GENERAL CLIMATOLOGY OVER INDIAN ANTARCTIC STATION, MAITRI

Dissertation submitted to the Jawaharlal Nehru University
in partial fulfilment of the requirements
for the award of the degree of

MASTER OF PHILOSOPHY

Submitted by

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SCHOOL OF ENVIRONMENTAL SCIENCES

JAWAHARLAL NEHRU UNIVERSITY

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JANUARY-97

DEDICATED
TO MY
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CERTIFICATE

This is to certify that the research work embodied in this dissertation entitled "General Climatology over Indian Antarctic station Maitri" has been carried out in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi for the partial fulfilment of the award of the degree of Master of Philosophy. This work is original and has not been submitted, so far, in part or full, for any other degree or diploma of any University.

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Acknowledgement

I take this oppertunity to express my sincire gratitude to Dr. V.K.Jain, my esteemed supervisor for keen intrest, able guidence and providing constant incouragement through out the course of present investigation.

I am deeply indebted to Dr. H. N. Dutta, Scientist, National Physical Laboratory New Delhi for contineuous help and providing the necessery data and lab facilities for carrying out this study.

Words are not enough to thank Miss. Jaya Naithani (Ph. D. student at N.P.L.) for constant helping and cooperating me throughout with my work.

I am graetly thankful to the Jawaharlal Nehru University for providing me finencial support in the form of U.G.C. fellowship to carry out this work.

I am also thankful to the librarians of the Department of Ocean Developmen New Delhi and India Meteorological Department New Delhi for permitting me to use their librery.

Finally, my sincire gratitude to my family members without their constnt inspiration this would have never been possible.

Arun Kumar Srivastava

PREFACE

Antarctica, the seventh continent of the globe, lies between Antarctic circle (66.33^0 S) and the south pole of all the continents, Antarctica is the coldest, windiest and the driest continent. It is unique continent as above 98% of its surface area is covered with a thick permanent sheet of ice and only about 2% of the area is rocky the continent rises from the sea level to great plateau which reaches to an altitude of over 4km. The combination of elevation and high albedo results in extremely low tempratures over the continent. The intense radia tive cooling from the ice slopes results in the formation and maintenance of nearly ever present thermal inversions over the continent leads to the development and maintenance of the most celebrated wind regime called the '***katabatic winds***'. These highly directional winds of extreme strength make Antarctica the windiest place on earth .

The large meridional temprature gradient between the coastal Antarctica and the relatively warm ocean surrounding it result in the development of intense cyclones. These cyclones originate between 50 to 60^0 S and moves south east word towords the Antarctic cost and then moves parallel to the cost. These transient moving cyclones results in the advection of warm moist oceanic air from the ocean towords the interior of the continent.

The tow% rocky area of the periphery of Antarctica is not a continuous patch of land but constitutes small patches scattered

around the continent's periphery. These patches are surrounded by the ice sheet and are named as "Oasis". The Indian Antarctic station **Maitri** (70.7^0 S ,11.7^0 E) is situated on one of the east

Antarctic Oasis called the Schirmacher Oasis.

The Antarctic continent is surrounded by a permanent sheet of áfloating ice called the shelf ice. The sea water surrounding the Antarctica continent freezes as water advances, thereby, shifting the average cost line to further north during the winter and spring months while in the summer and autumn months when extension of sea ice is minimum, Maitri site behaves like a coastal station.

All this unique features like the presence of ice sheet, long winter night, average slope of the continent scal inversions and associated phenomena make Antarctica the most interesting place for the studies of the climatic features. Since Antarctica has been as a special conservation area, the climatic studies are extremely useful in the studies of the Environmental Impact Assessment.

India ábegan its systematic study of this ecologically fragile continent in the year 1981 with the establishment of its first Antarctic station **`Dakshin Gangotri'** on the ice sheet. The initial phase of the Indian Antarctic Station was to gain experience for the maintenance of the station and to conduct scientific experiments in the cold, windy environment. However in the year 1988 a permanent station called **`Maitri'** was established on the Schirmacher Oasis. This station offered much better facilities for accommodation and laboratory experiments. The atmospheric science group of (National Physical Laboratory (NPL) New Delhi has participated in the Antarctica Expeditions right from the beginning.

An automatic weather station was established in the year 1989. In the year 1991-92, a 28 meter tower was also established but the meteorological sensors could only be mounted on it in January, 1993. Since then the atmospheric data are being recorded continuously. Some of the supporting meteorological data are recorded by the India Meteorological Department New Delhi.

This thesis is devoted towords the study of climatology over the Indian Antarctic station,

Maitri and is mostly based on the data collected during the year 1992.

In chapter I, a brief history of Antarctica and the importance of atmospheric studies over it are discussed. This chapter also describes various stations over Antarctica where meteorological observations are being carried out. This is followed by a brief description of Antarctica Oasis with a special emphasis on the Schirmacher Oasis as the Indian Antarctic station is situated on this. After this a brief history of Indian meteorological observation is also given, in todays contest Antarctica is a prime store of past knowledge on world climate and atmospheric changes Antarctica serve as the major `heat sink' in the thermal balance of the Earth and plays key role in the energy balance of the Earth's climate.

Chapter II describes the Atmospheric instrumentations used at **Maitri** viz. a PC based monostatic acoustic sounding system, a 28m instrumented tower , an automatic weather station and a solar radiation measurement equipment.

The meteorological sensors on the 28m tower have mounted at four levels (1.8, 4.5, 11.3, and 28m), the air temprature, humidity, wind speed and direction are measured using the platinum resistance thermometer(PT 1000),a sensitive humicap sensor,a cup anemometer and a sensitive rotating arm wind vane, respectively .

Chapter III describes the general climatic features of the **Maitri** site in Antarctica, mainly solar radiation, wind, pressure, humidity, snowfall and snowdrift, visibility and cloudiness and the inversion have been discussed in detail for the year 1992.

Finally, chapter IV summaries studies carried out and presents some of the important conclusions and recommendations for the future works to be under taken at the Indian Antarctic station, **Maitri.**

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Chapter 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Antarctica, the seventh continent of the globe, is the world's fifth largest continent. It lies between the Antarctic circle (66.33^0 S) and the south pole (Fig. 1.1). Of all the continents, Antarctica is the coldest, windiest and the driest continent. Its area is ~ 14.5 M km^2, of which about 98% is covered with a permanent sheet of ice and the rest ~2% of the area around the continental periphery is rocky. The continent rises from sea level to a great plateau which reaches to an altitude of over 4 km,over 60% of the continent is situated above 2 km in elevation and nearly 30% above 3 km, emphasizing unique, elevated nature of the ice surface (Parish, 1988). The highest mountain peak of Antarctica is 5,140 m high Vinson Massif (78.6^0 S; 85.4^0 W), while the South Pole is at an elevation of 2,800 m (Silverstein, 1967) ,this gives a dome shape to the continent. The Antarctic ice sheet, with an average thickness of about 2.3 km contains more than 90% of the world's ice and 70% of world's total fresh water.

Figure 1.2 gives the height contours of the continent. The approximate radius of 2,000 km alongwith the maximum altitude of 4 km gives an average slope of the continent as 2/1000 (Parish,1988) with the exception of the areas like the Trans Antarctic mountains and the Antarctic Peninsula.

The 2 % rocky area is not a continuous patch of land but constitutes small patches scattered around the continent's periphery (Figure 1.3). These patches are surrounded by the ice sheet and

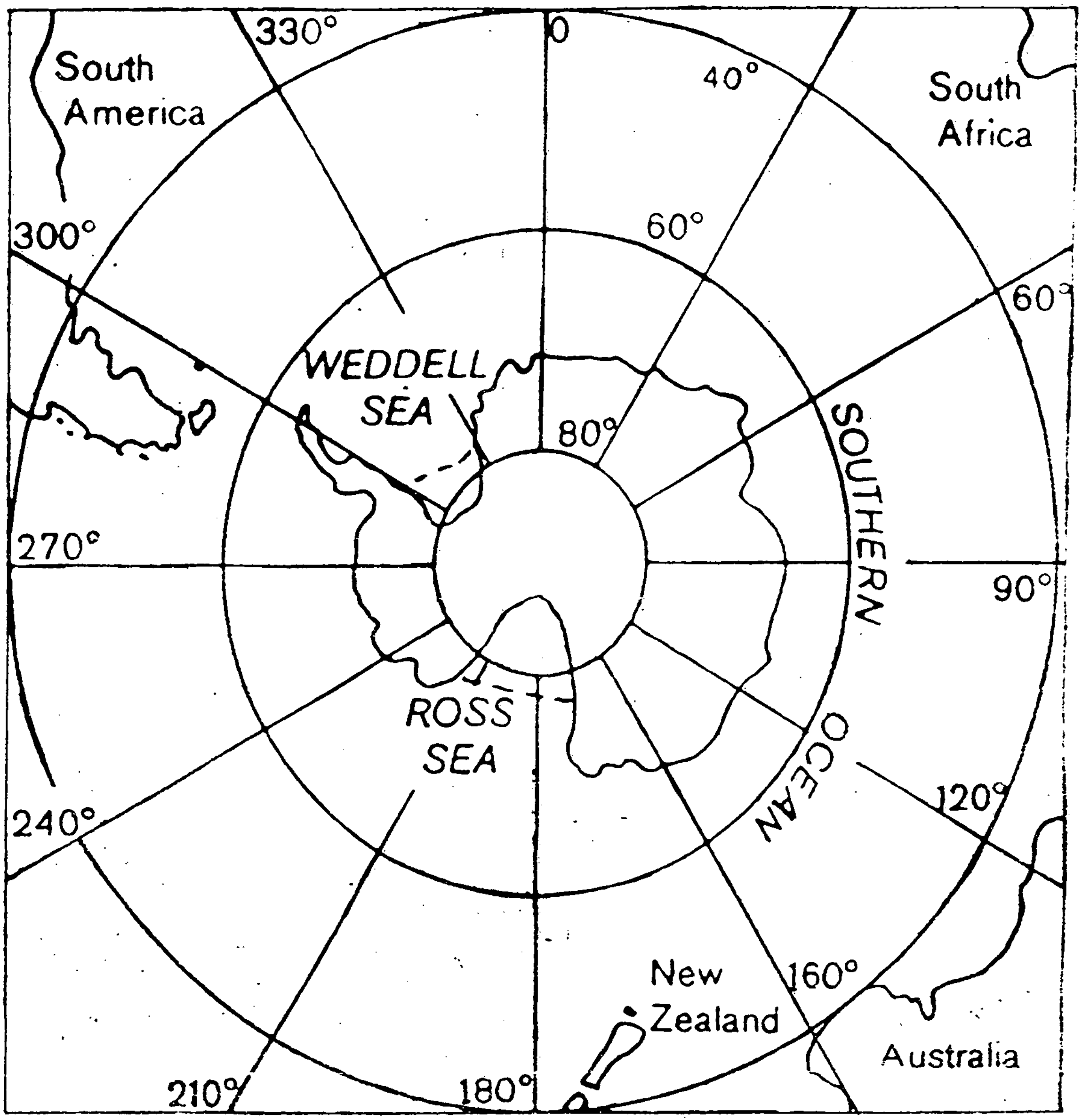

Figure 1.1 Antarctica in the relation to the surrounding land masses (after Campbell and Claridge, 1987)

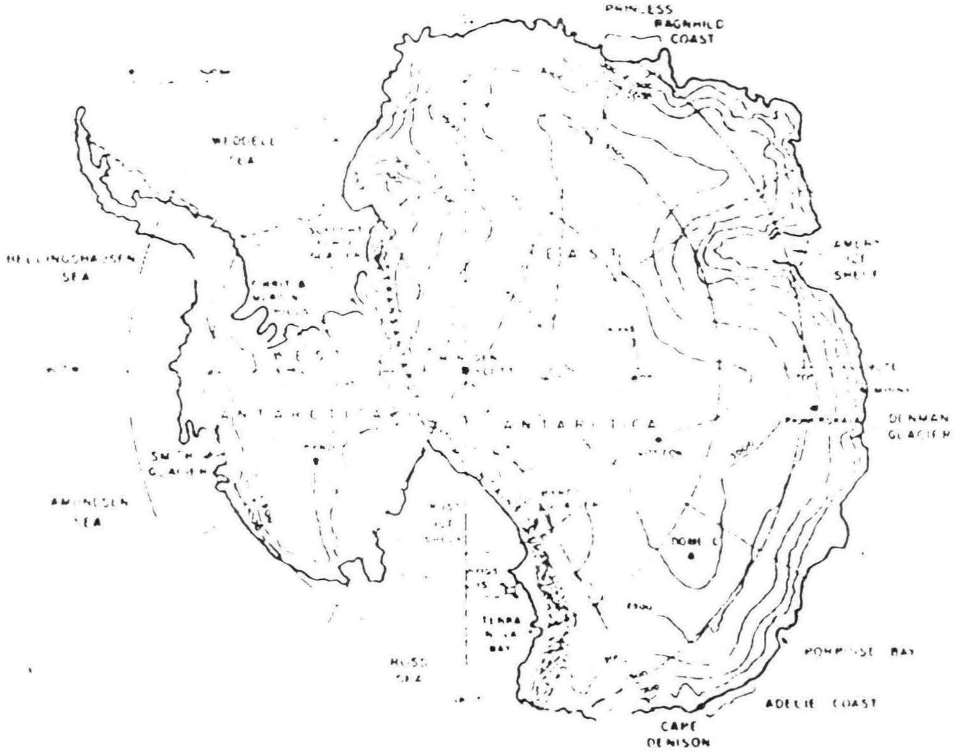

Figure 1.2 Height contours of the of the Antarctica continent (after Parish and Bromwich, 1991)

Figure 1.3 Distribution of ice free areas (Oasis) in Antarctica The Indian Antarctic station is situated at Schirmacher Oasis (after Compbell and Claridge, 1987)

were named as "**Oasis**" (Stephenson, 1938).

The entire continent is surrounded by a floating ice shelf which is a cantilevered mass of ice of length varying from a few km to as much as 1,000 km. Fig. 1.4 shows the shelf in the Indian Bay area which is about 250 m thick. This comprises of about 1.5 M km^2 of the total area. The extent of sea ice surrounding Antarctica varies greatly with the march of the seasons. By the end of the summer, i.e. in February, about 3 M km^2 of the sea is covered by ice (van Loon, 1967). With the onset of winter darkness, the area of sea covered by ice increases, until September-October when it can extend over an area of approximately 20 M km^2 (Figure 1.5). The seasonal difference between the maximum and the minimum sea ice cover is there fore greater than the area of the Antarctic continent itself.

The presence of the ice sheet, average slope of the continent and associated phenomena make Antarctica the most interesting subject for all the human endeavors. Today, all the activities in Antarctica are governed by the Scientific Committee on Antarctic Research (Parsons, 1987).

1.2 OASES IN ANTARCTICA

The first reference to oasis in Antarctica was made in October 1936 by A. Stephenson, a member of the British Graham Land Expedition of 1934-37 (Stephenson, 1938). John Pickard (1986) defined Antarctic oasis as an area substantially free from ice which separated from the ice sheet by a distinct ablation zone, and which is kept free from snow by ablation due to low albedo and positive radiation balance.

Location of 8 major Antarctic oases is given in Figure 1.3. All these oases lie on the coastal periphery of Antarctica and are referred to as the low altitude coastal oases (Picard, 1986). The

Figure 1.4 Photograph showing floating ice shelf in the Indian Bay area.

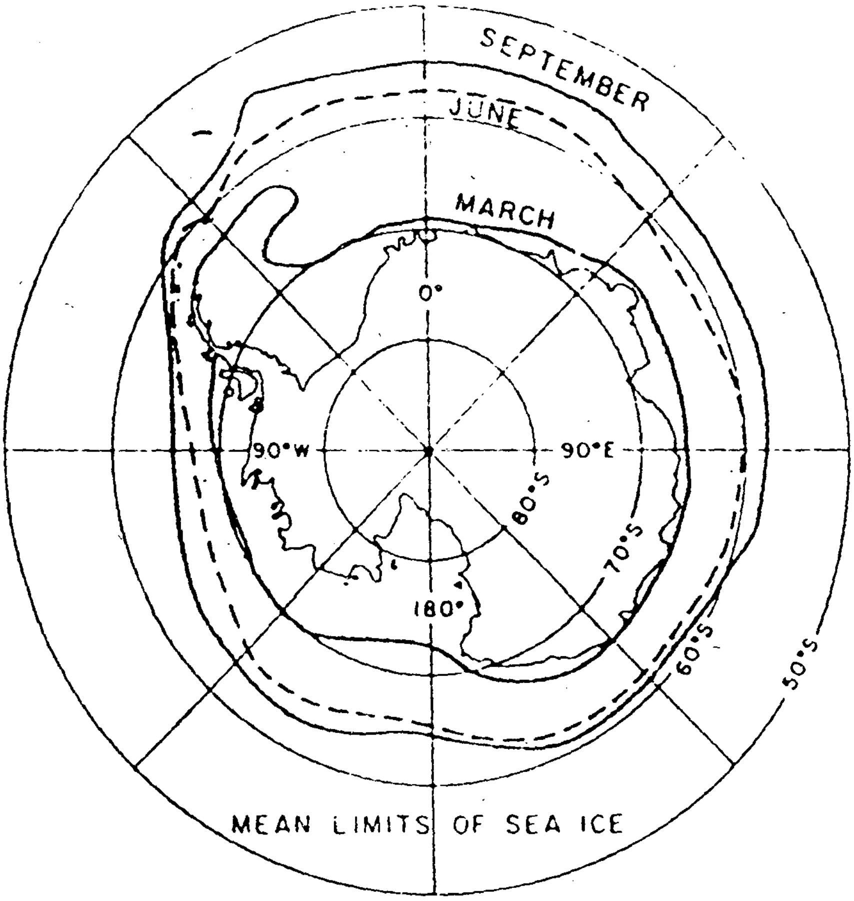

Figure 1.5 Ice limits around Antarctica in March, June and September (after van Loon, 1967)

largest of these oases is the Bunger Hills, the next is the Vestfold Hills. All these oases are continuous rocky areas with at least one boundary as the ice sheet and another an active outlet glacier. These points indicate that either the ice once flowed over the oasis or they once had been ice covered, the ice flow is presently deflected around it. This is confirmed from the receding movement of the glaciers in these oases.

1.3 SCHIRMACHER OASIS

Schirmacher oasis was discovered on 3 February, 1939 by Schirmacher while returning from a photographic reconnaissance flight in the Wholthat Massif to the floating base of the German Expedition of 1938-39 (Ritcsher, 1939; Richter, 1984), and was named "Schirmacher Seenplate". Schirmacher oasis is one of the smallest east Antarctic oasis (Figure 1.6). This region forms a part of Dronning Maud land and is about 70 km south of the Princes Astrid coast of East Antarctica. It is a small range of low lying hills. The elevation of the oasis ranges between 0 and 228 m with an average of about 100 m (Simonov, 1971). It has a maximum length of about 20 km and a width of about 3.5 km. It is oriented approximately in the east-west direction and forms a small obstruction to the flow of the glacier. Towards the north of it lies the shelf ice, while towards its south lies the polar ice which goes on increasing towards the pole. The coordinates of the oasis are 70^0 46$'$ 04$''$ -70^0 44$'$ 24$''$ S; 11^0 49$'$ 54$''$ (+/-48) - 11^0 26$'$ 03$''$ (+/-02) E (Richter,1984). Its area is about 72 km^2 of which about 3% is always free from ice cover even during the winter. The remaining area is normally covered with snow in winter which melts off during the summer. This melted water along with the melted glacier water gets accumulated in the depressions between the hills forming small pools and lakes. About 30 such fresh water lakes exists in the oasis. Thus, compared to the rest of the ice

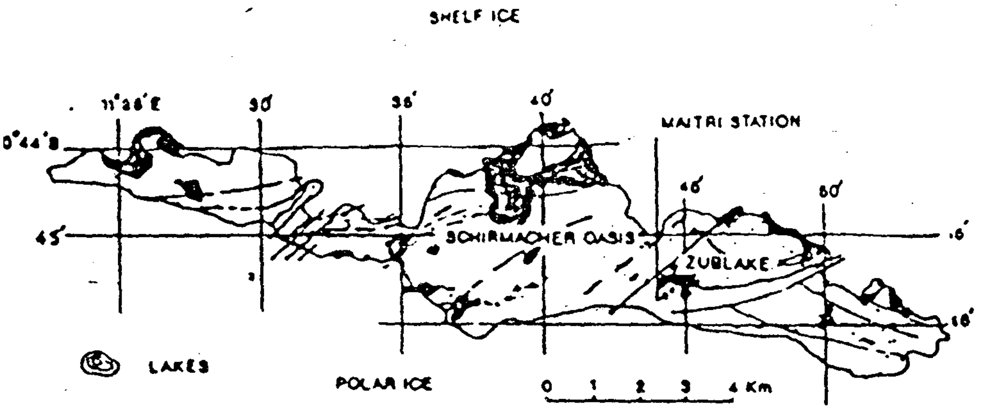

Figure 1.6 Map of the Schirmacher Oasis, Dronning Maud Land (after Kamf and Stackebrandt, 1985).

covered continent these regions are relatively warm and provide favorable conditions for biomass production. The rocky locations are favored to establish the stable and permanent research station in Antarctica. The first Indian station named as **Dakshin Gangotri** was built over shelf and by now it has been abandoned as it has sunk 40 feet below the shelf ice.

1.3.1 LOCATION OF THE INDIAN ANTARCTIC STATION IN SCHIRMACHER OASIS

As already discussed, the oases provide a stable platform for the location of a permanent research station in Antarctica, in addition to the better climatic conditions and availability of fresh water lakes round the year.

Indian Antarctic station -**Maitri** (70^{0} 45′ 39″ S; 11^{0} 44′ 48″ E), is situated on the Schirmacher Oasis (Wastard and singh, 1988) adjacent to one of the biggest fresh water lakes called Zub lake and locally named as '**Priyadarshini lake**' (Figure 1.7). The site has extensive ground available for easy landing of big helicopters, including MI-8 type.

1.4 ANTARCTIC EXPLORATION

Antarctica has one of the most hostile climates in the world, with its subzero temperatures compounded by raging winds and endless frozen polar night. Today, Antarctica is more a challenge to the technology as man has already proved its survivability in this cold climate.

Antarctic exploration was first undertaken in a spirit of adventure allied to a desire for

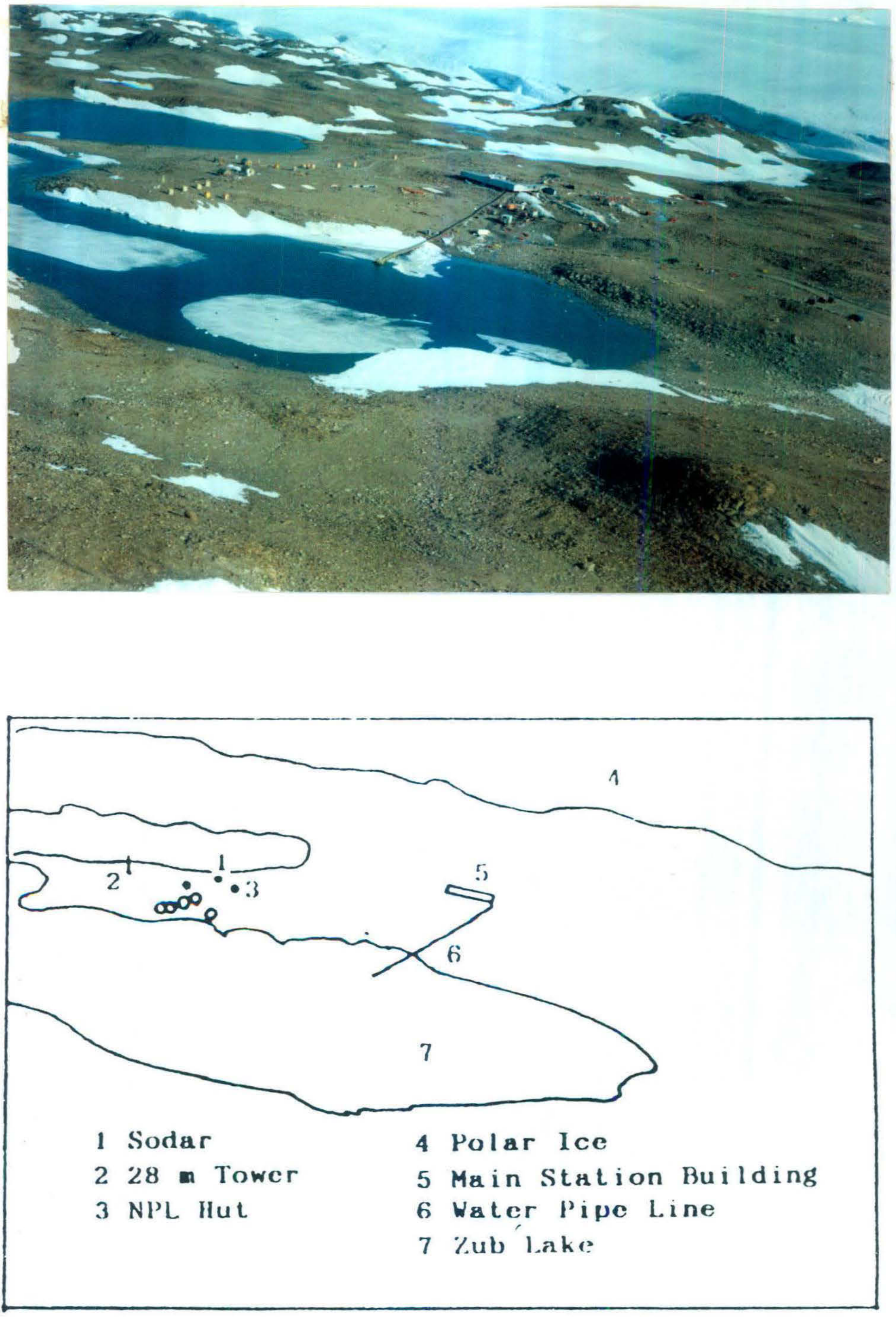

figure 1.7 Aerial photograph of the Maitri station building, various scatterred huts housing different instruments and the Zub lake during summer. The photograph also shows how the undulations of the hilly area and the polar cap ice (towards the south of Maitri station) various features are marked below the photograph

knowledge. Medieval geographers had believed that south of the equator there lay a vast continent, the ***'Terra Australis Incognita'***, fig. 1.8, which they showed on their map, stretching as far as the south pole. The first recorded sighting of any of the lands, now regarded as part of the sub-Antarctic island groups, was made in 1675 by an English merchant, Antonio de La Rochi, who discovered South Georgia (Bonner and Walton, 1985).

Then came the economic interest and different whaling, sealing (fur seals), krill industries sprang up (Mitchell and Sandbrook, 1979; Parsons, 1987). People started discovering various sub-Antarctic islands and formally started territorial claims (Bonner and Walton, 1985; Parsons , 1987). Apart from the economic interest in south sealing, there also ran a scientific interest in Antarctic exploration among the nations of Europe. Towards the end of the century, however, economic and scientific interests combined to open a further period of Antarctic exploration.

The International Geophysical Year (IGY) which took place in 1957-58 identified Antarctica as a region of utmost importance for scientific investigations (Parsons, 1987). The meteorology and climatology of Antarctica were studied. Synoptic weather observations were made at all these sites and many also made upper air measurements using balloons.

1.5 IMPORTANCE OF ATMOSPHERIC STUDIES OVER ANTARCTICA

Atmospheric studies over Antarctica are important for the following aspects:

1. Climatic history
2. Global circulation
3. Global warming
4. Global pollution(reference levels)

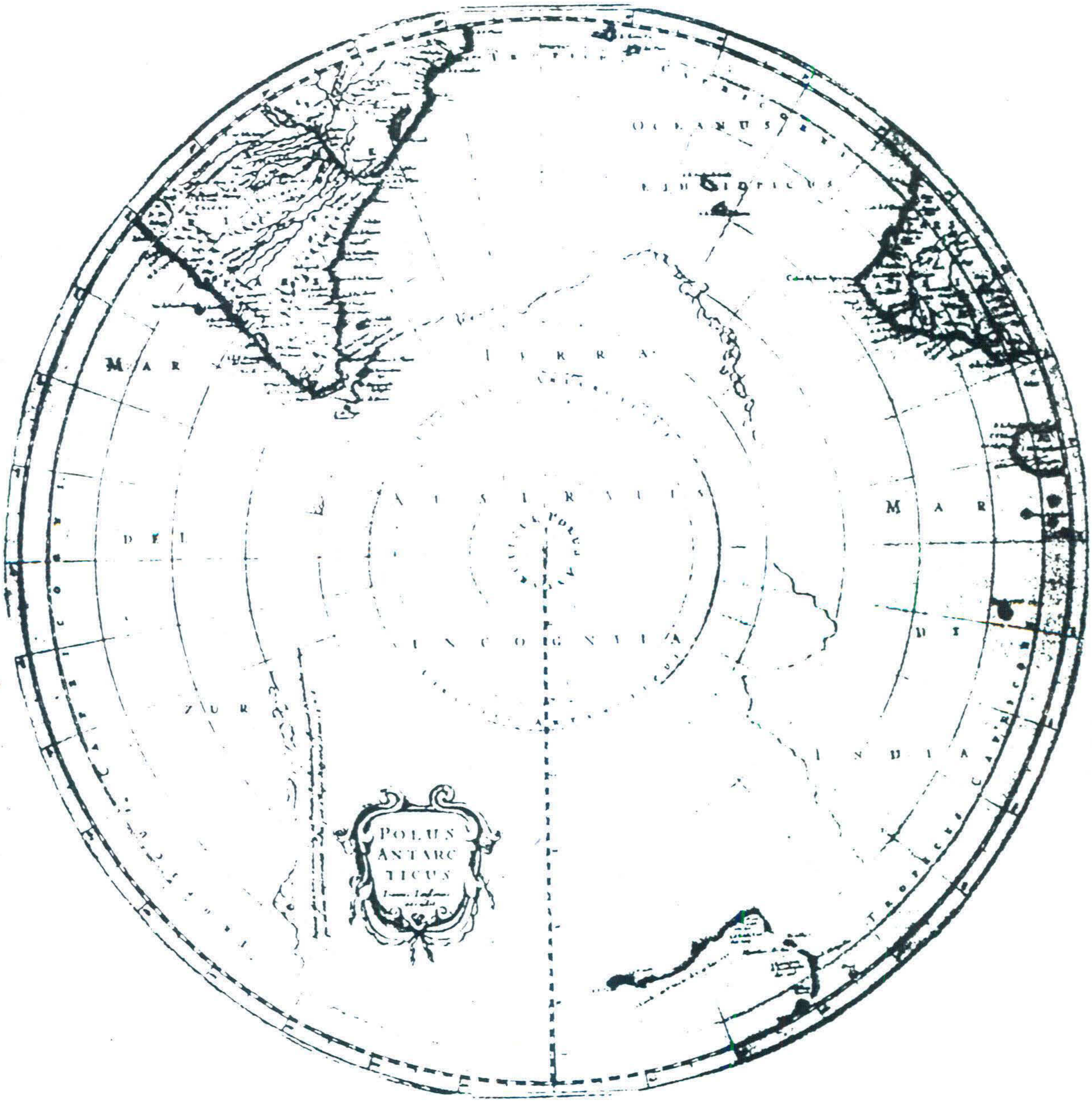

Figure 1.8 Teera Australis Incognita this map was published in 1650,was based on one prepaired in 1641 by Henricus Hondius. The polar continent is delineated partly by island chains and partly by an inspired line (after Walton 1987)

Antarctica is a prime store of past knowledge on world climate and atmospheric changes. The 2,000 m thick ice, carries within it the climatic history of the past 200,000 years (Peel, 1983; Lorius et al., 1985; Bonner and Walton, 1985).

Antarctica plays a key role in the energy balance of the earth and hence the Earth's climate (Rubin, 1962). It serves as the major `heat sink' during summer and as a source of heat during winter. Thus, to device a way of reliably forecasting weather and climate, it is first necessary to understand how the atmosphere works and how the energy which drives the global weather system is acquired, stored and distributed.

Antarctica being the remotest and unhabitate portion of the globe, the data of temperature recorded over Antarctica can reveal the global warming as the measurements do not contain any local contamination(Trends, 1993).

Similarly, since the Antarctic continent is surrounded by ocean all around up to a distance of about 2000 km, the pollution level of various pollutants can be treated as the reference pollution levels for most of the pollutants.

Apart from these global problems, meteorological studies are required for day-to-day planning of various out door activities for the expeditioners.

1.6 HISTORY OF METEOROLOGICAL OBSERVATIONS IN ANTARCTICA

The span of direct observations of the Antarctic climate is very short, just a little over 200 years. James Clark Ross made the first qualitative and systematic meteorological observation of lasting value near the Antarctic continent (Meinardus, 1938; Bonner and Walton, 1985). One of the significant discoveries was that the mean surface atmospheric pressure was markedly lower in the southern hemisphere than in the northern (Meinardus, 1938). The explanation for this was interpreted in terms of much stronger westerly circulation prevailing in the southern hemisphere.

For the first 124 years of direct observations, only ten expeditions penetrated south of 50^0 S and their observations were mostly of the ocean climate (Meinardus, 1938). However, several of the observers did collect meteorological data from some subantarctic islands (Meinardus, 1938; Bonner and Walton, 1985). Notable amongst these were the Ross Expedition on Kerguelen , the British and German expeditions to observe the transit of Venus (1874-75) and the German expedition to Royal Bay, South Georgia, during the First International Polar Year (1882-83).

At the turn of the century, Antarctic meteorology made a revolutionary advancement. The first of the wintering bases on the continent was at Cape Adare, Victoria Land, where the British Southern Cross Expedition made detailed daily observations of atmospheric parameters during February 1899 until January 1900 (Borchgrevink, 1901). These data gave the first clear indication of the weather condition likely to confront any party exploring the interior.

Admiral Byrd's expedition during 1930's (Grimmer and Haines,1939; Grimminger, 1941; Court, 1949) produced new information on the vertical structure of the polar atmosphere. Normally temperature profiles were obtained to an altitude of about 1 km, and occasionally in excess of 2 km, using kites and up to 11 km with the aircrafts. From the point of view of the atmospheric boundary layer, the stable temperature inversion which occurs over Antarctica in winter became evident for the first time.

The French expedition which wintered at Port Martin during 1951 and 1952 recorded daily average wind speed of 48.5 m/s (108 miles / hr) which is a world record (Prudhomme and Le Quinio, 1954 and Le Quinio, 1956). They also hold the record for the lowest sea level atmospheric pressure of 926.9 mb. But, by 1955, only 12 fixed, permanently manned weather stations were in operation south of 55 °S.

Most of the meteorological evidence for Antarctica, and in particular for the interior of the continent, has been obtained since the beginning of the IGY in 1957.

1.6.1 HISTORY OF INDIAN METEOROLOGICAL OBSERVATION

With the passage of time and the technological advancements, many countries have established their scientific bases at Antarctica realising its vast potential. Table 1.1 lists major meteorological stations along with their periods of operation. These stations have supplied most of the basic information about the past and the present Antarctic climatology. Their precise geographical locations are shown in Figure 1.5.

India started exploring this icy continent in the year 1981 (Sreedharan and Sharma, 1985; Bhattacharya, 1987; Desa et al., 1983; Katyal and Upadhyay, 1983; Bhukan Lal, 1987; Lal, 1988; Pasricha et al., 1991; Naithani and Dutta, 1995; Naithani et al., 1995). In the year 1983-84, India established its first permanent station named '**Dakshin Gangotri**' on the ice shelf (70.8 S; 12 E) ion Princess Astrid Coast. It got sunk in ice which necessitated the erection of another permanent station. **Maitri** (70.7^0 S; 11.7^0 E) was established in the year 1988-89 (Wastard and Singh, 1988; Lal, 1988; Pasricha et al., 1991), located in Schirmacher oasis

A number of institutions and universities in India have participated in all the Indian Antarctic Expeditions right from the beginning (1981) and have established a number of atmospheric monitoring equipments.

Table 1.1 List of some of the meteorological stations in Antarctica (Schwerdtfeger, 1984; Scar, 1993).

Name (Abbreviation)	Lat.	Long.	El.(m)	operation duration
Amundson-Scott(SPO)	90		2835	since Jan 1957
Byrd(BYR)	80.0	120.0 W	1530	since Jan 1957
Cape Denison(DEN)	67.1	142.7 E	6	Feb 1912-Dec 1992
D10	66.7	139.8 E	240	since Jan 1980
D57	68.18	137.52	2105	since Jan 1981
D80	70.02	134.7 E	2500	since Jan 1983
Davis(DAV)	68.6	78.0 E	12	since 1969
Dome C	74.5	123.0 E	3280	since Feb 1980
Faraday(FAR)	65.3	64.3 W	11	since Jan 1947
Halley(HAL)	75.5	26.6 W	35	since Feb 1956
Maitri(MAI)	**70.7**	**11.7 E**	**116**	**since Jan 1989**
Mawson(MAW)	67.6	62.9 E	8	since Feb 1954
Mcmurdo(MCM)	77.9	166.6 E	24	since Apr 1956
Mirny(MIR)	66.6	93.0 E	42	since Mar 1957
Mizuho(MIZ)	70.7	44.3 E	2230	since Apr 1976
Molodeznaya(MOL)	67.7	45.9 E	39	since Feb 1963
Neumayer(NEU)	70.6	8.2 W	40	since Mar 1981
Novolarez(NOV)	70.8	11.8 E	99	since Feb 1961
Pionerskaya(PIO)	69.7	95.5 E	2740	May 1956-Dec 1958
Port Martin(PMA)	66.8	141.4 E	14	Feb 1950-Jan 1952
Syowa(SYO)	69.0	39.6 E	15	since Feb 1966
Scott Base(SCO)	77.9	166.7 E	14	since Mar 1957
Vanda(VAN)	77.5	161.6 E	94	since 1969
Vostok(VOS)	78.5	106.9 E	3488	since 1958

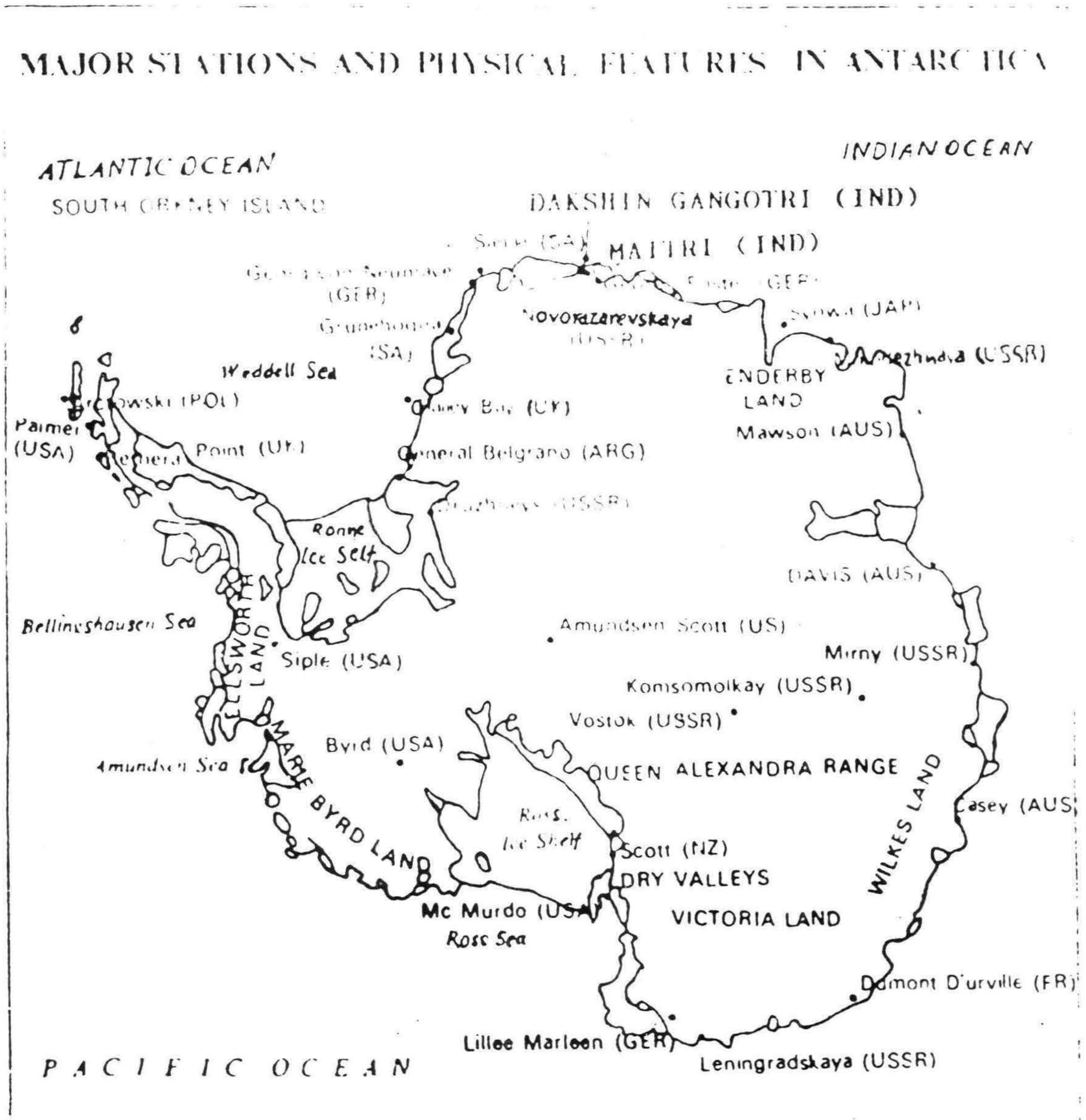

Figure 1.9 Map showing the location of major meteorological stations in Antarctica (after USARP,1984)

1.7 AIM OF THE PRESENT WORK

Fig. 1.9 shows the geographical location of various stations in Antarctica. The Indian Antarctic station, Maitri has a unique place in the east Antarctic region. There is no other meteorological station within a rangeof about 400 km around it. This necessitated the generation of its own meteorological data for various day-to-day activities (convoy operations, helicopter services, field work etc.) and scientific investigations related to the study of global change,, energy budget and pollution etc.

The present work aims to study the general climatology of Maitri by analysing the meteorological data collected at the Indian Antarctic station, Maitri during the year, 1992.

Chapter 2

METEOROLOGICAL INSTRUMENTATION AT THE INDIAN ANTARCTIC STATION MAITRI

2.1 INTRODUCTION

Probing the atmosphere over Antarctica using modern techniques started with the IGY and in the last few decades, a variety of instruments have been deployed over this icy continent to study the short as well as the long term trends of meteorological parameters (Neff, 1980; Kobayashi and Ishikawa, 1983; Schwerdtfeger, 1984; King and Anderson, 1988; Argentini et al., 1990; Streten, 1990; Pasricha et al., 1991; Naithani and Dutta, 1995; Naithani et al., 1995). By now, many Antarctic stations have a full fledged met programme which is essential for various programmes.

The techniques used for studying the met parameters are broadly classified into the following two categories:

1. Direct or in-situ measurement techniques, and
2. Remote sensing techniques.

The direct sensing techniques include surface instruments, instrumented towers, free rising balloons, aircraft instruments, etc. While the remote sensing techniques include radar, sodar, lidar, atellites, mixed radio acoustic systems, etc. Depending upon the meteorological parameters to be measured, both of these techniques have their own importance and are at times complementary or supplementary to one another.

The remote sensing techniques are relatively less expensive as compared to in-situ sensors, such as aircraft measurements. They also provide a better resolution in time and space than that is available by the in-situ instrumentation. The remote sensing techniques are generally automatic and can be operated on real time basis without any manual attention as compared to the radiosonde or aircraft measurements. But the information provided by the former techniques are often *qualitative* and confined to the measurement of one or two meteorological parameters only. The direct probing techniques, on the other hand, give us reliable *quantitative* estimates of atmospheric parameters, but the measurements are point measurements in the case of stationary instruments or one-dimensional as supplied by radiosondes or air crafts, etc. The precise and accurate measurements of meteorological parameters need appropriate combination of the direct and the remote sensing techniques for a better understanding of the atmospheric dynamics.

The Indian Antarctic programme is relatively new as the permanent Antarctic station, Maitri was established only in the year 1988-89. At present both the direct and remote sensing instruments are in use at the Maitri station. The instrumentation consists of:

1. An Automatic Weather Station measuring all met parameters, and
2. A PC based monostatic acoustic sounding system to map the atmospheric dynamics right from surface up to a height of 1 km.

Figure 2.1 gives the detailed map of the Maitri station showing the main building and various met instruments. Because of undulations various experiments have to be spread over an area of about 400 m^2.

2.2 METEOROLOGICAL MEASUREMENTS

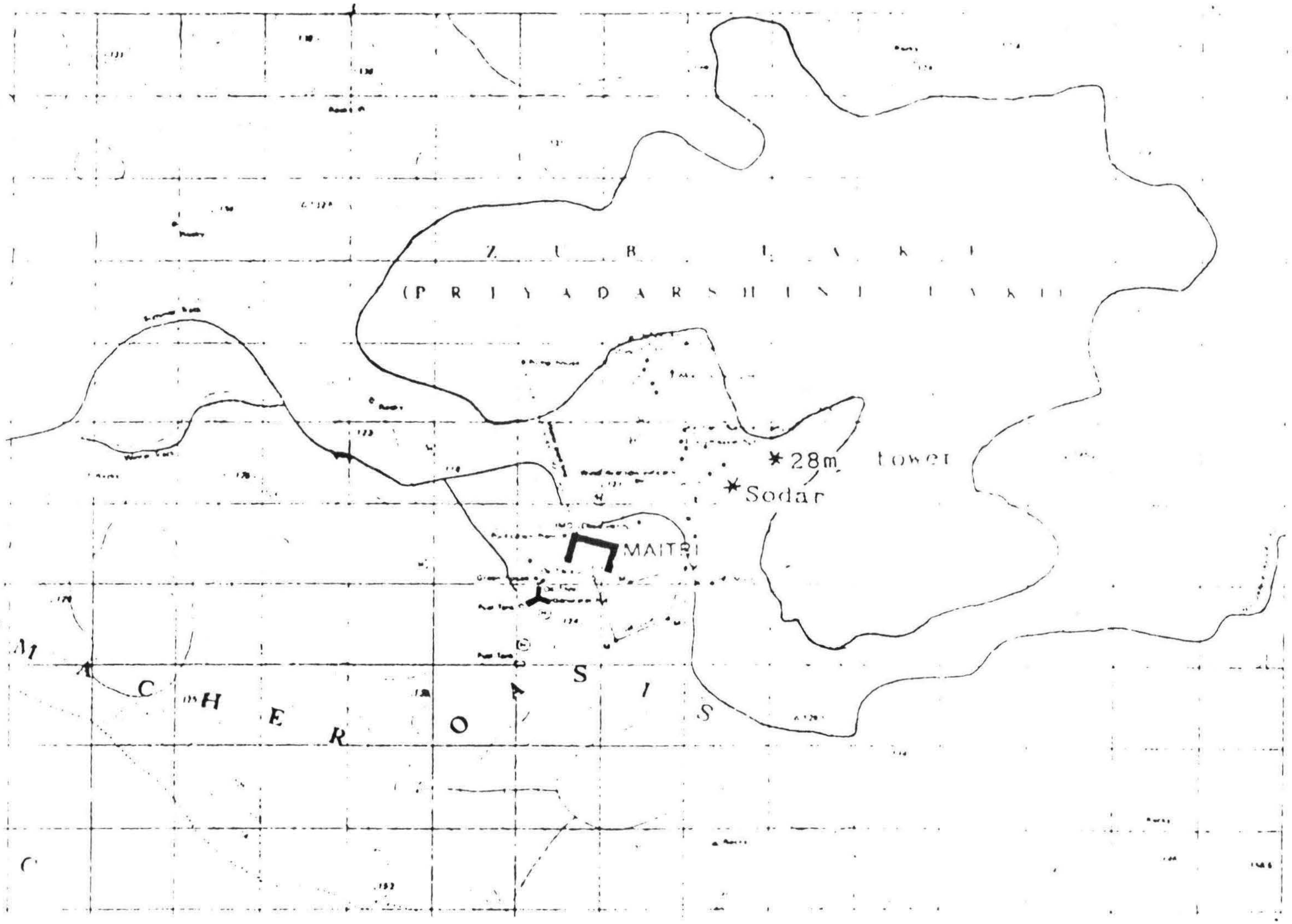

Figure 2.1 Detailed map of Maitri showing the main station building marked as Maitri, location of various ABLexperiments (*) and the Priyadarshini lake (published by Survey ofIndia 1993)

The meteorological sensors have been mounted on a 28 m tower to yield met parameters and to compute heat flux. The sensors have been installed at four levels measuring 1.8, 4.5, 11.3 and 28 m from the ground, respectively. The different heights were so chosen that the spacing between different level sensors is nearly logarithmic. This is because the profiles of temperature and wind parameters are height dependent and tend to decrease more steeply near the ground due to frictional drag, surface heating, evaporation, etc.

The meteorological sensors were of slow response type and were mounted on 1 m booms. The air temperature and humidity were measured using the platinum resistance thermometer (PT 1000) and a sensitive humicap sensor, respectively. While wind speed and direction were measured using a cup-anemometer and a sensitive rotating arm wind vane, respectively. All these sensors were calibrated by the India Meteorological Department, Pune. Pyroanometer for the measurement of solar insolation was mounted on a separate mast. The data loggers for all the met sensors have been placed inside the NPL hut situated at a distance of about 130 m from the 28 m tower (Fig. 2.2). Fig. 2.2 shows the location of various instruments, buildings and the NPL hut at Maitri .

2.2.1 DESCRIPTION OF TOWER INSTRUMENTATIONS

The instrumented tower (Figure 2.3) is located in the South-East (SE) direction (upwind) of the instrumentation hut (housing the data logger) at a distance of about 125 m. The south-east direction being the prevailing topographical wind direction, the observations were not affected by the station buildings and other structures. The wind speed and direction sensors were mounted on 1.5 m booms extending in the SE while the temperature and humidity sensors were mounted on

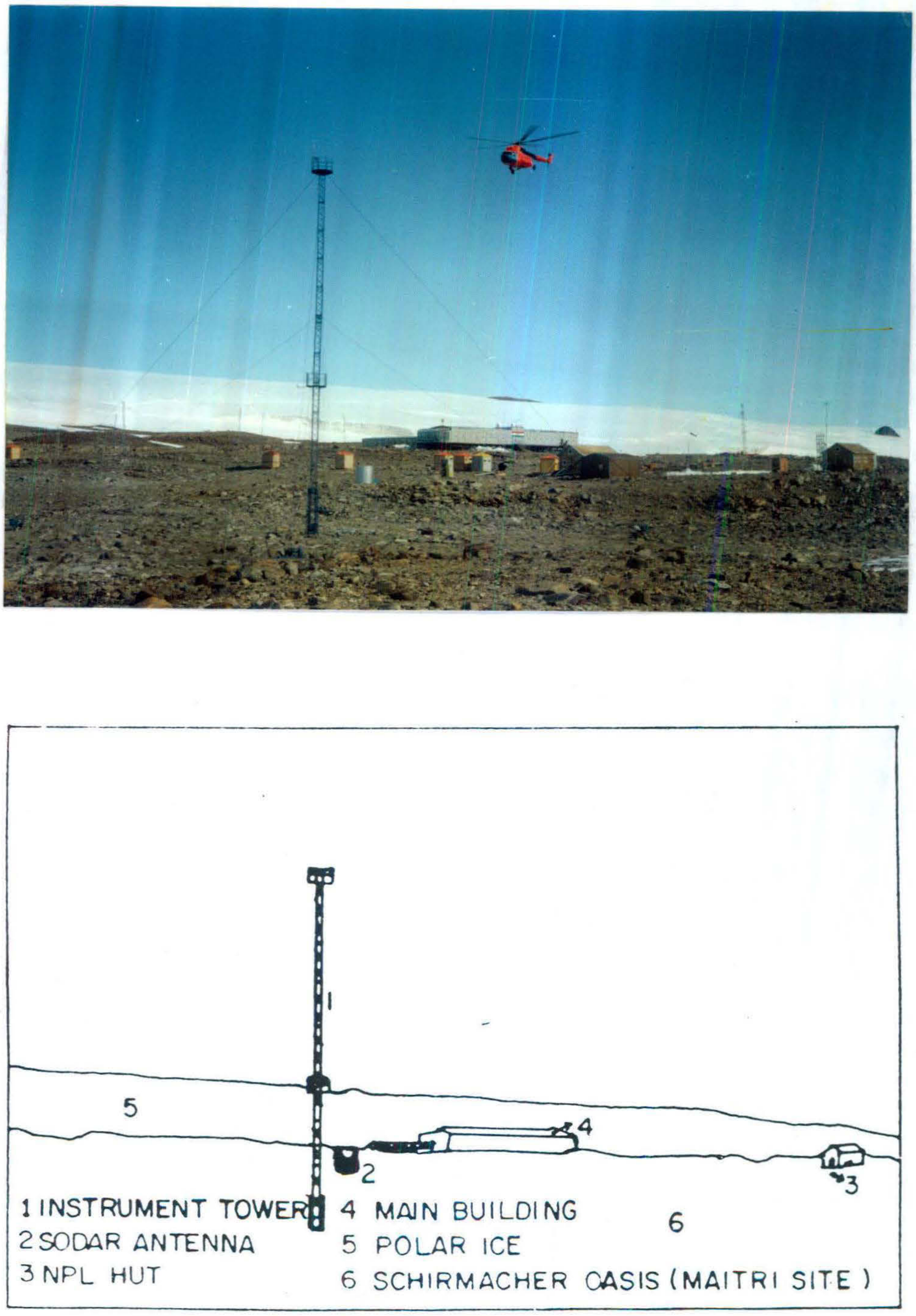

Figure 2.2 Photograph showing the location of main station building various scatterd hutts housing different instruments, sodar antenna and the 28m tower in the Schirmacher region. Polar ice is also seen, various feature are marked below

Figure 2.3 Photograph showing the 28m tower. Tow plateforms fitted 11m and 28m are also seen. The the back ground shows partially snow covered hilly terrain

Figure 2.4 Photograph showing the installation of sensors on the 28m tower in progress. The temperature and humidity sensors are facing south-west while wind vel.& dir. sensors faces south-east

booms facing south-west (Figure 2.4). Since the wind from the north-west sector was observed for a very small percent of time, no effort was made to eliminate the shadowing effect of the supporting tower.

2.2.1.1 Cup Anemometer The cup anemometer consists of 3 hemispherical cups or truncated cone cups fixed to rotate in horizontal plane on their axis of symmetry. Due to the movement of air mass, momentum is transferred to cups which start rotating. Suitable transducer is coupled to convert rotations into electric signals which are then recorded in the data logger. Low inertial system gives fast response with a limited range. With proper design, fairly good response and a range of measurement can be obtained. Starting speed, over speeding and friction are some of the factors which induce errors in the measurement.

Specifications:

Sensing : 3 cup assembly and Optical (IR) sensing, Hall effect sensor and multipole magnet for low power amplification.

Range : 0 - 60 m/s

Distance constant : approximately 1.5 m

Threshold : < 0.3 m/s

Accuracy : 2 %

Output Frequency : proportional to wind speed i.e. 17 Hz/m/s

Cup diameter : 50 Cm.

The sensors were fitted with 10 watt heating elements to 'combat' icing and riming.

2.2.1.2 Wind Vane It consists of two sub assemblies, the vane and the signal generator. The wind vane are properly balanced and critically damped to get fairly fast response and avoid over/undershooting. The sensor was provided with 10 watt heating element.

Specification

Sensor : Light weight vane coupled to linear potential

Mechanical angle : 360^0

Electrical angle : 357^0

Threshold : 0.3 m/s

Accuracy : 2^0

Physical dimension : 250 mm

Vane sweep : 350 mm Brass, Aluminum construction with weather-proof paint.

2.2.1.3 Platinum Resistance Thermometers In the resistance thermometer sensor, the resistance offered by a high platinum wire to the passage of an electric current is a function of temperature and forms the basis of a precision resistance thermometer. The platinum resistance thermometers are very accurate sensors, give moderate response time and are widely used for surface/tower measurements. The temperature sensors were housed in a well insulated shield in the form of an umbrella over the top of the housing to protect them from direct exposure. The reflected component of radiation in the ice-free zones in summer is minimum. However, extra care was taken in the design of the shield to keep these effects at a minimum. In the winter period, when the Schirmacher region is covered with snow, the albedo is high but the sun is no longer above the horizon.

Specifications:

Sensor : The temperature sensor is a Platinum wire whose resistance varies with temperature (0 to 5 volts corresponds to-40 to +60^0 C)

Accuracy : + 0.3^0 C.

Response time : Approximately 30 seconds

2.2.1.4 Humidity Sensor In the humicap sensor a thin film of gold is sputtered in a fixed pattern on both sides of a thin hygrometer polymer substrate to form two electrodes of a capacitor with polymer as dielectric. As humidity changes, the capacitor changes due to change of dielectric constant of the polymer.

Specifications:

Range	: 5 - 100 % relative humidity
Accuracy	: + 2%

2.2.1.5 Data Logging System Data logger for the 28 m tower sensors consists of a microprocessor based data logging system. Analog signals from the instruments are led by a 5 core cable to the logging hut situated about 125 m from the tower. The data logger also supplies power for heater element which gets switched on automatically, the moment air temperature falls below -5^0 C or if the cups do not rotate due to heavy ice formation. All the heater controls and sensors are connected to the main data logger through a 64 pin connector.

2.2.2 SOLAR RADIATION MEASUREMENTS

The total amount of energy received by a horizontal surface exposed to radiation from the sun and sky is of fundamental importance in meteorology. The solar radiation from the sun and the part which reaches the earth after being scattered or reflected by the atmosphere and its constituents (e.g., clouds, smoke, dust, etc.) is contained in the range of wavelengths between 0.3 and 4 microns. The intensity of radiation is expressed as the amount of radiant energy falling on unit area of the surface in unit time. The unit usually used is watt/m^2. The solar constant, being the mean value over the whole year of the intensity of solar radiation reaching a surface placed normal to the sun's rays just outside the earth's atmosphere, is assumed to be about 1380.6 watt/m^2

2.2.2.1 Principle Thermopiles are used as the sensitive elements for the measurement of solar radiation. In this, a thin blackened surface, supported inside a relatively massive, well-polished case, is exposed to the radiation. The difference in temperature between the sensitive surface and some reference point or pointsinside the instrument case is measured by several thermo-junctions arranged in series. The temperature of the blackened surface rises, until its rate of loss of heat by all causes, isequal to the rate of gain of heat by radiation. This rise in temperature sets up a thermal e.m.f. which is measured on a recording millivolt meter.

In the Moll-Gorczynski pyroanometer, the sensitive surface consists of the thermo pile elements arranged as shown in Figure 2.5, and coated with Parson's optical black lacquer. Thermo pile is made up of 14 alternate strips of manganin andconstantan, 5 mm long, 1 mm wide and 0.005 mm thick. The active or hot junctions (a) lie along the centre line of the surface, while the outer passive or cold junctions (p) are in good thermal contact with the relatively massive supporting posts which are insulated electrically but not thermally from the base plate (g) by a coating of tissue paper and shellac. Both active and passive junctions are exposed to radiation, but the active junctions have a very small heat capacity owing to the extreme thinness of the strips, while the passive junctions have a larger thermal capacity and heat conductivity due to their connections with the base plate. The temperature of the centre of the receiving surface is therefore raised above that of the instrument and this temperature increase is taken to be a function of the radiation fallingon the sensitive surface.

If the rise in temperature is to be a function only of the intensity of radiation, the rate of loss of heat by the thermopile must be independent of the external conditions, such as the ambient temperature or the wind speed past the instrument. If therise in temperature is to be proportional

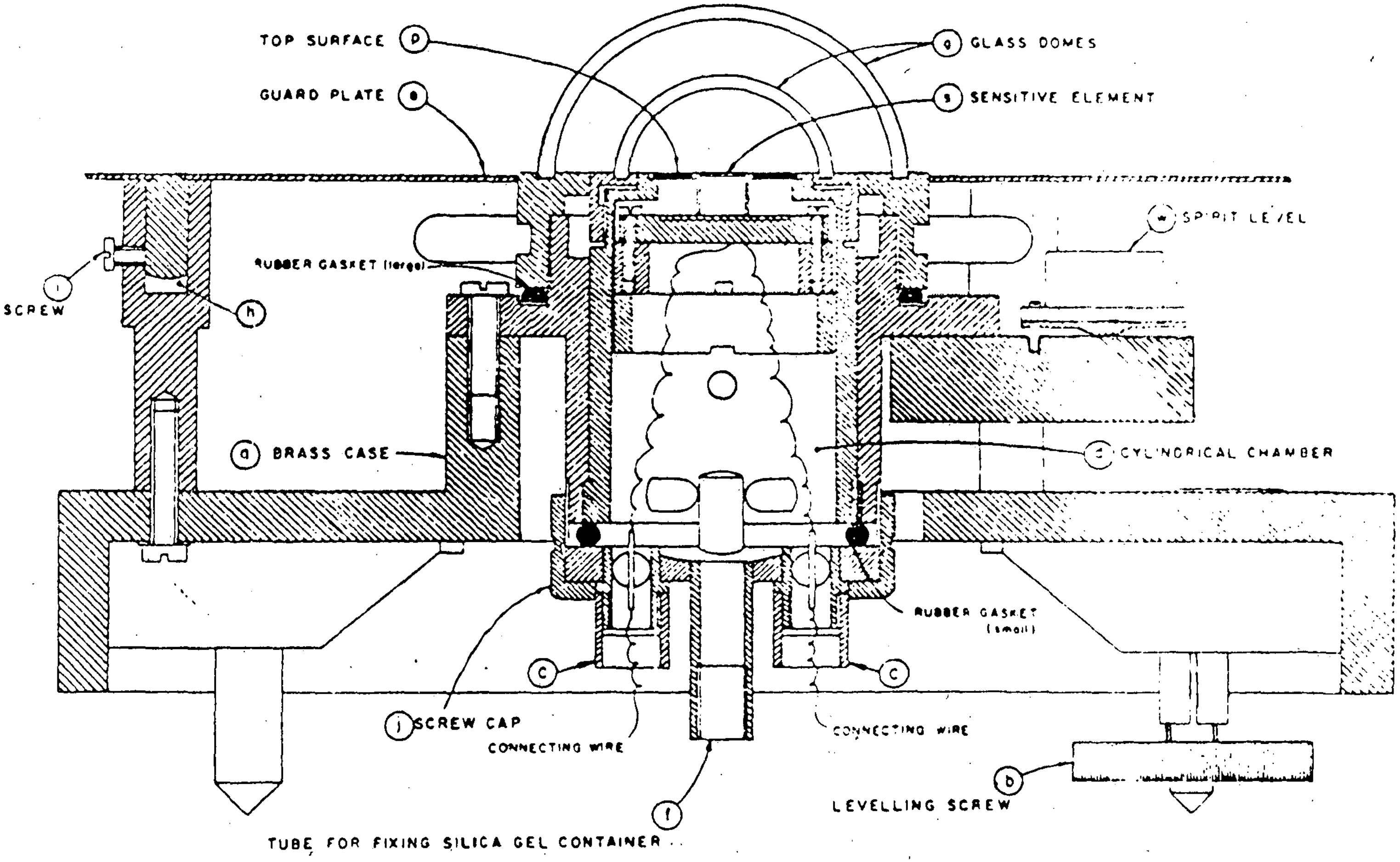

Figure 2.5 The sketch diagram of pyroanometer

to the radiation intensity, all convection currents must also be avoided. The time constant or lag coefficient should also be kept conveniently small. By making the case massive and the outer surface highly polished, the temperature is kept uniform. While by covering the receiving surface with two concentric hemispherical glass domes, the sensitive surface is shielded from wind and rain and the tendency to form convection currents are reduced.

The suspended moving coil galvanometer recorder is used with the pyroanometer for recording continuously the solar radiation.

2.2.3 DATA COLLECTION AND QUALITY CONTROL

Data-logger was programmed to calculate the mean value of each channel over a desirable period. The data was accessed after every one second and was stored to calculate averages over a period of 10 minute and 30 minutes. Under normal atmospheric conditions a 30 minute averaging time was chosen.

2.3 REMOTE SENSING TECHNIQUE

Amongst the various remote sensing techniques, the most commonly used technique to probe the atmosphere, is the acoustic remote sensing. Because of its high sensitivity to temperature and velocity fluctuations in the atmosphere in comparison with lidar or radar, and because of its low cost of fabrication and continuous operation, this system has been most commonly used by various workers to probe the Antarctic boundary layer (Neff and Hall, 1976; King et al., 1987; Culf, 1989; Fiocco et al., 1990 and Dutta et al., 1991; Jaya, 1995). It gives us the detailed description of the atmospheric dynamics on round the clock basis under various atmospheric conditions.

The acoustic sounder (sodar) was specifically developed for Antarctica, at the National Physical Laboratory, New Delhi and was installed at Maitri station in the year 1990-91. It is a PC controlled system so that the continuous recording could be madeautomatically for days together. Also, the color display of the data gives a better insight into the atmospheric dynamics.

2.3.1 ACOUSTIC SOUNDER OR SODAR

In this system acoustic energy transmitted vertically up intothe atmosphere is scattered by turbulent fluctuations of temperature and wind velocity and by sharp temperature gradients. In the monostatic mode, information only from the small-scale (~10 cm) temperature fluctuations is provided. Such fluctuations are generally associated with turbulence within regions of non-zero potential temperature gradient. The intensity of the received signal contains the information on temperature turbulence in the scattering medium. Apart from the dynamics of the atmosphere, the parameters that can be monitored by the sounder are height/thickness of inversions, their time of onset and dissipation and dynamics.

The block diagram of the acoustic sounder showing the entire system operation and sub-system assemblies are shown in Figure 2.6. Figure 2.7 shows the sodar system electronics installed in the instrumentation hut at Maitri.

In actual practice, a powerful pulse of sound (100 W; 2000 Hz) is transmitted vertically up into the atmosphere. The echo returns are received by the same antenna and then amplified to display the atmospheric processes. One such photograph of inversions is shown in Fig. 2.8.

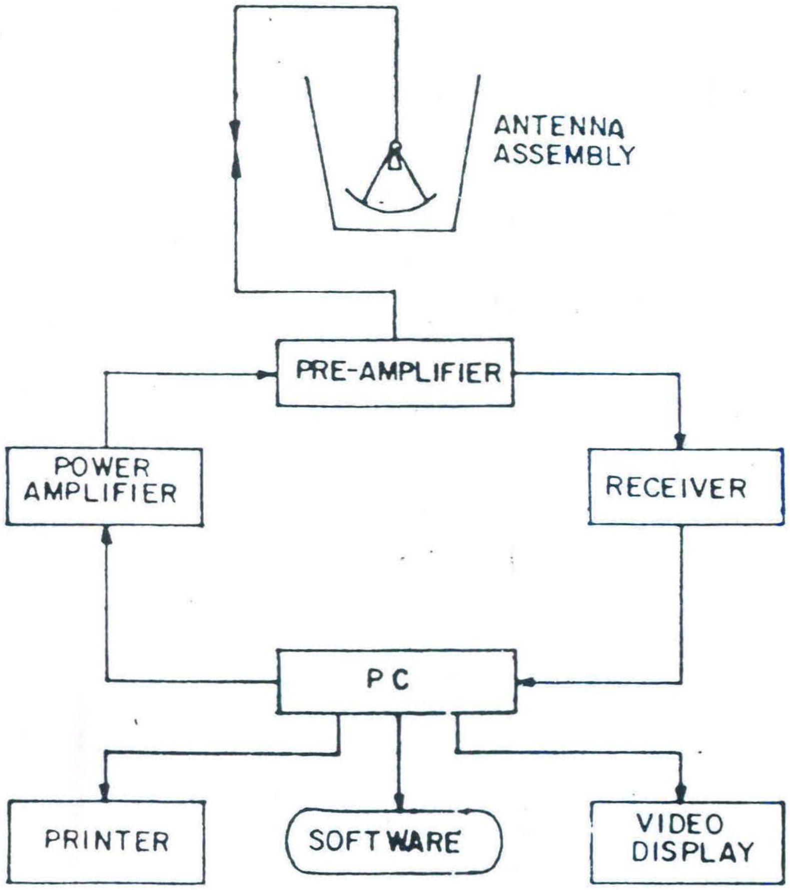

Figure 2.6 Block diagram of acoustic sounder showing entire system assembly

Figure 2.7 Photograph showing sodar system electronics (blue rack) and the automatic weather station installed in the NPL hut at Maitri. The vidio screen shows that recording is in progress

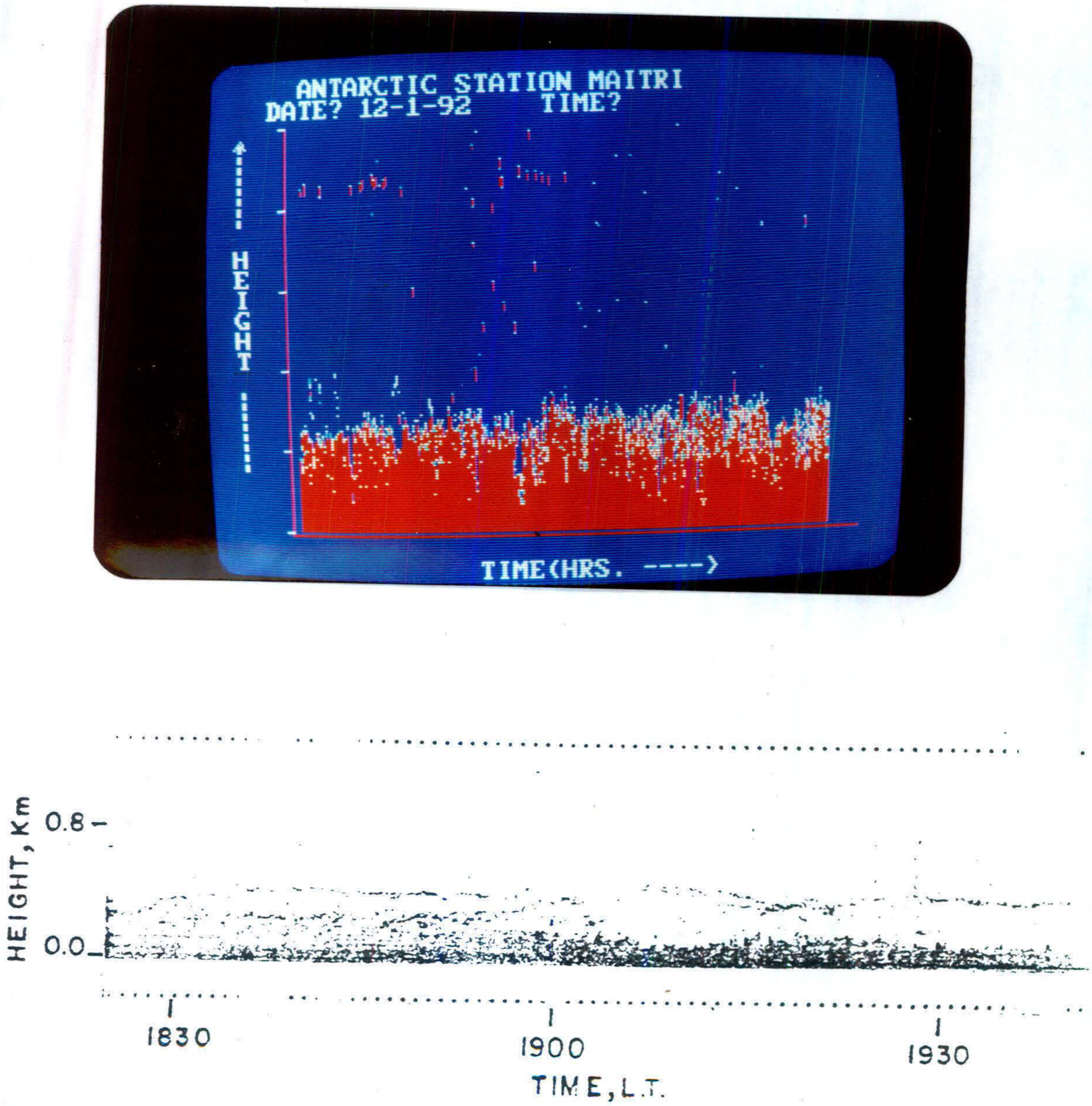

Figure 2.8 Photograph showing the inversion at Maitri Antarctica during the year 1992

The Fig. 2.8 shows that the inversion at Maitri is about 400 m thick. These types of inversions are seen throughout the year at Maitri.

Fig. 2.9 and shows the sodar antenna installed at Maitri. This has been specifically developed to withstand the low temperature and high Antarctic winds.

The data from all these instruments obtained for the period of one year duration during January to December, 1992 has been analysed to study the climatology over MaitriAntarctica. The study has been presented in the next chapter.

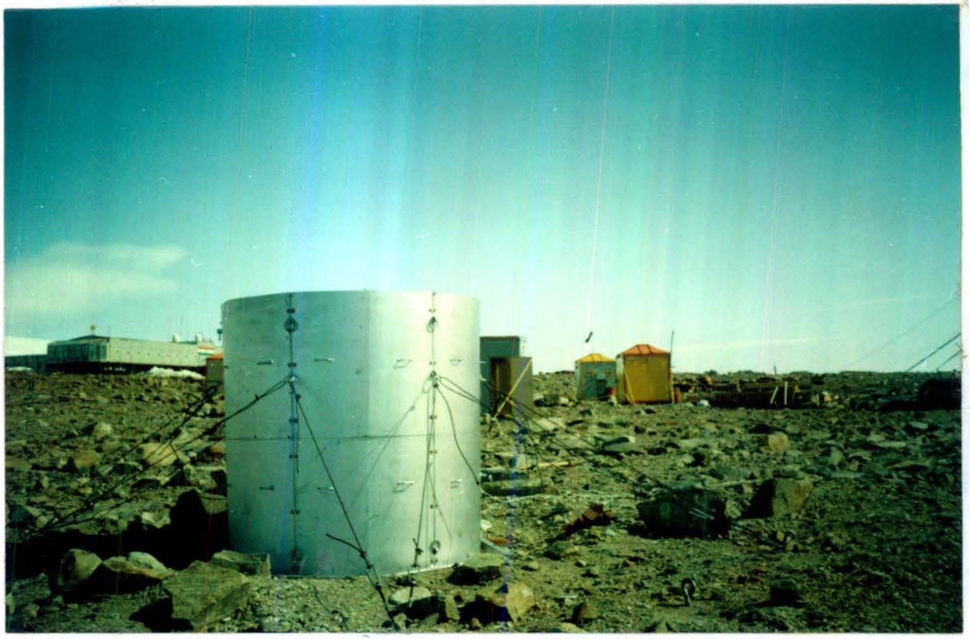

Figure 2.9 Photographs showing the sodar antenna installed at Maitri, from tow different positions

Chapter 3

CLIMATOLOGY OVER MAITRI

3.1 INTRODUCTION

The general climatic features of the Antarctic continent as awhole are discussed in this chapter. In Antarctica, the most important aspects related to its environment are the following:

1. Solar Radiation
2. Temperature
3. Wind
4. Pressure
5. Humidity
6. Snow fall and snow drift
7. Visibility and cloudiness
8. Inversions

The general trend of these parameters is discussed below.

3.2 SOLAR RADIATION

The radiation budget of the Antarctic climate is one of the most interesting features. Due to the ice cover, the continental surface has an albedo approximately between 70-80%, implying that three-quarters of the incident short-wave radiation from the sun is reflected back into the space. Little of this reflected solar radiation is absorbed by the thin overlying atmosphere.

The incoming total solar radiation data has been analysed to compute mean hourly mean daily and monthly values. The monthly daily averaged solar radiation has been plotted in Fig. 3.1a This shows that the maximum solar radiation is receieved during the peak summer season, i.e. during December while, no energy is receivedduring the dark polar night (June-July). Mean hourly values of solar radiation recorded at 1400 hrs and at 2000 hrs for various months are also plotted and compared in fig.3.1b. It may be noted that even in peak summer months (December-January), the decrease in solar radiation in evening is ~1/5th of the local noon value. A major cause for this variation may be due to fact that, in fact Maitri is located in Schirmacher region wherein, the polar cap ice thickness is about 80 m towards South. In the evening, the sun goes below the polar cap ice and the entire Schirmacher region is shadowed, resulting in sudden cooling at night even in the peak summer.

Fig. 3.2 shows the average solar radiations during December and May which represents winter and summer months respectively. It is character feature of Antarctica that there is no Sun shine in winter months of June and July. There is significant diurnal variation in the received energy in both winter and summer. It has maximum around local noon and minimum around mid-night.The different values of solar radiation corresponding to figure 3.1a&b and figure 3.2 are tabulated in tables 3.1and 3.2.

Table 3.3a gives the global solar radiation (the sum of direct and diffused solar radiation incoming on a horizontal reference area) received at different places in Antarctica. Table 3.3b gives the duration of daylight at various latitudes. The factors affecting the global radiation in Antarctica depend upon the mass of air through which the solar energy is transmitted, the cloud cover, latitude,

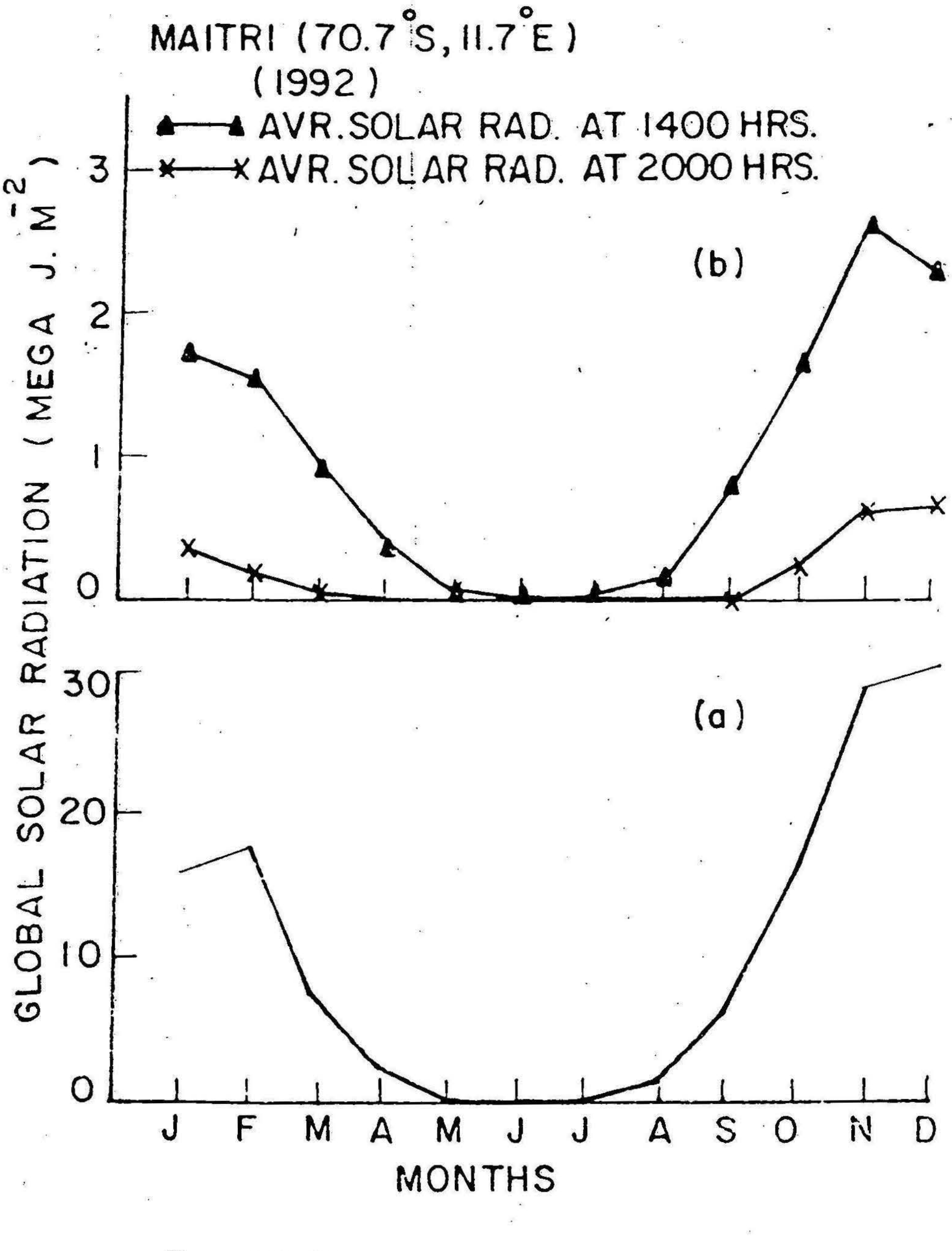

Figure 3.1a Mean monthly variation of solar radiation at Maitri during, 1992

Figure 3.1b Mean monthly variation of solar radiation at Maitri at 1400hrs and at 2000hrs during 1992

Table 3.1 Mean monthly Golbal solar radiation (Mega Joule M^{-2}) at Maitri in 1992

MONTH	TOTAL	At1400hrs	At2000hrs
JAN	17.34	1.70	0.37
FEB	17.91	1.56	0.20
MAR	7.73	0.88	0.05
APR	2.95	0.36	_
MAY	0.34	0.05	_
JUN	_	_	_
JUL	_	_	_
AUG	1.71	0.13	_
SEP	6.89	0.77	_
OCT	16.49	1.63	0.22
NOV	28.97	2.36	0.60
DEC	29.24	2.29	0.60

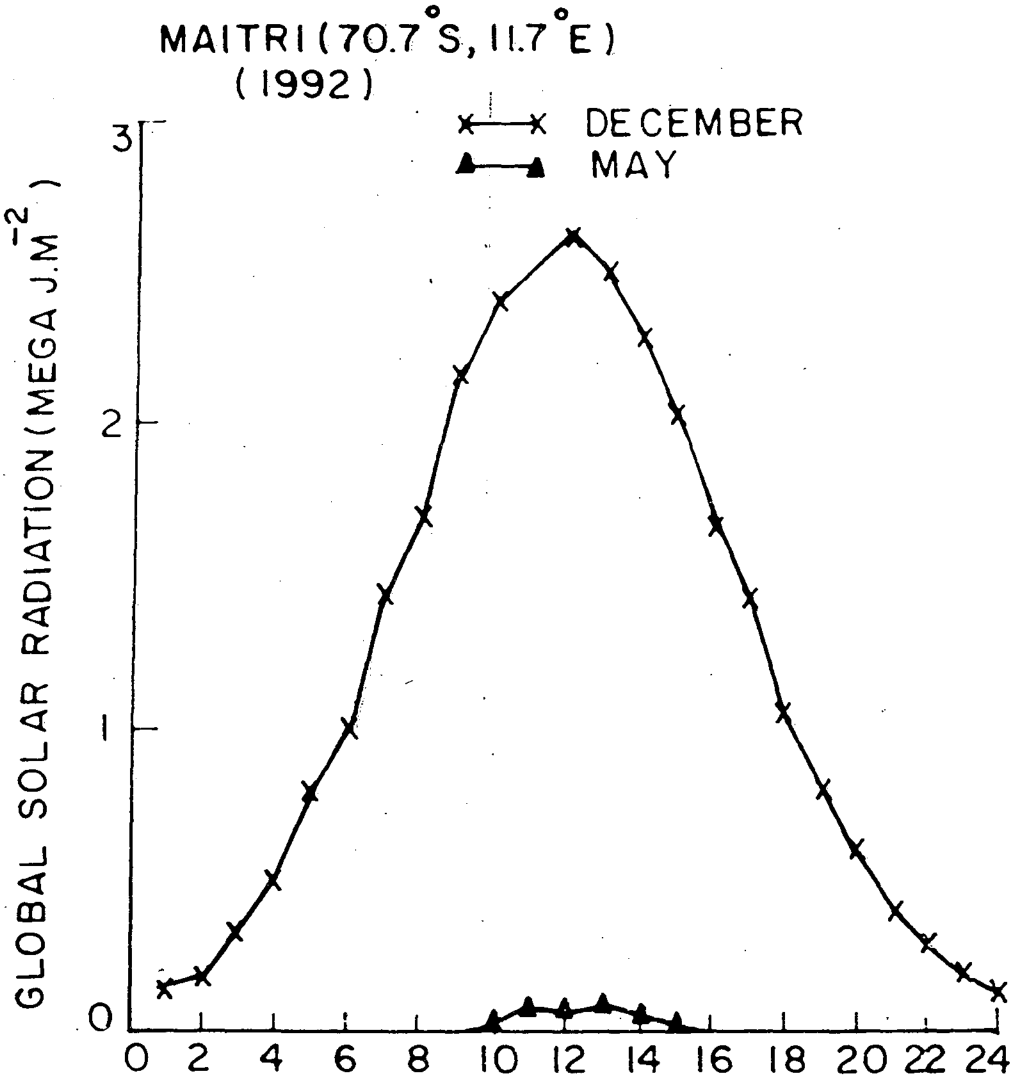

Figure 3.2 Mean hourly variation of solar radiation at Maitri in a summer month Dec. and a winter month May, 1992.

Table 3.2 Mean hourly Global solar radiation (Mega Joule M^{-2}) in Dec.and May 1992 at Maitri Antarctica

Time hrs	December	May
0100	0.14	_
0200	0.18	_
0300	0.32	_
0400	0.51	_
0500	0.81	_
0600	1.04	_
0700	1.42	_
0800	1.69	_
0900	2.17	_
1000	2.41	0.03
1100	2.52	0.07
1200	2.63	0.08
1300	2.51	0.09
1400	2.29	0.05
1500	2.06	0.02
1600	1.66	_
1700	1.42	_
1800	1.06	_
1900	0.82	_
2000	0.60	_
2100	0.40	_
2200	0.28	_
2300	0.17	_
2400	0.13	_

Table 3.3a Mean monthly and yearly sums of global solar radiation in M J /M^2(second line), recorded at various stations on on the continent.The first line indicates station, latitude, longitude,elevation from msl (m) and observational period, see table 1.1 for abbreviation of station (after Schwerdtfeger, 1984 and Stretan, 1990)

J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
HAL, 75.5 S, 26.6 W, 35 m, 1963-1972												
762	395	189	28	0.1	-	-	10	115	384	687	885	3455
FAR, 65.3 S, 64.3 W, 11 m, 1963-1972												
552	349	185	73	20	4	12	67	187	407	556	654	3065
MAI, 70.7 S, 11.7 E, 116 m, 1991-1993												
815	**490**	**260**	**61**	**7**	**-**	**-**	**30**	**160**	**440**	**710**	**895**	**3868**
MAW, 67.6 S, 62.9 E, 8 m, 1968-1983												
517	380	288	149	70	42	55	118	218	371	472	563	3243
MIR, 66.6 S, 93.0 E, 42 m, 1963-1973												
843	519	302	107	23	3	10	64	227	472	778	968	4316
MIZ, 70.7 S, 44.3 E, 2230 m, 1979-1980												
902	561	319	78	5	-	<0.5	38	205	521	847	1123	4599
MOL, 67.7 S, 45.9 E, 39 m, 1963-1973												
829	496	257	75	11	-	5	57	217	502	775	1004	4228
NOV, 70.8 S, 11.8 E, 99 m, 1963-1973												
832	485	248	69	4	-	-	34	175	454	721	915	3937
VAN, 77.5 S, 161.6 E, 94 m, 1969-1970												
812	408	88	9	-	-	-	4	39	298	701	800	3159
VOS, 78.5 S, 106.9 E, 3488 m, 1963-1973												
1087	601	224	18	-	-	-	3	98	458	940	1235	4664

Table 3.3b Significant dates of the duration of the daylight at various latitude (Schwerdtfeger1984)

Latitude	S-POLE	85°S	80°S	75°S	70°S
Sun stays above horizon until	Mar 23	Mar 10	Feb 25	Feb 12	Jun 26
Sun remains below horizon from	Mar 23	Apr 04	Apr 19	May 05	May 25
Sun returns at	Sep 21	Sep 08	Aug 25	Aug 08	Jul 19
Sun stays above the horizon from	Sep 21	Oct 05	Oct 18	Nov 02	Nov 19

elevation from mean sea level and the distance from the coast. From the two tables it can be seen that depending upon the duration of daylight, the solar radiation received at the surface varies greatly from month to month. This, in turn, is responsible for the development and maintenance of nearly ever present temperature inversions over the continent (Philpot and Zillman, 1970; Schwerdtfeger, 1970, 1984; Parish, 1988).

3.3 TEMPERATURE

The combination of altitude, winter darkness, weak transport of heat from lower latitudes, extremely high winds, intense radiation loss from the surface and very low humidity produce an annual temperature variation quite unlike observed elsewhere on the earth. Climatically, Antarctica is the coldest region on earth, the average annual temperature being below - 5^{0} C, while part of the high plateau has an average annual temperature below- 55^{0} C (Schwerdtfeger, 1984). The minimum temperature recorded so far is - $89^{0}.3$ C in 1983 at Vostok (Schwerdtfeger, 1984)

Fig. 3.3 presents monthly daily average temperature. The extreme maximum and minimum observed during each month are also plotted. It may be noted that the mean temperature ranges between +1.3 to -18.9^{0} C. However, the extreme values range between +7.8 to -31.7^{0} C. The average monthly values of extreme maximum, extreme minimum and daily mean tempratures are given in table 3.4.

The peculiar annual march of temperature near the surface of the Antarctic plateau is controlled by the radiation conditions. Summer is very short, only for the period from December to January. Because of short duration and the shape of the temperature variation, it is called the '***pointed summer***'. The summer warming arises from the combination of increased solar radiation

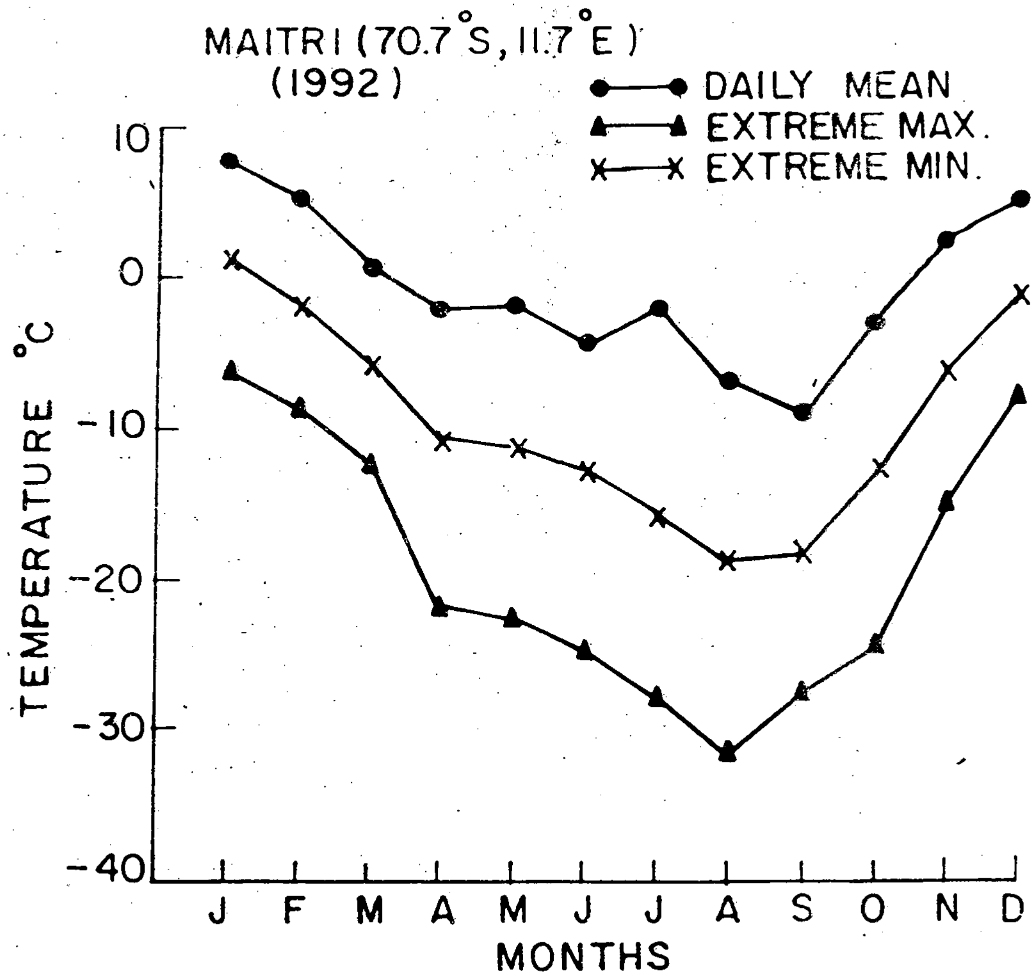

Figure 3.3 Mean monthly variation of max.,min. and aveg. temperatures at Maitri during, 1992.

Table 3.4 Climatic data of Maitri Antarctica, 1992(After Kopper,1995)

Month	Tempreture°C			Mean wind vel.	MSL press (mbar)	Prevail. Wind dir.	Relative Hum. (%)	Mean cloud. (octas)	Number of days with		
	extr. max.	daily mean	extr. min.						blizzards	vel>1 12m/s	snow fall
Jan	+7.8	+1.3	-6.4	7.2	989.4	ESE	62	5.4	—	3	6
Feb	+5.3	+0.7	-8.4	7.2	991.1	SE	55	4.5	—	3	4
Mar	+1.0	-3.8	-12.2	10.3	984.3	SE	53	5.7	13	12	8
Apr	-2.2	-8.4	-22.3	8.8	984.6	SE	42	3.9	12	8	8
May	-1.5	-8.4	-22.5	10.8	990.3	SE	39	4.2	6	16	2
Jun	-4.0	-9.7	-25.2	9.3	994.9	SE	35	3.5	1	8	3
Jul	-2.0	-13.1	-28.0	7.7	982.3	SE	32	4.1	6	6	13
Aug	-6.8	-16.0	-31.7	7.2	978.7	SE	30	3.4	6	4	8
Sep	-9.0	-14.9	-27.7	6.7	985.0	SE	37	3.2	5	4	1
Oct	-3.0	-9.5	-24.5	7.7	986.5	SE	43	3.7	8	6	5
Nov	+3.2	-3.0	-15.0	6.7	979.5	ESE	55	3.7	3	2	7
Dec	+5.0	-1.5	-7.7	6.7	984.2	ESE	67	5.2	2	4	6

and a small reduction of surface albedo (resulting from slight metamorphoses of the snow surface as it ages during the spring).In the present context, it is important to note that the efficient removal of thermal energy back to space from the continental ice slopes results in the radiation flux divergence at the surface.. The first light snowfall or influx of drifted snow after mid summer restores the surface albedo and with waning solar input, the temperature begins to fall rapidly. By the end of March the sun has set for the winter and a stable situation called the *'coreless winter'* is reached, in which, for the next six months, the temperature varies by only a few degrees. The lack of well defined minimum in the mean temperatures and the reversals of the expected cooling trend in winter, together create what is known as the coreless winter (Wexler 1958, 1959; Schwerdtfeger, 1970; Wendler and Kodma, 1984). However, the minimum temperature is observed at the end of winter, just a day or so after the return of the sun.

Table 3.5 gives the mean monthly temperature at different stations in Antarctica including the **Maitri** station (Allison et al., 1993; Schwerdtfeger, 1984). The stations stretch from close to sea level to over 3500 m in altitude. At the coastal stations, temperatures below - 20^0 C have been observed, while at the interior stations above 2500 m (D80, Dome C, Vostok), even the warmest month had a mean temperature below - 20^0 C. For all the stations, the summer temperature shows a maxima in January except for **Maitri** (a coastal station) and D80 and Dome C (interior stations), which show a maxima in December. The winter temperatures do not appreciably change from month to month and the minimum temperature is observed in August for all the stations except Vanda and Mizuho. In general the *'coreless winter'* is evident at all stations; the winter temperatures do not have distinctive minima and the temperature traces are rather flat. The station D80, although situated at the same latitude as **Maitri**, has much lower temperatures throughout the year. It is because of its elevation from the sea level. Same is the case with the station D10 which is situated south of Maitri,

Table 3.5 Mean monthly temp. (^{0}C) at different interior and stations at Antarctica with ten or more years of record. For the temp. values, no sign means below 0^0C,* indicates distance from cost;coordinates and abbrevietions used are given in table 1.1.Our data for Maitri station is only for (1991-93). (Schwerdtefeger 1984 and Alison et.al.,1993)

J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
HAL												
4.8	9.8	16.6	20.0	24.4	26.6	28.9	28.5	26.2	19.2	11.6	5.3	18.5
FAR												
+0.3	+0.1	1.0	3.4	5.8	8.1	10.7	11.0	8.3	5.1	2.6	0.4	4.7
MAI, *70 km												
+0.5	**3.5**	**7.8**	**12.0**	**13.8**	**15.2**	**17.4**	**18.1**	**17.9**	**12.4**	**5.8**	**+1.2**	**10.2**
MIR												
1.6	5.3	10.1	13.9	15.3	15.6	16.6	17.4	17.2	13.5	7.0	2.4	11.3
MOL												
0.5	4.0	8.3	11.4	14.2	16.3	18.0	18.7	17.8	13.8	6.1	1.4	10.9
NOV												
0.7	3.7	8.0	12.1	13.3	15.9	17.7	18.5	17.4	12.4	5.9	1.1	10.6
VAN												
+1.3	5.9	20.4	29.7	29.2	30.0	38.0	32.3	31.2	15.7	6.2	+0.4	19.8
MIZ												
18.6	24.3	31.5	36.5	38.7	40.9	39.1	40.4	39.3	35.2	25.0	18.0	32.3
VOS												
32.3	44.3	58.0	64.9	65.9	65.1	67.0	68.3	66.3	57.1	43.4	32.3	55.4
D10, *80 km												
2.9	6.3	11.6	15.5	17.2	18.0	18.7	19.0	16.6	15.1	9.2	3.7	12.8
D80, *400 km												
24.5	31.5	41.6	47.0	50.0	48.0	50.6	50.8	44.8	39.6	34.7	24.5	40.6
Dome C, *860 km												
29.9	40.8	52.5	59.6	61.9	61.0	61.3	63.0	57.8	50.5	39.6	29.0	50.6

and has much lower temperatures for the whole year. This is because D10 is also situated on the ice-shelf at a higher elevation than the **Maitri** station.

3.4 SURFACE WINDS

The radiative flux divergence over the sloping ice surface is responsible for the forcing of the celebrated Antarctic surface wind regime, the ***katabatic winds***. The intense cooling along the continent slope implies a density contrast between the very cold air adjacent to the ice and the relatively warm air somehorizontal distance away. This results in a terrain induced horizontal pressure gradient force often termed as the 'sloped-inversion' force, which is directly proportional to the magnitude of the inversion strength (horizontal density contrast) and to the steepness of the terrain slope (Ball 1960; Mahrt and Schwerdtfeger, 1970; Schwerdtfeger, 1970, 1984; Lettau and Schwerdfeger, 1967; Parish and Waight, 1987). It is this sloped-inversion force which is a dominant forcing mechanism for the surface wind regime called the katabatic winds, wherein the cold dense air mass on to the higher plateau falls down due to the force of gravity towards the coast in a direction set by the fall line (direction of the maximum slope).

The study of wind velocity is absolutely essential to consider the chill factor which the human body experiences in Antarctica. It is important to note that as the wind velocity increases, the load of the warm clothing on the body increases which results in reduced work efficiency in the out door activities. Moreover, high winds at Antarctica are often katabatic in nature with high gustiness and full of drift snow forcing all activities tocome to a halt.

Fig. 3.4a presents average monthly wind speed.Mean daily wind speed are found in the range of 6.7 to 10.8 m/s. Fig 3.4b gives number of days when winds were greater than 12.0 m/s and the

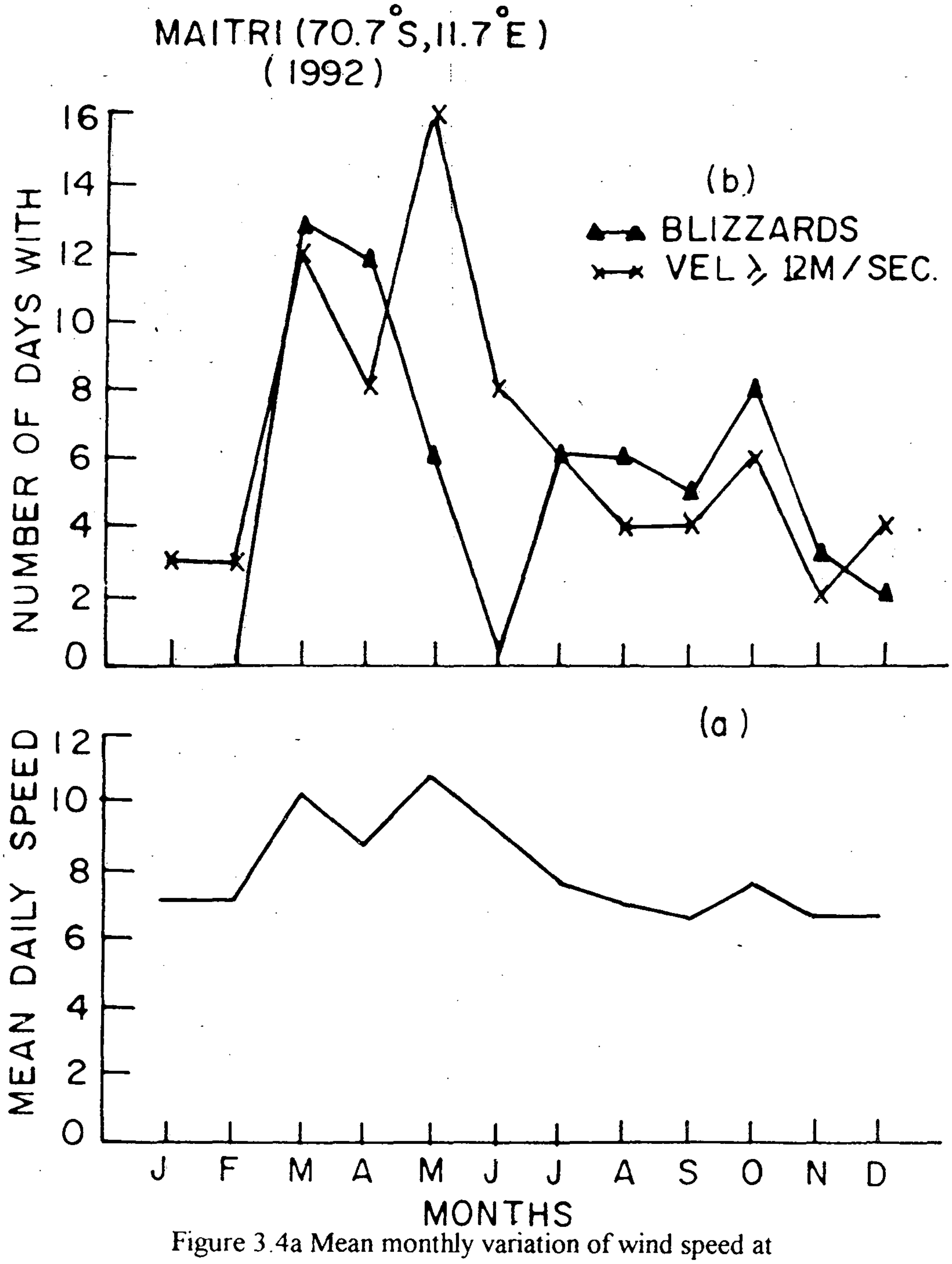

Figure 3.4a Mean monthly variation of wind speed at Maitri, during 1992

Figure 3.4b No. of days when wind speed is >12 m/s and no.of days when blizzards have been recorded in each month at Maitri during, 1992 number of days, in each month when the blizzards have been recorded. This figure shows that normally, winds are higher in transition seasons i.e. during March-May and September-October months. The wind speed along with the prevailing wind direction in different months aregiven in table 3.4. Table 3.6 provides a comparision of mean monthly wind-speed at various stations in Antarctica, it may be noted that the mean monthly wind speed are highest at Maitri compared to other stataions practically in all months except January, April and October.

It is interesting to note that the time-averaged near-surface streamline of the cold air drainage over Antarctica (Parish,1988) observed at our station shows that, winds really do not travel more than about 500 km (Fig. 3.5). The figure depicts various confluence zones where the surface winds from the interior of the continent converge (Parish and Bromwich, 1987). Such zones provide an enhanced supply of radiatively cooled near-surface air to the coastal slopes and allow the resulting katabatic winds to be stronger and more persistent. Thus the katabatic winds provide a flushing arrangement over this icy continent leading to several novel features of the climate over Antarctica.

As seen in Fig. 3.5, the katabatic flows are always directed towards the periphery, therefore, we always get high winds from the S, SSE, SE orESE sectors. This is evident from Fig.3.6 (or table 3.7) which shows the wind rose data for Maitri. It is clearly seen that winds are normaly flowing out of the continent, which is a typical feature of katabatic winds resulting from the slope induced inversions.

3.4.1 BLIZZARDS

Blizzard is a special weather phenomena in Antarctica Under a blizzard, the surface snow starts blowing in association with strong winds, significantly reducing visibility (horizontal as well

Table 3.6 Mean monthly wind speed(m/s) at various stations in Antarctica (Alison et.al.,1993). The position and elevation of the stations are given in table 1.1

MONTH	D57	D80	Dome C	Maitri
JAN	8.4	4.8	2.5	7.8
FEB	9.5	5.7	2.7	11.0
MAR	9.5	6.3	3.7	9.7
APR	10.0	6.3	3.2	8.9
MAY	11.0	7.2	3.0	12.1
JUN	10.0	7.2	3.6	12.8
JUL	9.8	6.6	3.0	12.8
AUG	9.2	6.5	2.6	10.2
SEP	9.3	7.3	3.3	11.0
OCT	9.6	6.1	3.4	7.7
NOV	8.3	5.3	3.6	9.6
DEC	8.2	4.8	3.0	8.9

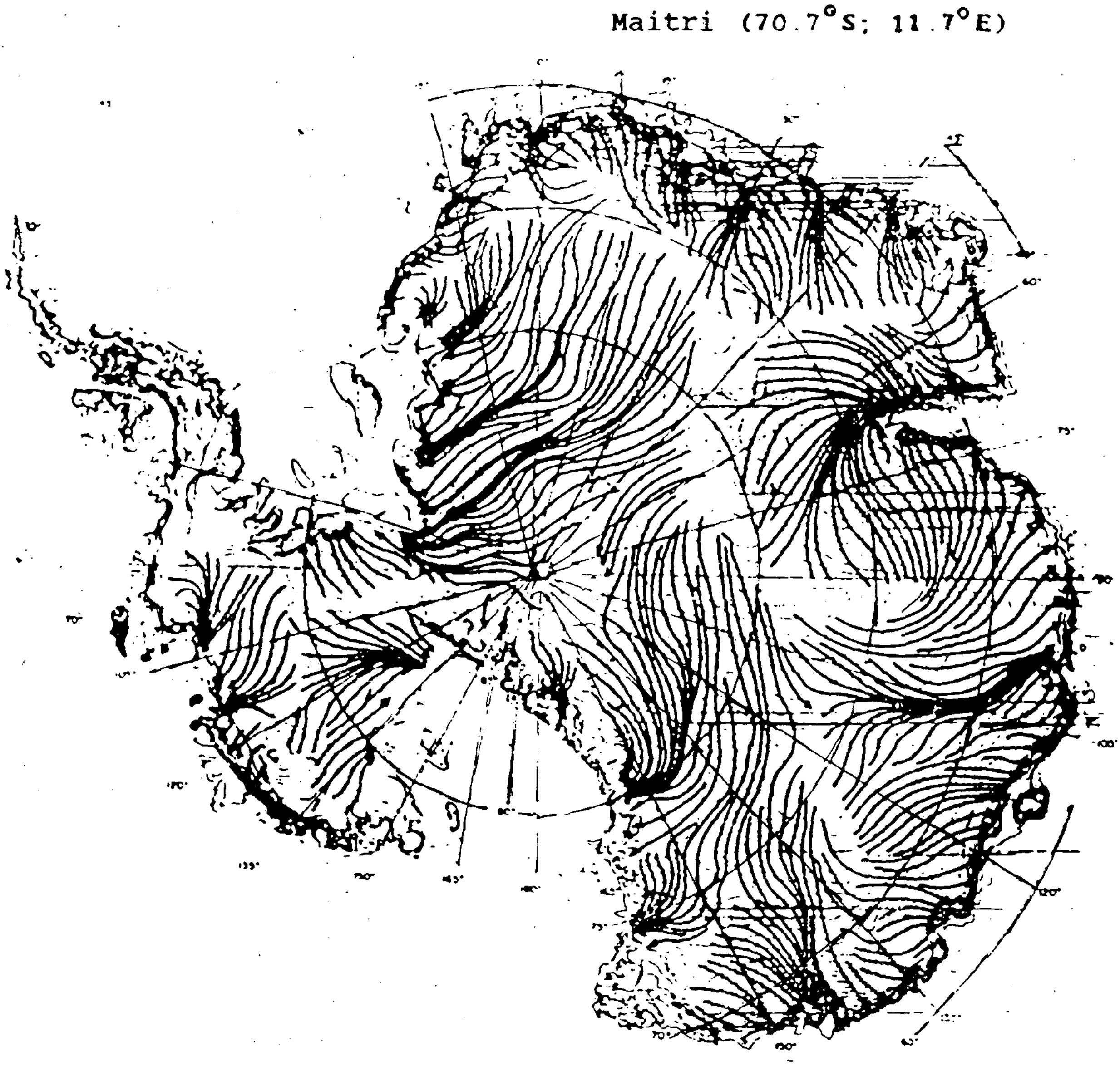

Figure 3.5 Formation of streamlines by katabatic winds, directed towords the periphery (after,Parish, 1992) at Antarctica

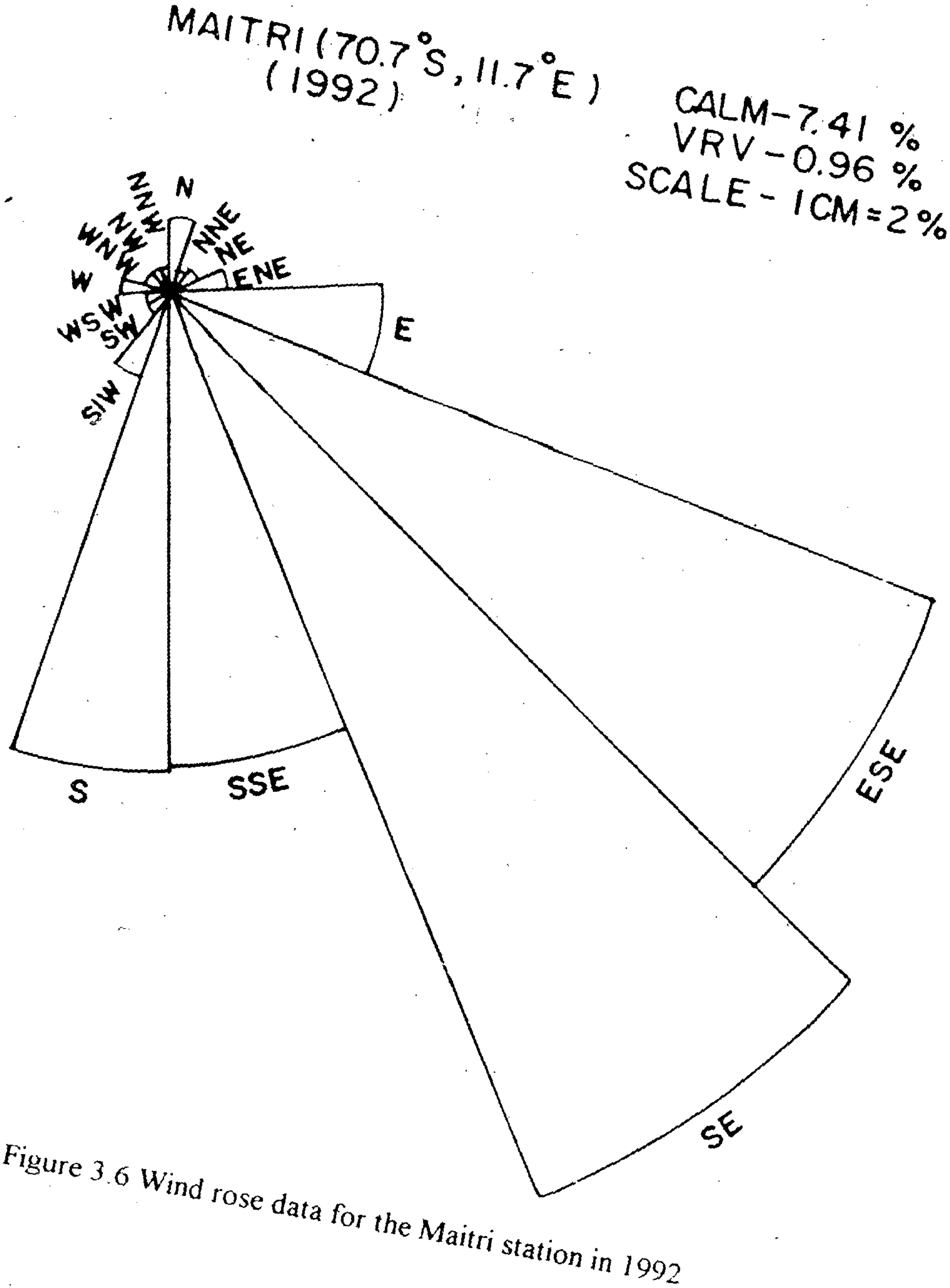

Figure 3.6 Wind rose data for the Maitri station in 1992

Table 3.7 Frequency of surface wind direction(%)at Maitri Antarctica, 1992 (after Kopper,1995)

CALM	7.41
NNE	0.41
NE	0.35
ENE	1.47
E	5.77
ESE	23.02
SE	26.84
SSE	12.77
S	12.88
SSW	2.32
SW	0.55
WSW	0.51
W	1.13
WNW	0.51
NW	0.65
NNW	0.31
N	2.12
VARIAB.	0.96
TOTAL	100.0

as vertical). Blizzards are frequent in Antarctica because of the continuous snowdrift-enshrouded katabatic storms throughout the non-summer months. For this reason Antarctica was dubbed as the ***"Home of the Blizzards"*** (Mawson,1915).

On the periphery of the continent, blizzards occur when low pressure systems move along or close to the coastline. Blizzards can be defined as anything between drifting snow with clear skies and moderate winds (5 - 10 m/s) to blowing snow storm with very strong winds. Strong winds are usually accompanied by drifting or blowing snow, as loose snow on the surface becomes entrained in the air flow. The mass of snow picked up by winds increases very rapidly as the wind freshens (mass is proportional to the fourth power of wind velocity, Streten, 1990).

We have made an attempt to study the blizzards in detail for two cases, one during summer (December) and another during winter (June).

Fig. 3.7 shows a part of the automatic weather chart representing a blizzard observed during 2000 hrs on December 13, 1992 to 2000 hrs on December 14, 1992,. During the 24 hour duration of the blizzard, all the meteorological parameters have been plotted in Fig.3.8 and 3.9 while the values are given in table 3.8. Figure 3.8 shows the hourly variation in wind velocity and wind direction at different time starting at 1800 hrs on Dec.13, 1992 and ending at 2200 hrs on Dec.14, 1992. The standerd deviation in wind speed and wind-direction has also been drawn on the same curve. With the help of the graph we can conclude that when the speeds are much high the variation in direction is very less, the wind is almost uni-directional, but when the velocity is low the direction is highly fluctuating.Thus we can say that during the blizzards the katabatic wind forms a channel.

Figure 3.9, shows that the blizzards are responsible for the increase of the temperature

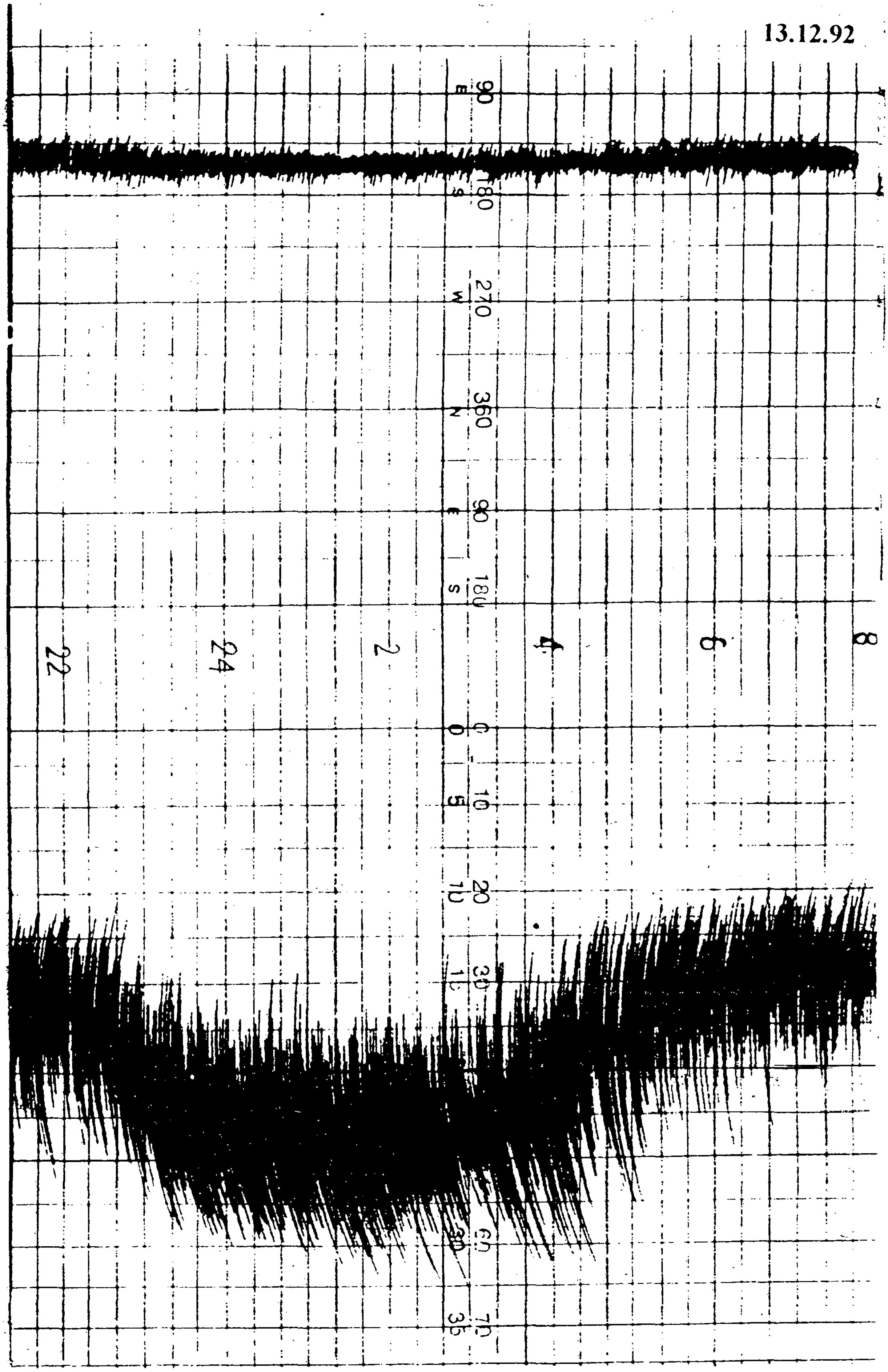

Figure 3.7 Automatic weather chart showing a ful fledge summer blizzard from 2000hrs.on 13.12 1992 to 2000hrs on 14.12.1992 at Maitri Antarctica

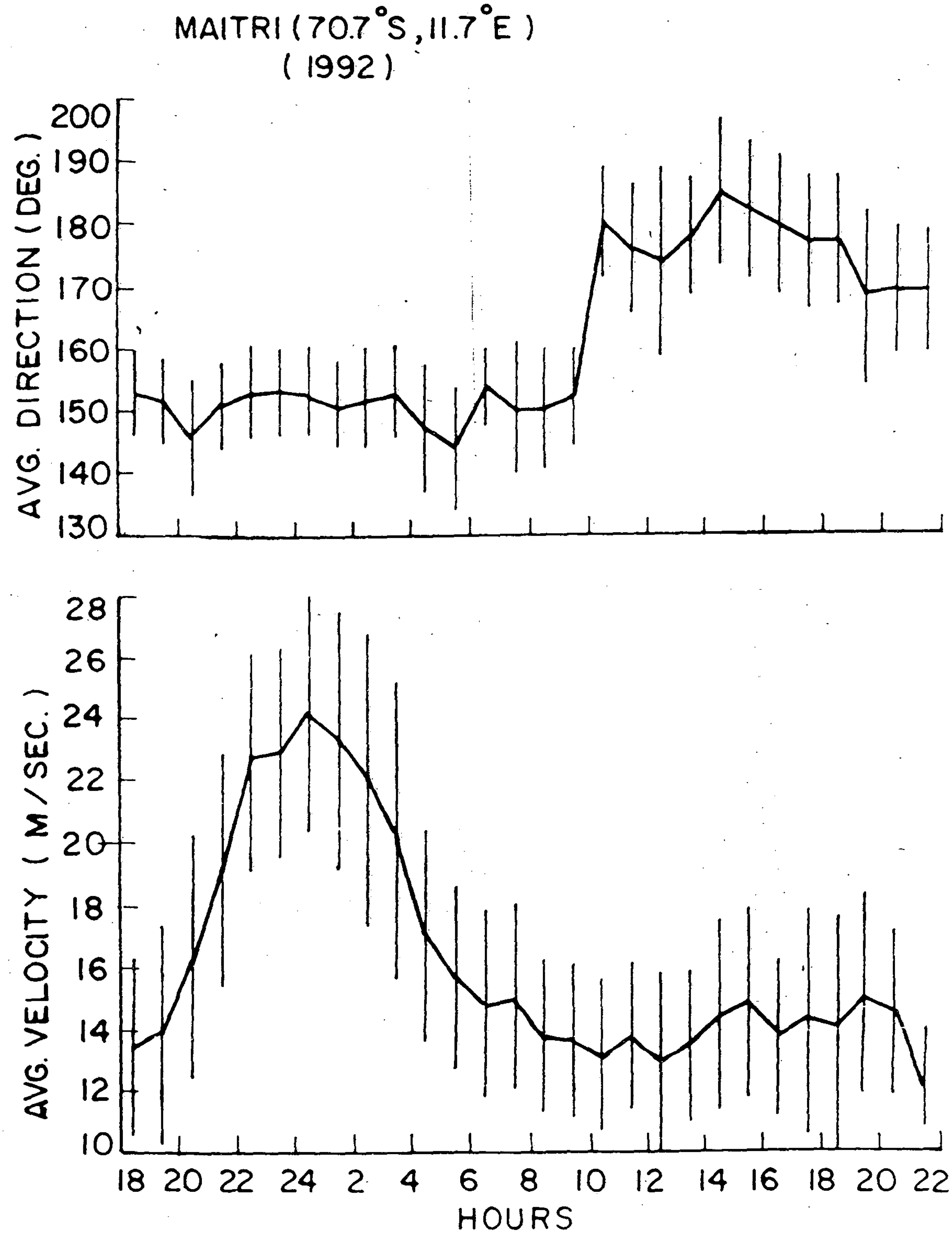

Figure 3.8 Mean hourly variation of wind vel. and wind dir. during a summer blizzard started at 2000 hrs Dec. 14,1992and ended at 2000hrs,at Maitri.The standard deviation at every 1 hr interval has also been plotted on the same curve

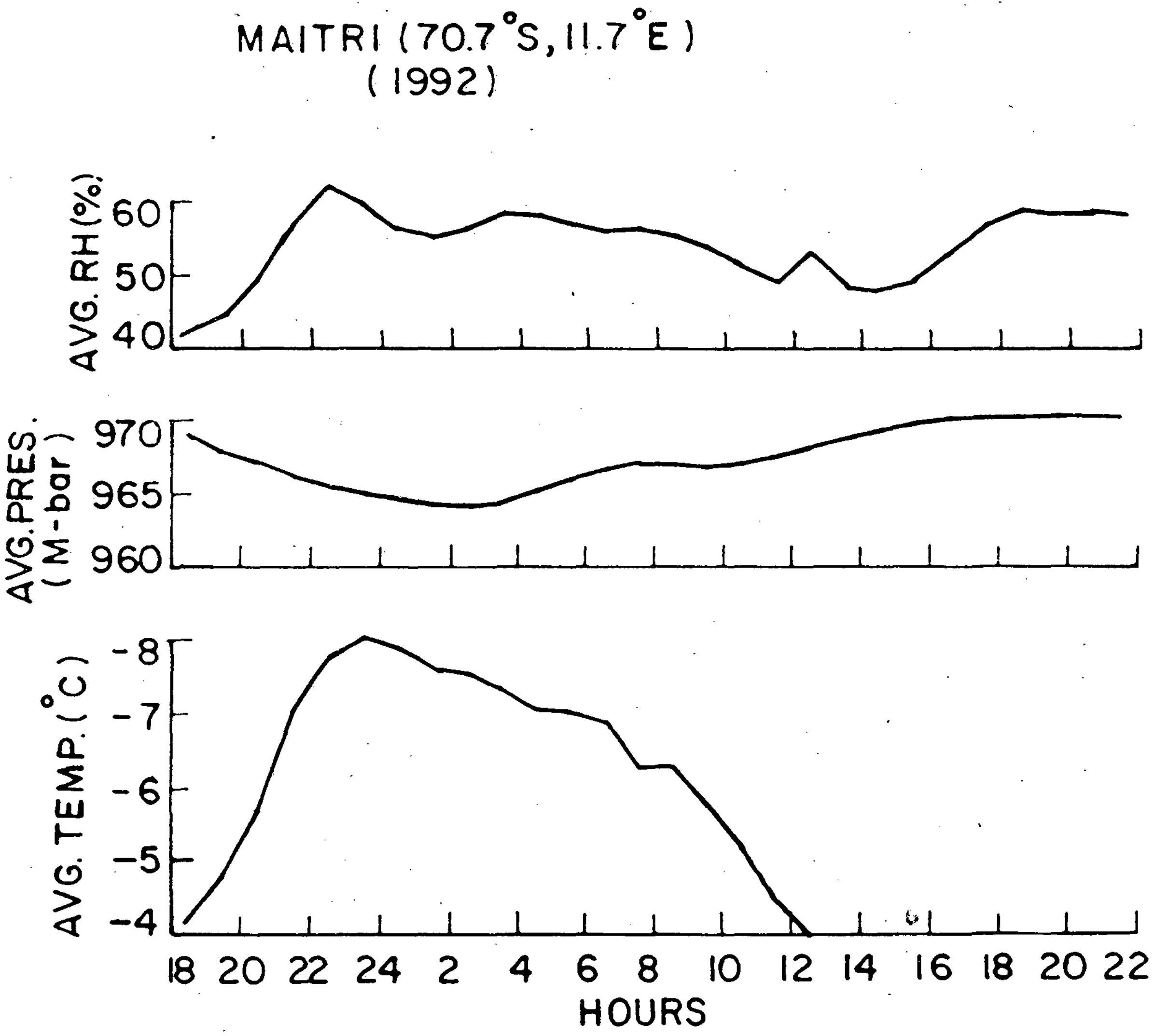

Figure 3.9 Mean hourly variation of Temp., Press, and RH during a summer blizzard from 2000hrs on 13.12.1992 to 2000hrs on 14.12.1992 at Maitri

Table 3.8 History of a summer blizzard of 24 hrs duration from 2000hrs on 13.12.1992 to 2000hrs 14.12.1992at Maitri

Time (hrs)	Avg.Vel (m/s)	Std.Dev. in vel.	Avg.Dir. (deg.)	Std.Dev. in dir.	Temp. (C)	Pressure (m.bar)	RH (%)
18-19	13.5	5.8	153	12.8	-4.2	969.3	42.4
19-20	13.9	6.9	152	13.7	-4.8	668.0	44.7
20-21	16.4	7.7	140	18.8	-5.8	967.1	49.5
21-22	19.2	7.5	151	15.2	-7.0	966.4	57.2
22-23	22.7	7.2	153	15.3	-7.8	965.6	68.4
23-24	22.9	7.5	153	14.3	-8.0	965.0	59.9
24-01	24.1	7.6	153	14.5	-7.9	964.8	57.1
01-02	23.3	8.4	152	14.4	-7.7	964.5	55.1
02-03	22.0	9.3	152	16.1	-7.6	964.2	56.7
03-04	20.3	9.8	153	15.6	-7.4	964.6	58.7
04-05	17.0	6.6	147	21.3	-7.2	965.5	58.7
05-06	15.6	5.9	144	19.8	-7.0	966.1	57.2
06-07	14.7	5.7	154	12.7	-6.9	966.6	56.1
07-08	14.7	5.7	150	22.5	-6.7	967.2	56.5
08-09	13.7	5.0	150	19.4	-6.3	967.2	55.1
09-10	13.5	5.0	152	15.5	-5.8	967.0	54.2
10-11	13.0	4.9	152	17.9	-5.3	967.0	51.7
11-12	13.7	4.9	176	20.4	-4.5	967.5	49.0
12-13	12.9	5.5	174	29.6	-4.0	968.3	53.6
13-14	13.3	4.9	178	20.1	-4.0	968.9	48.6
14-15	14.3	6.2	185	24.4	-4.0	969.3	48.5
15-16	14.7	5.9	182	22.0	-4.0	969.7	49.1
16-17	13.6	5.0	180	22.4	-4.0	970.1	52.2
17-18	14.2	5.3	177	20.9	-4.0	970.5	56.5
18-19	12.9	6.5	177	21.0	-4.0	970.4	52.1
19-20	14.9	6.3	168	28.4	-4.0	970.5	58.7

which is due to the turbulent mixing of the upper air with the ground level air. Another important feature which is of great interest is that the direction of the wind remained practically along the SE, SSE, SW sectors.

Similarly, the blizzard observed during the winter season is shown in fig. 3.10.It actualy lasted for 103 hours(starting on 9.6.1992 at 0900 hrs and ending on 13.6.1992 at 1600 hrs).It would have probabky been responsible for the enhancement of the mechanical mixing/turbulence, as evident by rise in temperature and fall in pressure and relative humidity. The various meteorological parameters during this blizzard, are shown in Fig.3.11 & 3.12, and tabulated in table 3.9.

3.5 PRESSURE

Large temperature contrast between the cold continent and the relatively warm ocean continually creates low-pressure areas (cyclones) over the ocean which travel eastward or south-east ward with the prevailing wind. Their tracks are sufficiently coincident to result in a persistent circumpolar band of low average pressure centered around 60 - 65^0 S. This zone of low pressure encircling the Antarctic continent is called the Antarctic or circumpolar trough. The characteristics of these systems have been described in detail by Van Loon (1972) and Streten (1980). The average speed of depressions at these latitudes is between 20 to 30 knots. The `lows' normally deepen when situated on the northern side of the trough and later commence to fill as they approach the coast on the southern side of the trough. At any particular time the Antarctic trough is occupied by decaying depressions originating at lower latitudes. Figure 3.13 gives the mosaic of satellite cloud pictures.

These synoptic scale cyclones move around the Antarctic continent but do not appear to penetrate far into the inland. If cyclonic storms are to progress inland, they must experience a sharp

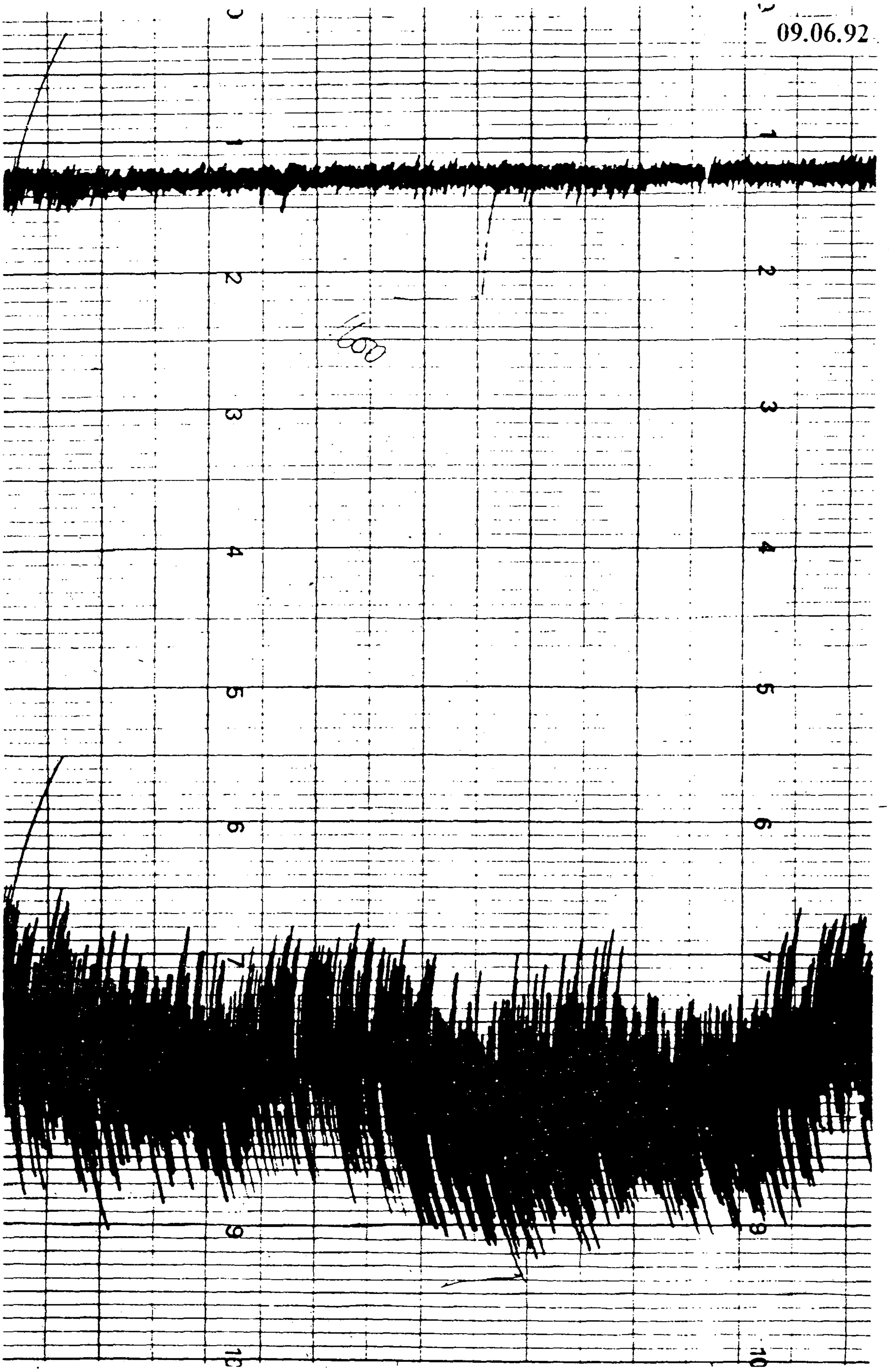

Figure 3.10 Automatic weather chart showing a ful fledge winter blizzard from 0900 hrs on 9.6.1992 to 1600hrs on 13.6.1992 at Maitri Antarctica

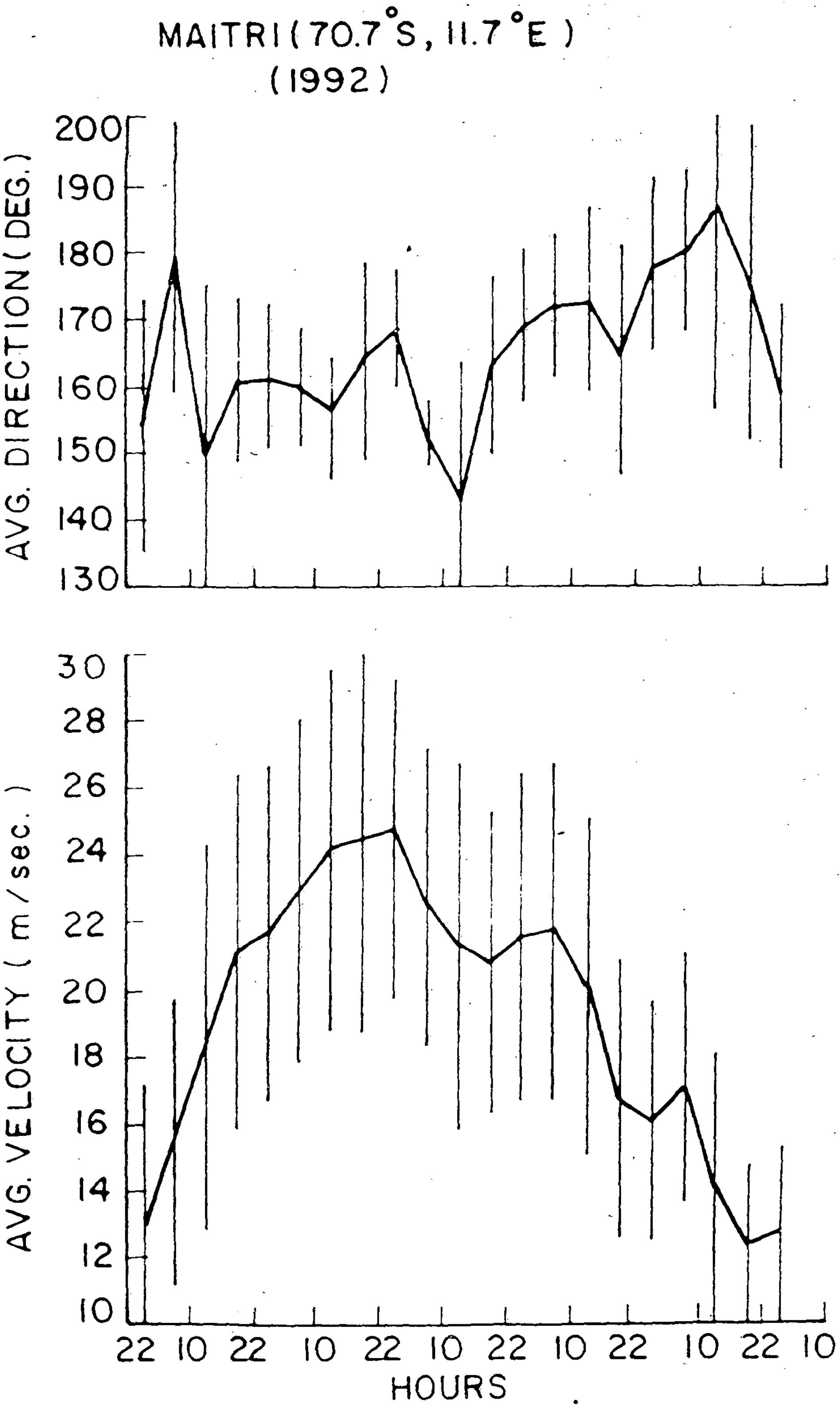

Figure 3.11 Mean hourly variation of wind vel. and wind dir.during a winter blizzard from 0900hrs on 9.6.1992 to 1600 hrs on 13.6.1992, at Maitri the standared deviation has also been plotted on the same curve at every 1 hr interval

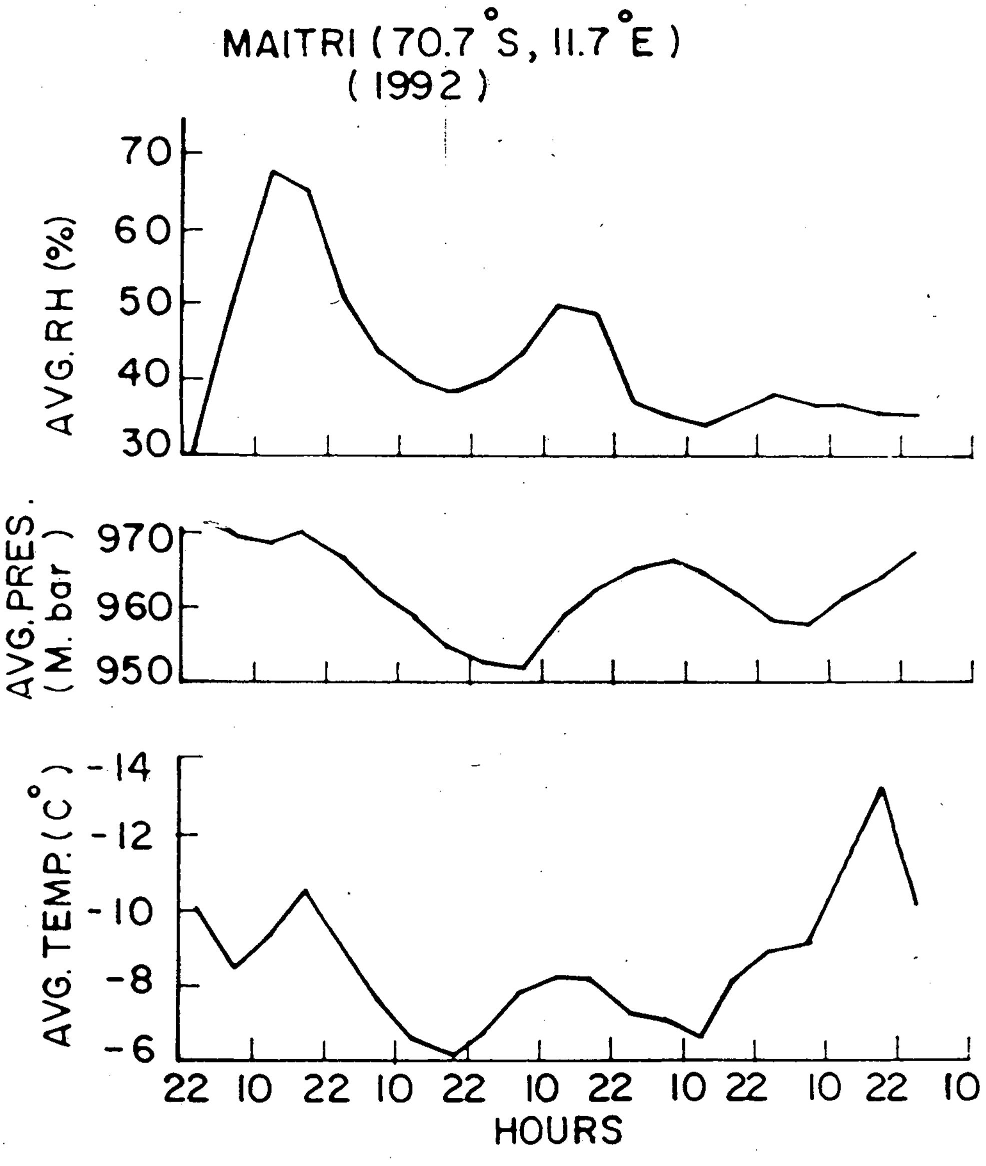

Figure 3.12 Mean hourly variation of Temp. Press. and RH during a winter blizzard from 0900hrs on 9.6.1992 to 1600hrs 13.6.1992 at Maitri

Table 3.9 History of a winter blizzard of 103hrs duration from 900hrs on 09.06.1992 to 1600hrs 13.06.1992 at Maitri.

Time hrs.	Avg.Vel. (m/s)	StdDev in vel.	Avg.Dir. (m/s)	Std.Dev. in dir.	Temp. (°C)	Press. (m.bar)	RH (%)
22-04	12.8	8.3	154	38.5	-9.9	971.8	33.0
04-10	15.5	8.8	179	40.0	-8.5	969.9	50.6
10-16	18.6	11.4	149	52.1	-9.4	968.4	67.4
16-22	21.2	10.5	161	25.1	-10.5	969.3	64.8
22-04	21.7	10.1	162	21.7	-9.2	966.7	51.2
04-10	22.9	10.2	160	18.2	-7.6	962.4	43.8
10-16	24.2	10.7	156	17.7	-6.6	958.5	40.0
16-22	24.4	11.2	164	30.0	-6.2	954.2	38.3
22-04	24.6	9.5	196	17.2	-6.8	952.3	40.0
04-10	22.7	9.1	153	9.3	-7.8	953.9	43.4
10-16	21.2	11.0	143	41.8	-8.5	958.0	49.8
16-22	20.8	9.1	163	27.1	-8.0	962.0	48.5
22-04	21.5	9.8	169	22.8	-7.3	964.8	37.5
04-10	21.7	10.0	172	21.5	-7.0	965.8	35.1
10-16	20.0	10.0	173	28.0	-6.6	964.8	34.1
16-22	16.6	8.6	164	35.3	-8.1	961.8	36.1
22-04	16.1	7.4	178	25.9	-8.9	958.5	38.2
04-10	17.2	7.3	180	24.2	-9.1	958.0	37.0
10-16	14.1	7.7	187	60.0	-11.2	961.4	36.8
16-22	12.3	4.6	175	47.0	-13.1	963.8	35.6
22-04	12.7	4.9	160	24.7	10.2	967.1	35.6

Figure 3.13 Mosaic of cloud picture in the infra red band by the satellite NOAA 4, 24-25 Sept., 1995 (after Schwerdtfeger, 1984)

increase in the height of the ice topography (Parish, 1988). Weather of the coastal regions amainly consists of a continual succession of cyclonic storm on a time-scale of 2-3 days interspaced with short periods of finer weather resulting from the intervening high-pressure ridges.

The cyclones provide the mechanism for meridional exchange of cold polar air with warm moist air from lower latitudes and thereby transport moisture into the south polar regions. Normal decrease of temperature in the early winter is halted from time to time when air from lower latitudes spreads over the coastline of Antarctica.

The average monthly sea level pressure is plotted in Fig. 3.14a, and the values are given in table 3.4. It shows that there are three minima in the pressure around transition months and peak winter months These minima are caused by strong cyclonic activity.

3.6 HUMIDITY

The Antarctic atmosphere is characterised by extremely dry conditions. Absolute humidity is always low but the relative humidity does exceed 90% during periods of blowing snow and warm air advection from the north. Figure 3.14b gives the averagerelative humidity in each month,while the values are in table 3.2 The maximum relative humidity in summer months can be due to evaporation from various local lakes and also due to the warm air advection from ocean due to cyclonic activity. While in winter and transition periods, the local lakes around Maitri freeze, thereby reducing evaporation and the extension of coast line to further north (due to the formation of asea ice) cools the advected air coming from the ocean.

3.7 SNOWFALL AND SNOW DRIFT

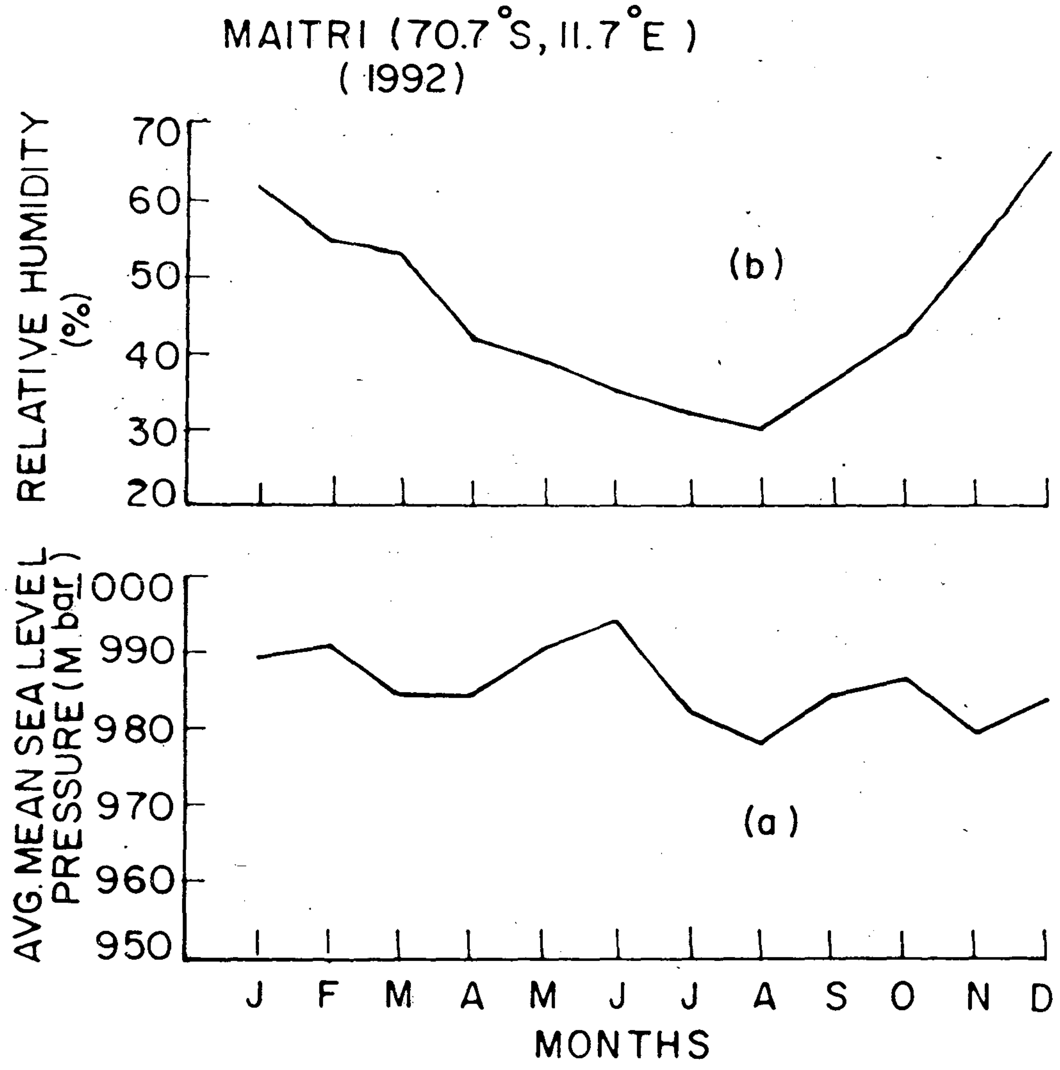

Figure 3.14a Mean monthly variation of sea level pressure at Maitri during, 1992

Figure 3.14b Mean monthly variation of relative humidity at Maitri during, 1992

Snowfall at Maitri occurs in association with the passage of depressions. The warm, moist air coming from the ocean helps in the formation of clouds and causes snow-fall. On an average, snowfall occurs on 4 to 5 days per month throughout the year. The frequency of occurrence of snow fall is defined as falling snow during calm wind conditions. Figure 3.15a gives the number of days per month the snowfall was received at Maitri. While the values are given in table3.4.

The number of days of drifting snow is maximum in winter and at equinoxes, and minimum in summer . The maximum is due to the maximum number of blizzards during that period. The frequency and duration of this snow drift dose not solely depends on katabatic or strng winds but also on the availability of the unconsolidated snow. The low frequency in summer is due to the limited availability of loose snow to be blown. During summer the ice cap towards the south of Maitri consists mainly of clear blue ice.

3.8 VISIBILITY AND CLOUDINESS

Visibility in Antarctica is extremely good. However, during drifting snow, the visibility may reduce to even zero. Figure 3.15b and table 3.4, gives the average monthly variation of cloudiness observed at Maitri. Cloudy days are defined as days on which the mean of cloud amount is equal to or greater than six eighths, while clear days are defined as the days on which the mean of cloud observed is equal to or less than two eighths. Clouds are observed more in summer than in winter or transition months. It is due to the fact that in winter, the averge coastline moves further to the north due to sea ice formation, while in summer due to melting of the sea ice the

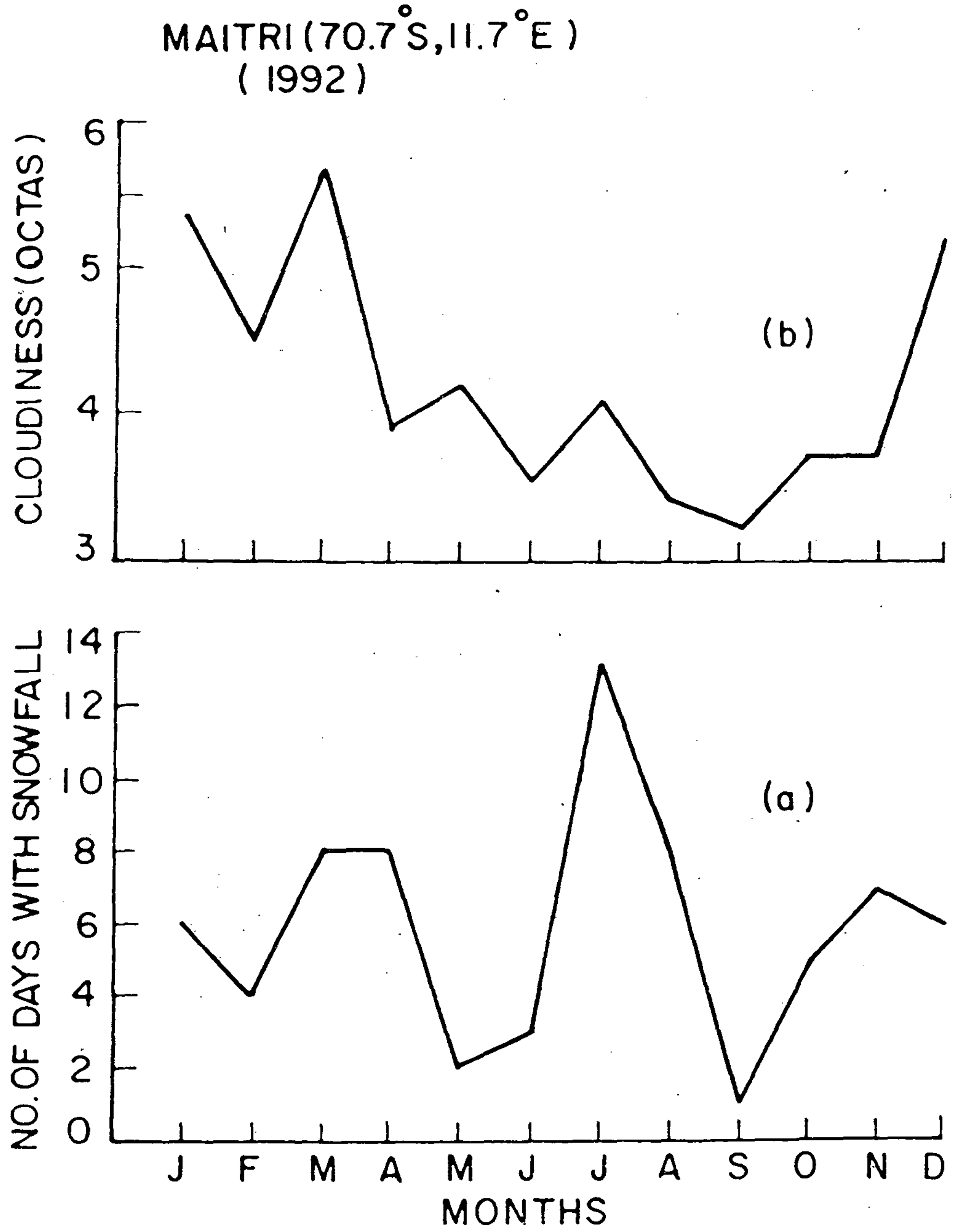

Figure 3.15a Number of days with snow fall in each month at Maitri ,1992

Figure 3.15b Mean monthly variation of cloudiness at Maitri,1992 cyclonic inflow of warm air towards Maitri causes fog and cloud formation. As shown in the figure, the number of clear days during winter and spring are higher. The reason being the frequent advection of warm, moist air towards **Maitri** , which helps in the formation of clouds and fog. During the rest of the year due to the formation of sea ice, the advected air cools during the passage to the continents interior. A photograph of low level cloud in a summer month is given in figure 3.16 .

3.9 INVERSIONS

In recent years, acoustic sounding has become an indispensable tool for the remote probing of the atmosphere not only at lower latitudes but also in the more harsh polar environment (Hall and Owens, 1975; Neff and Hall, 1967; Neff et al., 1977, Neff, 1978; Neff, 1980; Colf, 1989, 1993; Argentini et al., 1992; Kobayashi et al., 1983; Fiocco et al., 1990; Liu et al., 1991; Liu and Bromwich, 1992, 1993; Dutta et al., 1991; Naithani and Dutta, 1995).

Acoustic sounder record, representative of surface based inversion is shown in Fig.3.17.Statistical analysis of the sodar data have been undertaken for the one year period given in figure 3.18. It shows that inversions are present for 93 % of the time over Maitri while for rest of the time, the atmosphere is in convective state. The convection dominates only during peak of winter and summer seasons

Surface based inversions are the most characteristic features of the Antarctic temperature regime (Liljequist, 1958; Phillpot and Zillman, 1970; Miller, 1974; Neff, 1976, 1980; Parish and Bromwich, 1987; Naithani and Dutta, 1995). These inversions are formed due to radiational cooling of the surface. The negative heat budget of the Antarctic continent throughout the year is

Figure 3.16 A photograph of low level cloud in a summer month at Maitri during, 1992

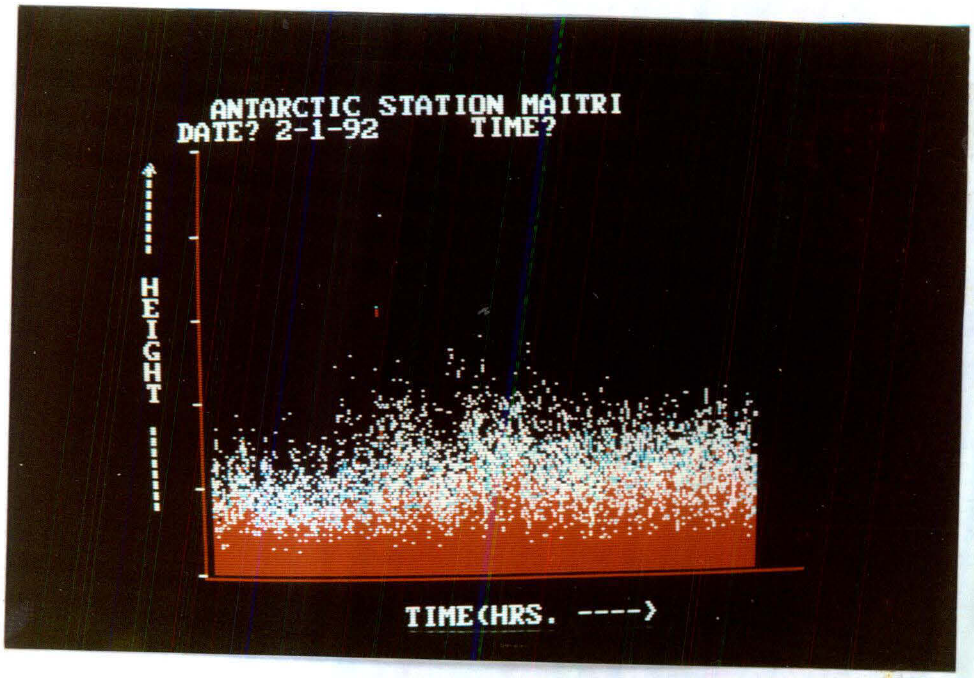

Figure 3.17 Surface based inversion at Maitri on12.1.1992

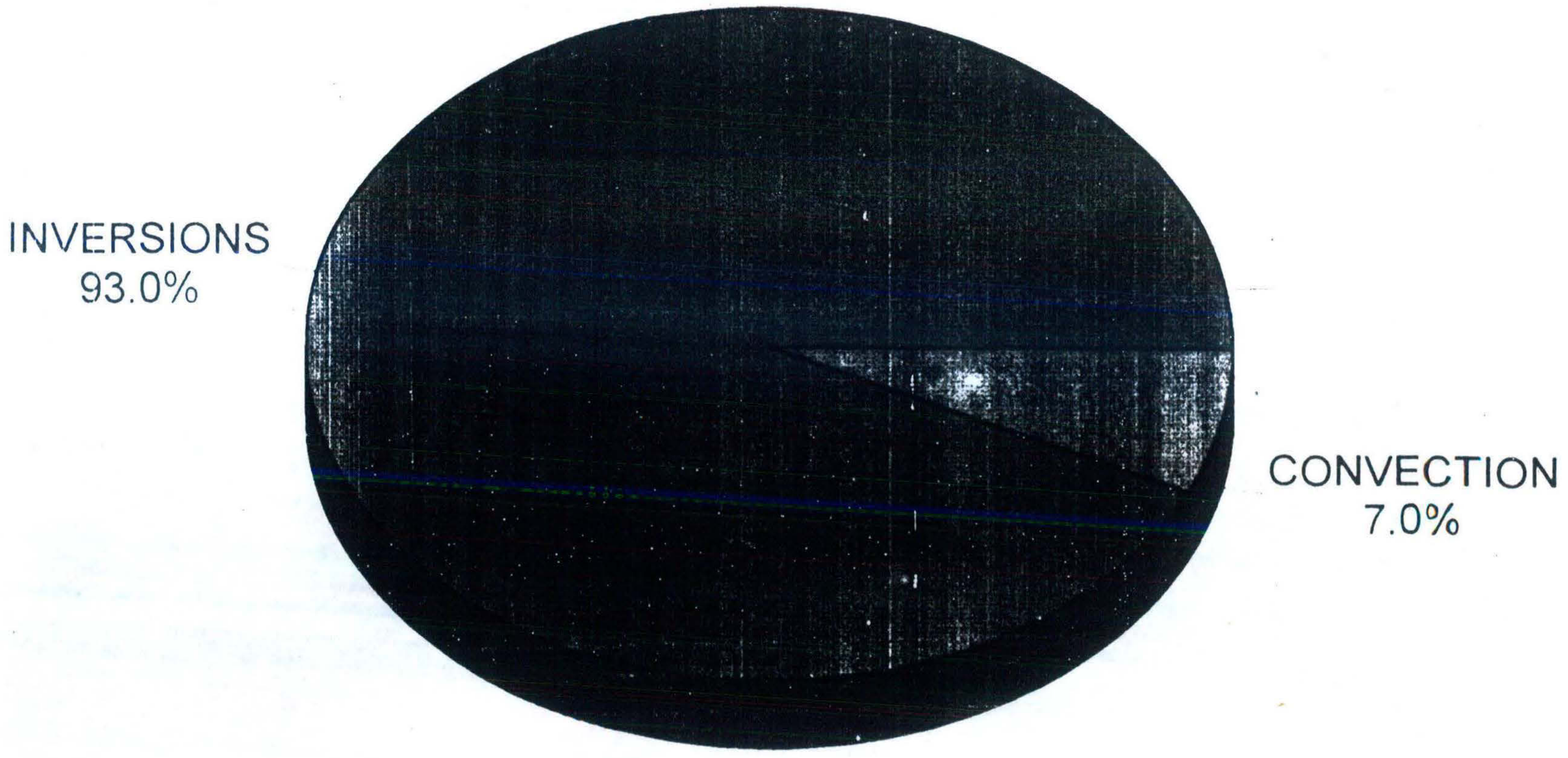

Figure 3.18 Percentage occurrence of inversion and convection as depicted by sodar for 1992 at Maitri

responsible for the development and maintenance of nearly ever present temperature inversions over the continent.

The ideal conditions for the development of SBI is long night (best satisfied in the polar regions), clear sky, and relatively calm and dry air. During the long polar night (June to August), these inversions, once formed, can persist throughout the winter (Neff, 1967, 1980; Schwerdtfeger, 1970, 1984; Streten, 1990) and are temporarily destroyed/weakened by the strong katabatic winds and cyclonic disturbances. Phillpot and Zillman (1970) have given a complete analysis of the low-level inversion strength for the whole continent. They defined the inversion strength as the difference between the highest temperature observed in a tropospheric sounding and the concurrent surface temperature.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

The notable features of the climatological study at Maitri are as follows:

1. The climate at Maitri is dominated by the extreme contrasts between the seasonal inputs of solar radiation.

2. A sub-zero mean temperature persists throughout the year at all seasons, except in the months of December and January.

3. The annual mean wind speed is approximately 10 m/s.

4) A diurnal variation in the temperature records is observed from mid-October to the first week of May.

5) The dominance of katabatic wind component in the surface wind regime áis observed as a result of the pressure gradient due to stably stratified air overlying the sloping surface and the eastward moving depressions .

6) As the surface wind speed increases, the wind direction be comes concentrated towards south-east, which is the direction of the maximum slope around the Maitri site.

7) Surface winds also depict a diurnal variation (along with temperature) in summer and to some extent in transition periods.

The diurnal variation of wind speed and direction being largest in summer.

8) Half yearly cycle of the mean monthly pressure is observed.

9) The number of blizzards are maximum during the spring season.

From the above study, it is clear that Antarctica provides a unique platform for the understanding of atmospheric processes in a hostile and complex environment. However, in relation to climatology, it is recommended that the further studies of Antarctic environment would help in solving importent global weather problems.

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