	9.6 4.1	14.7 8.1	7.4 5.2	70.1 31.0	84.5 37.6
CI. THIN OVER CU.	4	17	114.4 23.1	63.4 14.2	9.1 5.6	18.7 12.3	23.4 14.2	8.7 4.7	62.0 22.9	76.8 23.7
CI. MOD. OCER CU.	5	23	156.0 19.7	75.0 10.0	9.0 4.4	17.1 9.5	23.0 14.0	8.3 5.0	74.3 28.4	72.1 31.1
CI. THIN OVER ST.	6	9	153.7 9.8	83.8 4.6	5.4 1.1	7.7 2.4	10.5 3.1	4.5 2.0	42.8 24.2	70.7 42.2
CI. MOD. OVER ST.	7	12	169.9 14.4	84.9 5.1	5.4 1.7	8.8 2.4	11.7 5.7	5.4 2.9	70.1 34.0	86.5 37.5
CU. SMALL OR SCAT.	8	14	95.1 11.5	46.8 7.7	15.1 7.7	26.3 13.0	27.3 13.0	12.7 5.9	36.0 22.2	38.6 20.9
CU. SMALL	9	22	104.3 11.0	55.2 7.5	12.4 6.3	23.0 12.5	29.7 13.2	11.5 7.8	49.2 20.0	60.0 24.1
CU. MOD.	10	10	105.6 19.9	65.2 9.8	16.9 6.6	34.7 11.4	37.8 6.7	17.9 7.6	58.0 25.0	63.5 16.2
CU. LARGE	11	13	111.8 23.0	72.2 9.6	13.0 5.5	20.3 9.9	29.4 14.1	13.1 6.6	47.2 22.2	60.7 22.1
STRATUS	12	21	127.7 10.0	88.1 5.2	6.1 2.6	11.2 7.8	14.2 11.9	5.4 3.2	34.1 21.4	53.4 26.4
STRATOCU.	13	22	119.9 18.7	79.8 10.7	8.1 4.3	15.2 8.9	19.8 13.9	7.6 4.3	56.1 30.5	67.4 36.8
ALTOCU.	14	7	111.2 16.0	66.2 9.3	14.2 6.3	31.3 11.1	24.3 4.4	13.4 5.2	49.6 14.3	64.8 17.1
ALTOST.	15	4	162.7 10.2	97.5 1.4	5.5 1.8	8.6 0.8	7.7 2.2	7.0 3.2	43.5 8.3	72.5 13.1
NIMBOST.	16	5	131.4 8.9	91.8 3.5	6.5 4.4	12.0 3.8	11.3 2.8	6.5 3.0	46.5 32.2	69.3 37.9
CUMULONIM.	17	6	196.4 3.3	96.4 3.8	7.0 3.0	7.9 3.7	13.4 5.5	6.3 2.9	64.3 31.2	81.3 26.9
CLEAR	18	30	84.2 9.5	38.8 10.1	6.9 3.9	12.0 7.7	12.2 8.1	7.8 6.3	34.5 20.3	42.0 23.4

Table 7.2 Manual cloud classification results

Hawkins[82] discovered in his manual classification that ambiguities arise in seperating some of the clouds due their similarities based on the measures proposed and suggested further investigation prior to the implementation as a fully automated classification technique.

Taking the information given by Table 7.2, empirical tests were conducted to see whether ambiguities between certain classes could be resolved for nowcasting. It was discovered that seperation of classes based on their measures leads to a better understanding of these ambiguities between certain classes and also to resolving some of these.

The seperation of classes was based on their mean infrared, visible, texture and gradient measures. The splitting of these classes into groups based on these measures became more managible and distinct, clearly highlighting the parameters upon which these could be differentiated. A relatively comprehensive decision making procedure can be devised, and is represented using tree diagrams in Figures 7.4,7.5,7.6, and 7.7. A decision is taken on a given cluster by its mean infrared value, followed by its mean visible and then its texture and gradient measures.

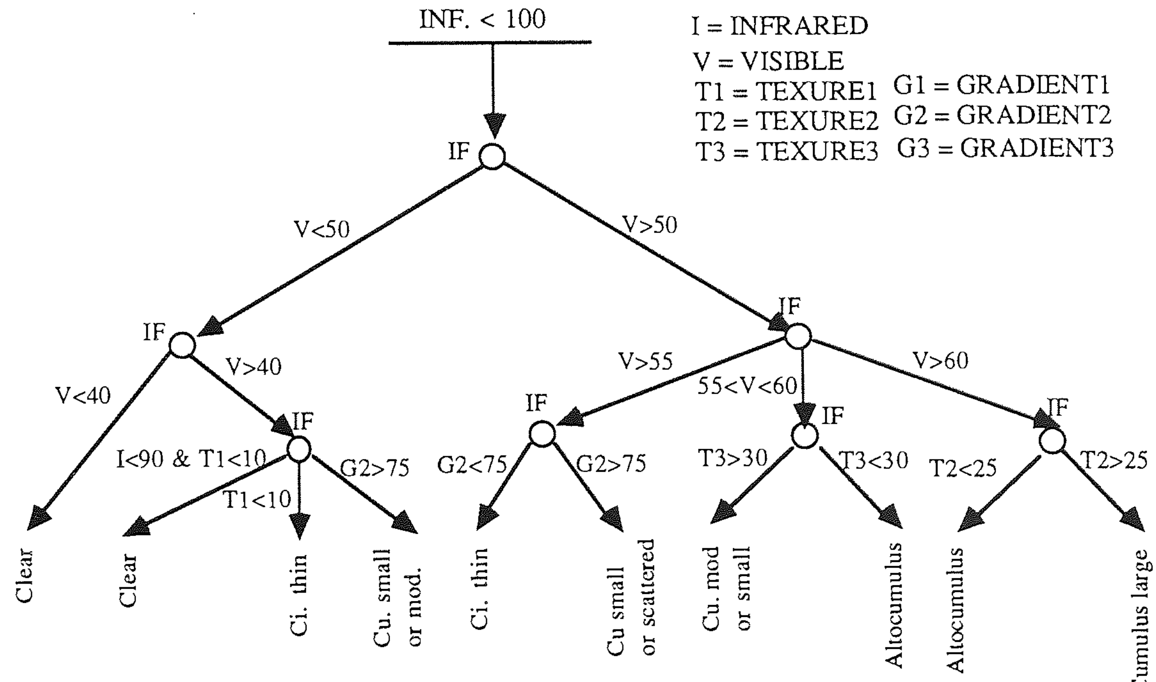


Figure 7.4 Cloud classification tree diagram

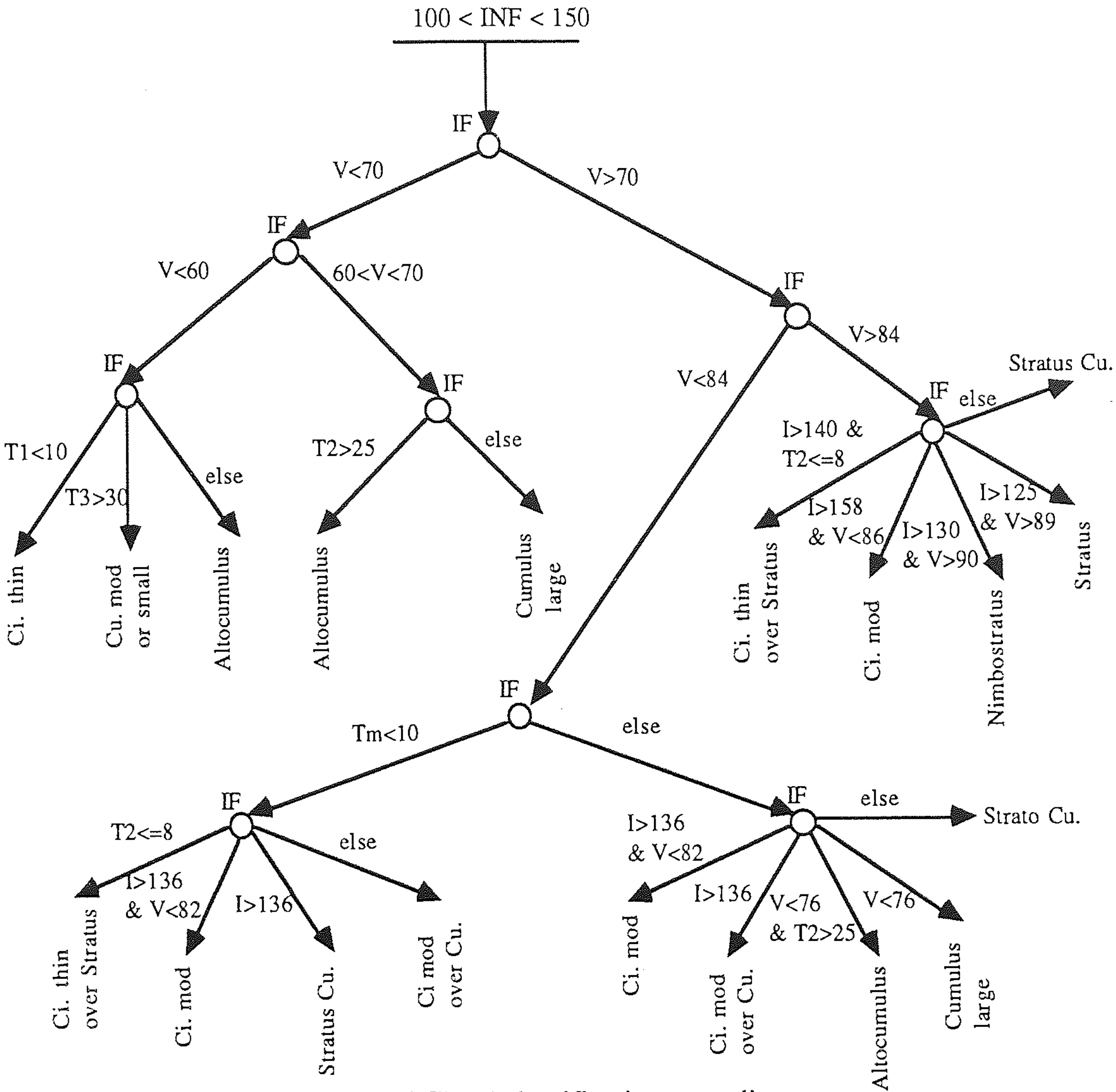


Figure 7.5 Cloud classification tress diagram

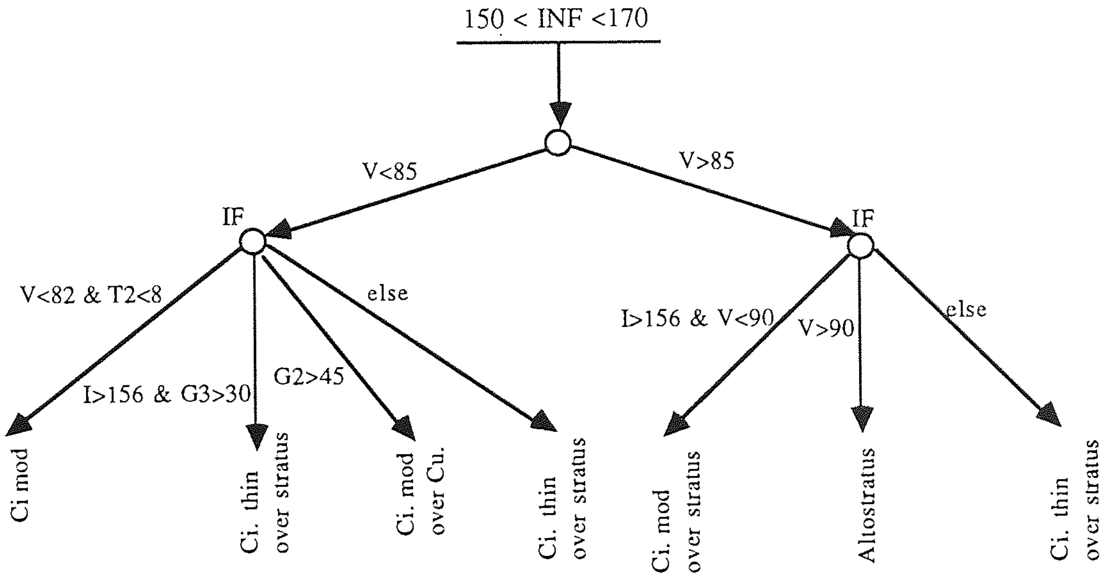


Figure 7.6 Cloud classifcation tree diagram

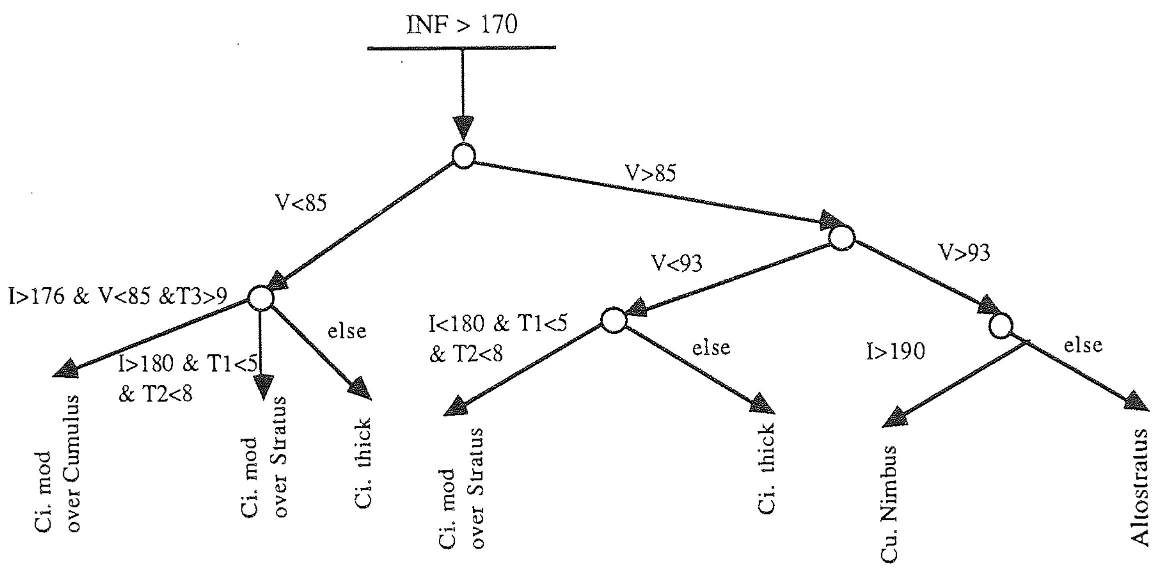


Figure 7.7 Cloud clasification tree diagram

In a fully automated cloud classification system, more steps are required to extract the information for its classification from the clusters derived. These steps leading to automatic classification are additional to those proposed by Hawkins[18] and they are:

STEP11 :

Cluster corresponding visible data.

STEP12 :

Determine mean values for each cluster in both the infrared and visible domain.

STEP13:

Determine each clusters size to set appropriate texture and gradient measures that could be extracted as clusters could be too small to extract these measures.

STEP14 :

Based on the information available classify the resulting clusters .

STEP15 :

Output results to the required medium.

As indicated earlier, in a fully automated system all the necessary information must be extracted prior to classifying the cluster. Calculation of texture and gradient for each cluster at three spatial grid points could prove difficult if the cluster was not sufficiently large enough to encompass such measuring points. If insufficient points exist within the cluster, bounderies between clusters would introduce higher differences and their incorporation for texture and gradient mesures will result in misclassification of the given cluster. The size of each cluster must be determined prior to extracting texture and gradient measures from the cluster.

To extract texture and gradient at three spatial points, the cluster must fit a pixel array of size >= 11*11. To determine the maximum array size available of a given cluster, the cluster is scanned after thresholding for each cluster within the overall data. Depending on the array size a decision is made to the level of texture and gradient measures available.

As the data is dynamic and cluster size varies, this could lead to the following permutation :

1) Cluster does not exist.
2) Cluster exists without the possibility of any texture or gradient measures.
3) Cluster exists but only texture1 and gradient1 available.
4) Cluster exists but only texture1&2 and gradient1&2 available.
5) Cluster exists with all measures available.

Conditions 1 to 4 provide a lack in information to classify the clusters and any decision on the categories affected is empirical based on the information available. In the automatic classification, these steps are incorporated on the nowcasting system and are depicted diagramatically by Figure 7.8.

Although ambiguities still exist in seperating between Altocumulus and Cumulus large or Nimbostratus and Stratus, most are removed with the method proposed. Further investigation is required to seperating these classes.

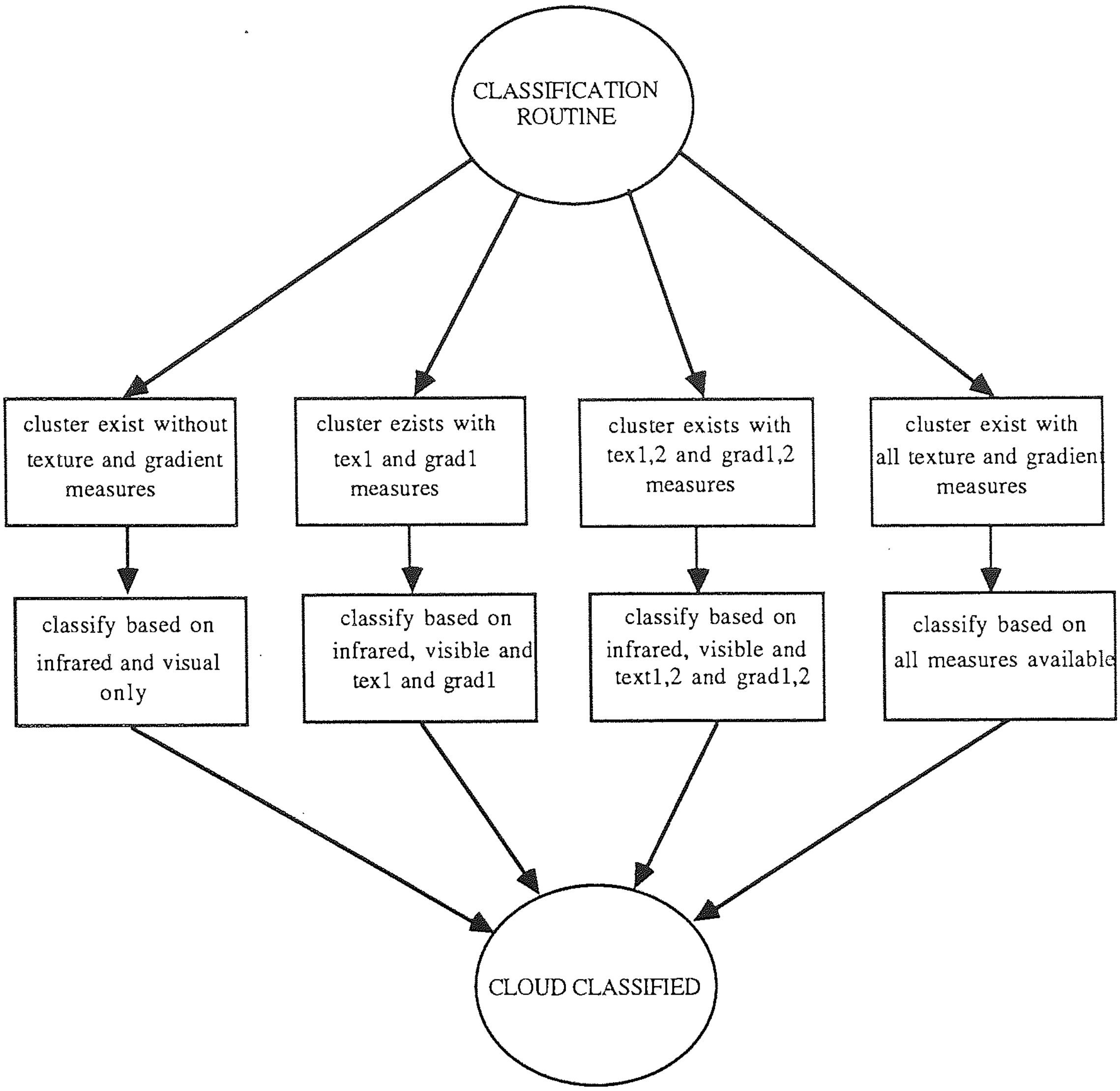


Figure 7.8 Automatic cloud classification

The technique implemented on the nowcasting system was subjected to trials on known samples of cloud formations and showed promise. The two clusters obtained from Plate 7.5 were classified as:

Cluster 3 : Altostratus

Cluster 4 : Cumulonimbus

The bright region over the area of interest is indicative of a cumulus category with high infrared values and bright visible values, while, the underlying cloud with very light precipitation was indicative of Stratus catagory.

Further subjective tests must be conducted on known samples for its validation as an operational classification system.

7.5 Extracting precipitation information from satellite images

Precipitation is one of the most significant meteorological and hydrological parameters, with implications also for vegetation, water resource management, industry, commerce, and recreation. However, it is notoriously difficult to monitor due to its very high spatial and temporal variability.

As satellite and radar data presents higher resolution of spatial and temporal measures, most efforts have been directed towards the extraction of this information from the data sets[85,86,87]. However, satellites with their wider spatial resolution are generating much interest for operational purposes.

Lovejoy et al.[85] found in their investigation that clouds with very cold tops give the heaviest precipitation and that the requirement for precipitation from any cloud is that its top temperature must be colder then -12^{o}C. Griffith et al.[86] derived an empirical relationship from satellite infrared images using raingauges and radar for calibration: The relationship between precipitation and satellite images have the following properties:

1) Raining clouds are those which are cold or colder then -20^{o}C.
2) Rainfall is directly proportional to cloud area on any given image.
3) Rainfall is inversely proportional to cloud top temperatures.

Tsonis[88] proposed a bivariate frequency distribution method in determining rain areas on satellite images and identifying them as raining or nonraining clouds. This technique was extented by Tsonis[89] to determining rainfall rate using threshhold parameters to visible data, as this contain more information about the aeriel extent of precipitation than the infrared data. Other studies of rainfall estimation methods from satellite data have been conducted by Barrett et al.[90], Griffith et al.[86], Bellon et al.[87] and many others. They all indicated certain amount of success and are progressively improving their methods.

The extraction of this information for the area of interest using the multi-spectral data is important for the nowcasting system. No tests were conducted to determine the likelihood of precipitation from the clustered images. It is unknown at this stage whether the findings of Griffith et al.[86] or Lovejoy et al.[85] of determining the probable precipitation associated with the segmented image using cloud top temperatures would be sufficient for the nowcasting system or the implementation of bivariate technique proposed by Tsonis[89]. It is likely that as research into obtaining quantitive precipitation from satellite images progresses, the latter would provide the most favourable solution for nowcasting.This remains an area of further work.

7.6 Conclusion

The satellite images contain features (such as cloud formations) which evolve dynamically and may be subjected to movement, growth, distortion, bifurcation, superposition, or elimination between one image to the next. The process of extracting a weather feature, following its motion, amd predicting its future evolution involves algorithms for normalisation, segmentation, filtering, image enhancement, texture and gradient measures, and correlation of multi-dimensional signals in different domains. It has been shown that these copious tasks can be handled using a modern desk-top computer for nowcasting.

Chapter 8

8.0 Conclusions and suggestions for future work

8.1 Conclusions

Several researchers have expressed that improvement in local weather forecasting can only come about by observing the state of the local atmosphere continuously and extending these current conditions using physical laws or simple extrapolation techniques to predict their future evolution. In countries where hazardous weather is a continuous problem destroying life and property, efforts are directed towards developing systems to observe the state of the atmosphere more closely and report any hazardous activities to the inhabitants. These are large scale projects extending to state or country, requiring excessive resources from the respective national meteorological offices and other collaborating bodies for their implementation.

The concept of continuously observing the state of the atmosphere on a more local basis and reporting these variations along with their evolution using simple extrapolation techniques have been discussed in this thesis. It has been shown that these less demanding tasks can be satisfied using a low cost desk-top computer system. Such a system proposed in this thesis is the real-time nowcasting system. The real-time nowcasting system operating locally can provide much detailed real-time information to the locality than the national forecasts from the meteorlogical office.

A recent article[91] further highlights the need for a system operating on a local scale providing weather information which affects the locality. The article reports on a network of weather watchers reporting current local weather conditions to a central office; where detail picture of the weather is constructed. The observers include police, coastgaurds, highway depots, long distance drivers and ordinary people. These are manual observations of the genral conditions at the observers site.

The objective of the real-time nowcasting system for localised weather can be trivially expressed as one of continuously sampling the state of the atmosphere using two differing sources of data, analysing the data sets to extract their future evolution based on their past-to-present variations and finally making this information available to locals of the site. The realisation of a system to achieve such a task is a non-trivial problem. Many difficulties arise in its realisation relating to numeruous factors and these must be individually solved. Some of these can be expressed as:

- The feasability of achieving such a demanding task.
- The overall system configuration required to achieve this task.
- The necessary configuration of any sub-systems to observe the state of the atmosphere.
- The necessary software for safely handling data in real-time.
- The necessary software for preparing and manipulating this real-time data.
- The necessary software for the presentation of atmospheric data for visual appreciation and interpretation.
- Any algorithms for analysing this two differing sets of data for prediction.
- The necessary hardware and software to make available this information to local users.

Each of the above can be further broken down into sub-tasks prior their individual realisation. This was the approach adopted in the design of the real-time nowcasting system for localised weather.

The various architectures of the AWS's reported in the literature and those commercially available make them less than ideal for adoption in nowcasting. The sub-system designed in-house to meet the essential requirements of continuously observing the state of the atmosphere at a locality, storing this to local archive, and most importantly making available this real-time information for display and analysis.

This sub-system is the GLNS. Every effort in its design has been towards simplicity in its operation and automation requiring minimal operator interaction. The dedicated software handles all the low-level operations for safe data capture with additional facilities for reporting erroneous readings and transmission failure via its screen.

Commercially available SDUS systems are specifically designed as display stations using low resolution graphics to present amorphous cloud structures as viewed by respective satellites. Considerable information is lost in the detail of multilayer clouds, making such systems less than ideal for extracting meteorological information. A standard receiver modified in-house is used to capture high resolution images automatically and extracting meteorological information.

The information from these two differing sources is ephermeral and must be captured in real-time. Real-time data handling within the PC system turned out to be the most crucial and yet the most demanding task in the design of the real-time nowcasting system. These desk-top computer systems are designed for single-task operation and do not readily lend themselves to multi-tasking operations. The requirement of the real-rime nowcasting system was for multi-tasking operations. Considerable effort was directed towards making the system function in a multi-tasking environment using interrupts and TSR processes. The data handling of the real-time nowcasting system becoming a transparent background task.

Extensive literature search revealed a lack in facilities for simple presentation of atmospheric data for visual appreciation and interpretation (particularly at outstations) for forecasters and other parties interested in its dynamical variation. Considerable effort in this research has been towards the presentation of atmospheric data (local ground data and also satellite data) in simple formats.

No work has been reported in the literature related to stochastic models of weather elements for simple extrapolation. The novel approach adopted in this thesis is one of constructing simple stochastic models of individual atmospheric elements using their site-specific variations to predict their future changes. Models representing individual elements have been constructed based on historical data for the site. It has been shown in this thesis that forecast lead-times of upto two hours can be achieved using these simple models.

Several objective techniques for extracting meteorological information from multi-spectral satellite images using computer algorithms have been proposed in the literature. Investigation revealed that extracting information automatically split into three distinct areas - 1) extracting wind motion vectors from clouds, 2) classifying amorphous cloud structures, and 3) extracting precipitation information from these images. As previous work was mainly biased towards synoptic-scale or to lesser extent meso-scale phenomena, it had meant that techniques for extracting information for nowcasting did not exist. Research efforts concentrated on the selection of the most appropriate techniques for further investigation for nowcasting.

Extracting wind motion vectors from satellite images using cross-correlation technique was selected for investigation. It has been shown in this thesis that the technique fails to highlight a single expected peak such that a computer search routine can extract wind motion vector automatically. Further, subjecting these images to various forms of degredation (such as dilating, contrast stretching, manual thresholding) and texture and gradient measures fail to improve for a computer to automaticlly extract the information. It has also been shown by way of an example under what circumstances the technique will work correctly such that a computer search routine can extract this information. However, its implementation under these circumstances is severely restricted for practical use. The most promising method is based on application of cross-correlation after segmentation.

Cloud classification from satellite images is an important component for meteorological and hydrological organisations. The technique selected for nowcasting was proposed by Hawkins[82]. There were restriction highlighted by Hawkins preventing its immediate use in automatic cloud classification. This thesis also shows how these limitations were resolved for its implementation of automatic cloud classification in nowcasting.

Several techniques have been proposed for extracting precipitation information from satellite images. The most simplest for further investigation would be the extraction of precipitation based on type of cloud (determined under cloud classification) and its cloud top temperature. However, the most promising is the bivariate technique proposed by Tsonis[89]. No conclusive tests were conducted to extract precipitation information from satellite images.

A prototype real-time nowcasting system for localised weather has been designed. By and large, software exist as modules. The software has been written in C and assembly. The processing times indicate that the processing is within the scope of the current system configuration. The production of an automated system is not seen as presenting major problems.

The main purpose of the system discussed in this thesis is to provide nowcasts to its locality and the sequential software satisfies this requirement. However, the application is proving to be a stimulus and test-bed for in-house research on many aspects of real-time digital image processing. In particular, it has provided a focus for continuing research work in to the use of parallel processing for real-time signal processing.

The desk-top computer based system is not intended to compete with the national meteorological office; its scope is strictly limited, and it augments the services of the meteorological office by dealing with weather only in a local context. Indeed, the system can be viewed as augmenting the work of the meteorological office by providing a local real-time weather station. A low cost system of this kind can be implemented at outstations where their mode of working is still as it was thiry years ago and lack most of the facilities offered by this system. The nowcasts produced by the system can be used as guidance forecasts of the locality along with those provided centrally to make an accurate very-short-range forecast.

8.2 Suggestions for future work

Nowcasts are by their very nature highly perishable, they must be disseminated promptly if they are not to lose their value. With rapid advances in information technology paving the way for distribution of information, new forms of transmission methods need to be investigated. Those presently available such as telephone dial in services, FAX messages, microcomputer down loading using MODEMS, synthetic speech messages, and amateur radio, etc. The most favourable and economical method readily available seems to be the amutuer radio services. The user simply needs to be equipped with a simple receiver to pick-up nowcasts. However, with the realisation of information services digital networks (ISDN); the distribution of nowcasts in both pictorial and graphical forms would offer the best solution. The information conveyed in this form is likely to be understood more than simple messages over a radio.

The univariate stochastic models derived for each atmospheric element assumes that each element is a seperate entity without any influence of the other elements making up the atmosphere. In practice, interactions between atmospheric elements exist and must be taken into account. The next stage of research would be to build multivariate models for each atmospheric element.

Tests need to be conducted on the use of cross-correlation technique for extracting wind motion vectors form satellite images after segmentation. No previous work related to this approach has been investigated.

Expert systems are being investigated for their implementation in every field of work. However, their implementation in weather forecasting has not been reported in the literature. This could be a fruitful avenue for investigation.

The availability of transputer arrays and DSP processing boards on PC syetms are giving enormous processing power to such small systems. The feasibility of developing atmospheric models can become realistic on these small systems.

As real-time data handling places a heavy demand on the PC system with satellite images occupying the resources of the system for a considerable period of time, a front-end processor (similar to that employed by ESA) concept can be implemented to handle all the data in a local buffer and carry out any pre-processing prior to its availability to the PC system for analysis.

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