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Weather & weather systems at Schirmacher Oasis (Maitri) during recent two decades - A review

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सार – भारतीय एंटार्कटिक स्टेशन मैत्री, पूर्वी एंटार्कटिका के अंदरूनी भाग और समुद्री तट के साथ–साथ गतिशील अवदाबों एवं चक्रवातों के विभिन्न प्रकार के परिवर्तीबाह्य प्रभावों से प्रभावित देखा गया है। परिध्रुवीय द्रोणी की सापेक्षिक स्थिति और ध्रुव के निकट उच्च दाब केन्द्र के सशक्त होने से मैत्री के वायुमंडलीय दाब में परिवर्तन आया है। दिन के, दैनिक एवं ऋतुनिष्ट तापमानों में भिन्नता मुख्य रूप से दाब प्रणालियों, अवरोही पवनों ऋतु परिवर्तन से सौर उष्मा रोधन में बदलाव, बादलों एवं बर्फ की परावर्तिता पर निर्भर करता है। दक्षिण की तरफ ढ़लान के कारण मैत्री स्टेशन पर अवरोही पवनों के बहाव की दिशा अधिकतर दक्षिण–पर्व दिशा की तरफ होती है। मैत्री स्टेशन पर मुख्य तौर पर बर्फीली हवाओं वाला मौसम रहता है, कभी कभी कोहरा और साफ मौसम होता है। यहाँ पर अधिकतर ओले के रूप में वर्षा होती है परन्तु सामान्य वर्षा कभी–कभार ही होती है। भारी अथवा सामान्य ओलावृष्टि इस बात का संकेतक है कि उष्ण हवाओं की बहत बड़ी राशि दक्षिण दिशा की तरफ बह रही है। सिरमाचर ओएसिस के निकट तापमान में तेजी से बदलाव होने के कारण यहाँ बर्फ की वर्षा होती है। अपेक्षाकृत उष्ण हवाएँ जब निचले अक्षांश से अधिक ठंडी सतह के ऊपर से धीरे–धीरे गुजरती है तो कोहरा बनता है अन्य ऋतुओं की तुलना में शीत ऋतु में मैत्री पर सबसे अधिक ओलावृष्टि होती है। ग्रीष्म ऋतु में तापमान बढ़ने से वायुमंडल के निचले स्तर पर बर्फ की पेलेट्स द्वारा गुप्त उष्मा का अवशोषण होता है जिसके फलस्वरूप जल की बूंदों के रूप में वर्षा होती है यहाँ पर शीत ऋतु के दौरान सबसे अधिक बर्फीले तुफान आते हैं जबकि ग्रीष्म ऋतु में बर्फीले तुफानों की संख्या सबसे कम होती है। प्रायः चक्रवातीय गतिविधियों के कारण उष्ण वायु की अधिक मात्रा सिरमाचर ओएसिस की तरफ से जाने के कारण मैत्री के तापमान में वृद्धि होती है। इस स्टेशन पर बर्फीले तुफानों की लम्बी अवधि निचले स्तर में मैत्री के पूर्व में स्थित धीमी गति से अवरूद्ध होने वाले प्रतिचक्रवात की शक्ति पर निर्भर करता है। हिम झंझावात के शुरू होने से पहले वायुमंडलीय इलेक्ट्रीक क्षेत्र में जबरदस्त उतारचढ़ाव देखा गया जो हिम झंझावात के शुरू होने का पहले से संकेत देता है।

ABSTRACT. Indian Antarctic station Maitri experiences varying external influences from interior of east Antarctica as well as moving depressions and cyclones along the coast. The relative position of circumpolar trough and strengthening of high pressure centre near pole influences variation of atmospheric pressure at Maitri. The diurnal, daily and seasonal variation of temperature mainly depend upon moving pressure systems, katabatic winds, change of solar insulation with change of seasons, reflectivity from clouds and snow surface. The katabatic winds prevail over Maitri which is highly directional from South- East sector due to increase of slope towards south. The blizzards are main weather at Maitri, fog and white out are occasional phenomena. The precipitation is mostly in form of snowfall but rain is very rare at Maitri. Heavy or moderate snowfall indicative of active front leading edge of warm air masses being transported southwards. Strong temperature variant near Schirmacher oasis give precipitation in form of snow. Fog occurred due to slow movement of relatively warm air from lower latitude over the colder surface. Winter season witnessed more snowfall accumulation at Maitri than other season. During summer rise of temperature accompanied with absorption of latent heat by ice pellets in low level of atmosphere results precipitation in form of water droplets. Highest number of blizzards occurs during winter season whereas lowest number of blizzards occurs during summer season. Normally due to cyclonic activities, warm air masses transported towards the Schirmacher oasis which causes rise of temperature at Maitri. Longer duration of the blizzards over the station depends upon strength of slow moving blocking anticyclone situated east of Maitri at lower latitude. Tremendous fluctuation of atmospheric electric field observed before onset is a pre-indication of commencement of blizzards.

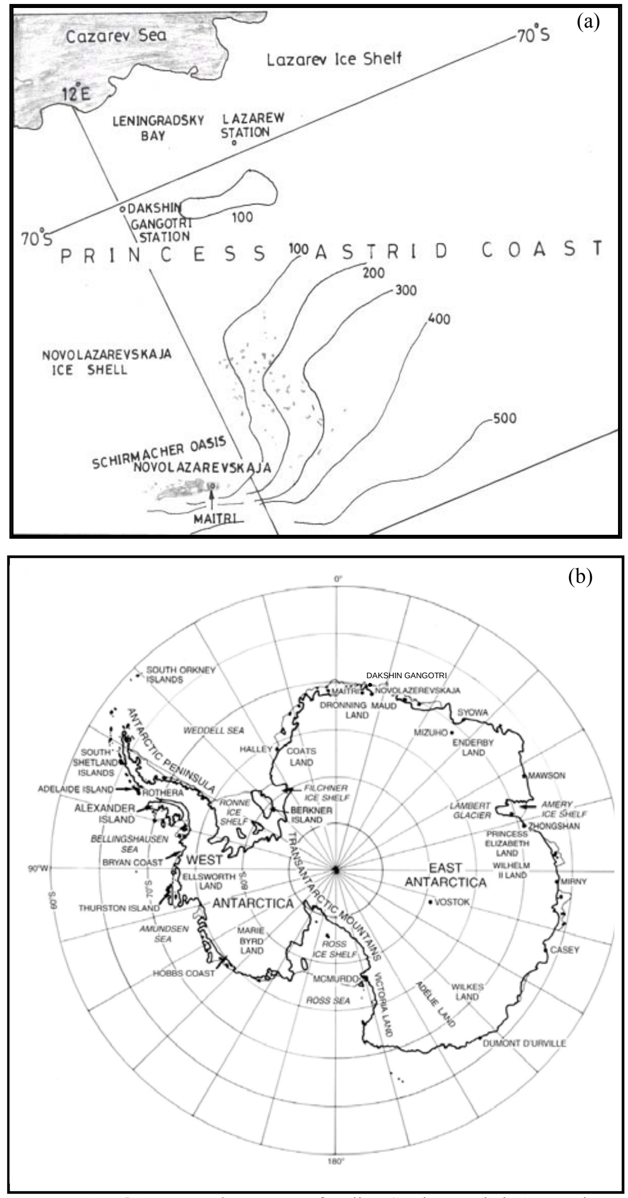
Key words – Katabatic winds, Blizzards, Schirmacher Oasis, East Antarctica, Maitri, Drifting Snow, Advection Fog, Circumpolar trough.

1. Introduction

The Antarctica region is regarded as last frontiers in understanding global weather and climate. It is the coldest place on the Earth. It holds many secret scientific puzzles and therefore its significance has been perceived internationally. This continent is not only of scientific curiosity but is also a key part of the fabric of earth's system. It has got unique importance because it is the only continent on the world map with a position at the pole surrounded by frozen seas. Antarctica and Southern Ocean are key elements in the global weather system which creates and transfers energy as winds, clouds, precipitation and blizzards. It plays very important role in general circulation in atmospheric and in coupled atmosphere - ocean-ice system. The contribution of Antarctica to global weather has a great influence from ocean currents than from atmospheric effects.

The Antarctic continent and its surrounding Southern Ocean are probably the least known regions of the world. There are 44 meteorological stations operated by 18 Scientific Committee on Antarctic Research (SCAR) nations. Technology has developed at such a rapid pace that a new standards of meteorological services in Antarctica can be specified. Representation of Antarctica in global numerical weather prediction models has improved; remote sensing of atmospheric variables and sea ice from polar orbiting satellites has become more sophisticated. Most of the SCAR stations provide routine coded surface synoptic weather reports to the Global Telecommunications System operated by the World Meteorological Organization (WMO). In addition, there are about 70 or so automatic weather stations other than the staffed stations that provide extensions to the surface weather–reporting network. Fourteen of the staffed stations are also providing upper–air soundings of meteorological variables with vertical profiles from the surface to altitudes of frequently around 25 km and occasionally 35 km (the lower stratosphere). Through weather satellites, we can track the forces that control the weather and forecast their behaviour up to a week or more.

Meteorological satellites are one of the most critical observing tools available to operational Antarctic weather forecasters and decision-makers. Having this information affords improved weather forecasts and, ultimately, increased safety for those working and travelling in and around the Antarctic. A number of polar-orbiting and geostationary satellites are available for operational weather forecasting and research purposes. The study of radiation, surface ozone and atmospheric turbidity etc., reception of gridded APT satellite pictures in the infra-red and visible channels from polar orbiting satellites(NOAA) and analysed weather charts from Pretoria (South Africa) help in monitoring of weather systems and prediction of weather over Maitri. The study of meteorological parameters and associated weather are part of programme during each of the scientific expedition to Antarctica. Maitri is dominated by katabatic flow of the winds of varying intensities which brings snow/ice in the form of blowing snow, drift and blizzards from



Figs. 1 (a&b). Layout base map of Indian Station Maitri, Antarctica

interior plateau. The cyclones push relatively warm and moist air towards the interior of the continent which leads to adverse weather condition over the station. The climate of the Schirmacher Oasis is relatively mild for Antarctic conditions. Because of the positive radiation balance, the Schirmacher Oasis is regionally classified as a 'coastal climate zone'. All meteorological observations such as pressure, temperature, wind speed/direction, precipitation and total global solar radiation etc., are being recorded at Maitri since 1990. The extreme weather phenomena, sharp topography and thermal contrast create difficult situations for conducting reliable analysis in this region.The challenging and amazing weather over the area created enthusiasm for this study.

2. Physiography

The continent consists of three parts, East Antarctica, West Antarctica and the Antarctic Peninsula, Figs. 1(a&b). Their areas are 10, 2.0 and 0.5 million sq km respectively. Most of East Antarctica is above 3000 m above sea level. The high land in East Antarctica is known as the Antarctic Plateau, where the ice is more than 2 km thick. The average elevation of the continent is 2.2 km, far above the 700m for other continents. Therefore atmospheric pressures at the South Pole (at 2,800 m) are about 680 hPa and at Vostok (3,500 m) about 620 hPa.

The Indian Antarctic Station, Maitri is located in the central part of Schirmacher Oasis of East Antarctica close to the periphery of the continent. Maitri is located in the central part of Schirmacher Oasis, Dronning Maud Land, East Antarctica This oasis is about 16 km long stretched in an east-west direction between 70° 44′ 21″ S to 70° 46′ 04″ S and 11° 49′ 54″ E to 11° 26′ 03″ E with a maximum width of about 3 km (Maria & Singh 2010). The altitude of Maitri is 117 m above sea level. The Schirmacher oasis forms a group of low lying hills about 50 to 200 m high. The scientific Russian station Novolazarevskay is situated towards the southwest about 4 km away from Maitri while "Gorge Foster", the German scientific station, is located 5 km away from Maitri towards the south–southwest. The Schirmacher Range lies in between the Wolthat Maassif about 70 km to the south of Prince Astrid Coast and the tip of the shelf ice that is about 100 km to the north. The Schirmacher is one of the smallest and typical oasis of the Antarctic. The northern boundary of the Schirmacher oasis has an abrupt and steep fall towards the shelf ice.

3. Data and methodology

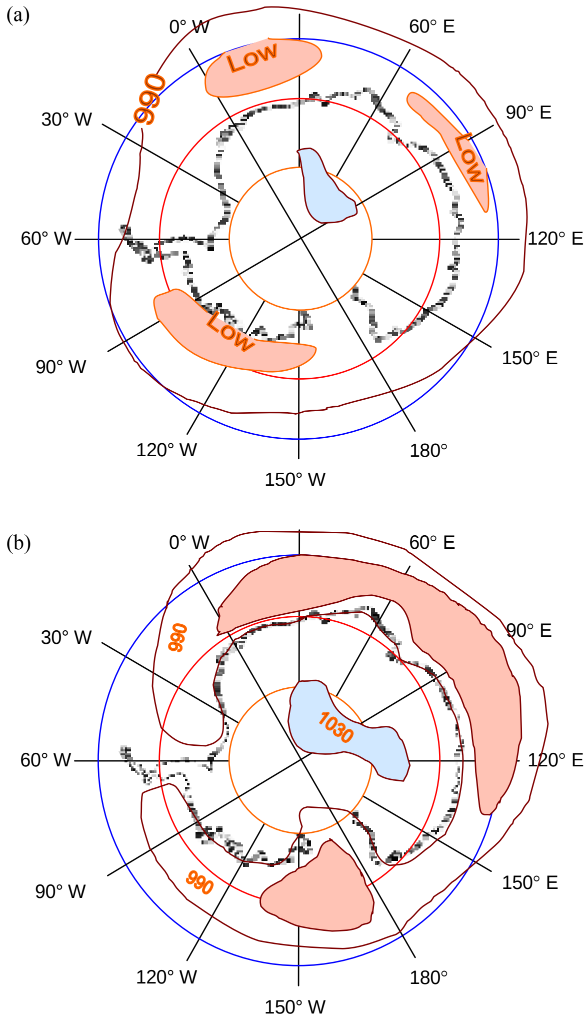
All meteorological parameters, *i.e.*, pressure, temperature, wind and associated weather over Dakshin Gangotri for the period 1985-89 and Maitri 1990-2010 have been analyzed. The statistical mean value in respect of all parameters for both the Indian stations Dakshin Gangotri and Maitri for the period mentioned above have been derived. The derived mean values have been critically examined for annual and seasonal variability of weather phenomena and a comparison is made with recorded observation of year 2010. Antarctica is one of the places on Earth where the sky is a constant source of amazement. Cold temperature, low humidity, lack of variation on the terrain, proximity of the magnetic and geographic poles all contribute to displays rarely seen at other latitudes. During past two and half decades, the available research contributions towards study of weather and weather system over Maitri have been reviewed with a view to provide an ample opportunity for further investigations. Due to geographical location of the Schirmacher oasis at east Antarctica the seasons are taken as summer (NDJ), autumn (FM) winter (AMJJA) and spring (SO) [Koppar, (1991)].

4. Synoptic-scale weather systems and circulation pattern

One of the most remarkable features of the sub-Antarctic latitudes is the high frequency of cyclonic storms, many of which are intense. These systems have a large impact on weather in the region and particularly at coastal locations, where most Antarctic stations are located (Simmonds *et al*., 1998). It is clearly important for a number of reasons that the behaviour of these systems be understood and that they be forecasted with acceptable accuracy. These transient systems are also significant in a climatological sense as they affect most of the pole-ward energy transport in the region (van Loon, 1979). In an attempt to understand the characteristics of cyclones in the high southern latitudes, it is important to bear in mind that this is a region of great temporal variability of the synoptic environment (Jones and Simmonds, 1993 b; King, 1994).

The main source of energy is the sun. Since its heating effect is greater at the equator than at the poles, it creates atmospheric circulation. Hot moist air rises over the equator and flows at higher level of atmosphere towards the poles, where it cools and sinks. A strong westerly circulation prevails during the winter season in the upper layers of the atmosphere due to circumpolar vortex. The vortex cuts off the central Antarctic weather causing temperatures to fall and stay low. The circumpolar vortex breaks up in the spring & summer season and maintains very low and stable temperatures in the winter. The 500 hPa level is everywhere above the orography of the Antarctic and is therefore useful for forecasting. At 500 hPa level the mean flow consists of a weak cyclonic vortex centred over the Ross Ice Shelf. The flow over the Southern Ocean is generally zonal with a weak wave number three pattern with troughs close to 20° E, 90° E and 90° W. At the 300 hPa level the vortex is stronger and centred closer to the pole and there is a weak trough/ridge structure that varies throughout the year.

The atmospheric circulation pattern near Schirmacher Oasis consists of one or two high pressure systems extending in meridional direction along the axis 10° W to 50° E [Figs. 2 (a&b)]. A quasi-stationary pressure system near coastal area of Schirmacher Oasis prevails between these high pressure systems which are maintained by ocean depression intruding from north. The branches of meridional cyclone trajectories cover most parts of Schirmacher Oasis. The south African branch of the cyclone trajectories moving along the east Antarctica



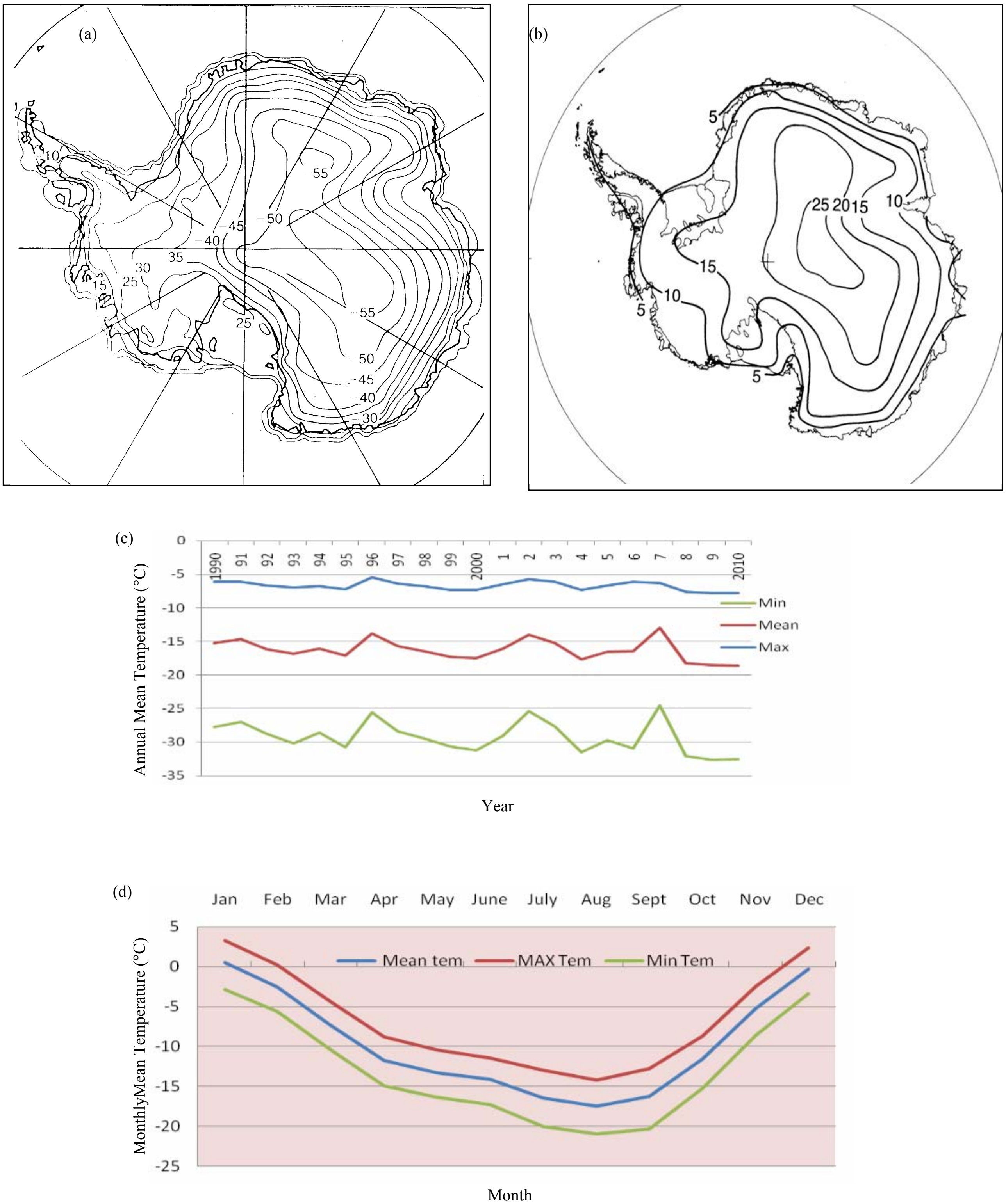
Figs. 2 (a&b). Climatological average MSLP (a) Summer 1980-2000 and (b) Winter 1979-1999 (Simmonds, *et al*., 2003)

coast penetrate deeper and produces a significant weather in the coastal areas of the Oasis. The Indian station Maitri at Schirmacher oasis is also influenced by peripheral areas of Antarctic high that forms clear, frosty weather dominated by katabatic winds. The Antarctica coastal region is confined as one of the high cyclonicity region. At Antarctica coastal region cold continental polar airmass and relatively warm moist airmasses meet, create thermal contrast which results in development of mesoscale systems. The highest cyclogenesis takes place during winter (Simmonds *et al*., 2003). The highest mesoscale cyclogenesis is associated with area of warm or cold air advection, low level baroclinicity and cyclonic vorticity over the region. The frequent cyclonic storm during winter accompanied with snow causes wind attenuate and temperature drops which create dryness. The cyclonic circulation causes flow of moist, warm maritime air masses from the ocean resulting in increase of temperature and strong winds over Maitri.

5. Surface temperature

Antarctica is extremely cold, the extreme temperatures at South Pole station are -14° to -81 °C, and at Vostok -21° to -89 °C. Near the coast above-freezing temperatures occasionally occur, but the annual mean is below 0 °C everywhere [Fig. 3(a)]. There is some similarity between the map of surface annual mean isopleths [Fig. 3(b)] and the pattern of annual mean temperatures in Antarctica. Temperatures of around -25 °C around the coast correspond to precipitation of around 400 mm/year, while about 50 mm/year precipitation over the Plateau correspondence to temperatures average -55 °C or so. The eightfold difference of precipitation is partly due to the 30-fold ratio of saturation vapour pressures (over ice) at the two temperatures. The annual range of monthly mean temperatures depends on location. The diurnal oscillation of temperatures is virtually absent, except along the coast, because of the high latitude and snow cover. The clear skies and dry air above the Plateau allow continuous long-wave heat loss from the surface, and even during the summer little heating occurs because of the high surface albedo. The resulting equilibrium temperature profile is very stable; this is consistent with a downward sensible heat flux, which compensates the net radiational loss at the surface.

The temperature of Schirmacher Oasis varies from season to season and depends upon available solar insolation, albedo, movement of trough with associated systems and katabatic winds. The average temperature of Maitri is -9.6 °C for the period 1990-2010 which is warmer as compared to mean annual normal temperature of Novolazarevska -10.3 °C. Dakshin Gangotri always recorded lower temperature than Maitri. Ever recorded minimum temperature -52°C and highest temperature 6 °C were recorded on 16th August 1985 and 21st December 1985 respectively at Dakshin Gangotri. The difference of maximum and minimum temperature reduces as the season advances towards mid winter. The diurnal variation of surface temperature depends upon available solar insolation. The diurnal variation in temperature and wind is maximum during summer months and decreases as winter advances (Naithani and Dutta, 1998). The diurnal variation of air temperature at Maitri shows occurrence of maximum temperature at local noon and minimum temperature at local midnight. The non periodicity of air temperature is related to movement of Depressions or Lows towards the station. The cool and warm events occur in winter and summer season respectively. The mean maximum temperature - 6.6 °C,



Figs. 3 (a-d). (a) Annual mean surface temperature (°C) in Antarctica, inferred from measurements at 10 m depth in the snow, after Connolley & Cattle 1994, and Radok *et al*. 1987, (b) Isopleths of the average strength (ºC) of the surface inversion in winter (June-August). (After Schwerdtfeger (1970, p. 275), (c) Mean annual variation of temperature during 1990-2010 and (d) Mean monthly temperature for Maitri (Antarctica) 1990-2010

TABLE 1

Mean Seasonal variation of temperature, pressure and wind during 2010 and 1990-2010

Season	Temperature		Pressure		Wind	
	1990-2010	2010	1990-2010	2010	1990-2010	2010
Summer	-0.1	-1.7	987.2	984.7	11.5	15.9
Autumn	-4.9	-4.3	985.4	988.1	16.2	22.0
Winter	-14.6	-17.3	986.5	984.2	18.1	12.2
Spring	-13.9	-14.9	984.6	983.7	15.8	12.5

monthly mean minimum -12.6 °C and mean temperature of Maitri is - 9.6 °C.

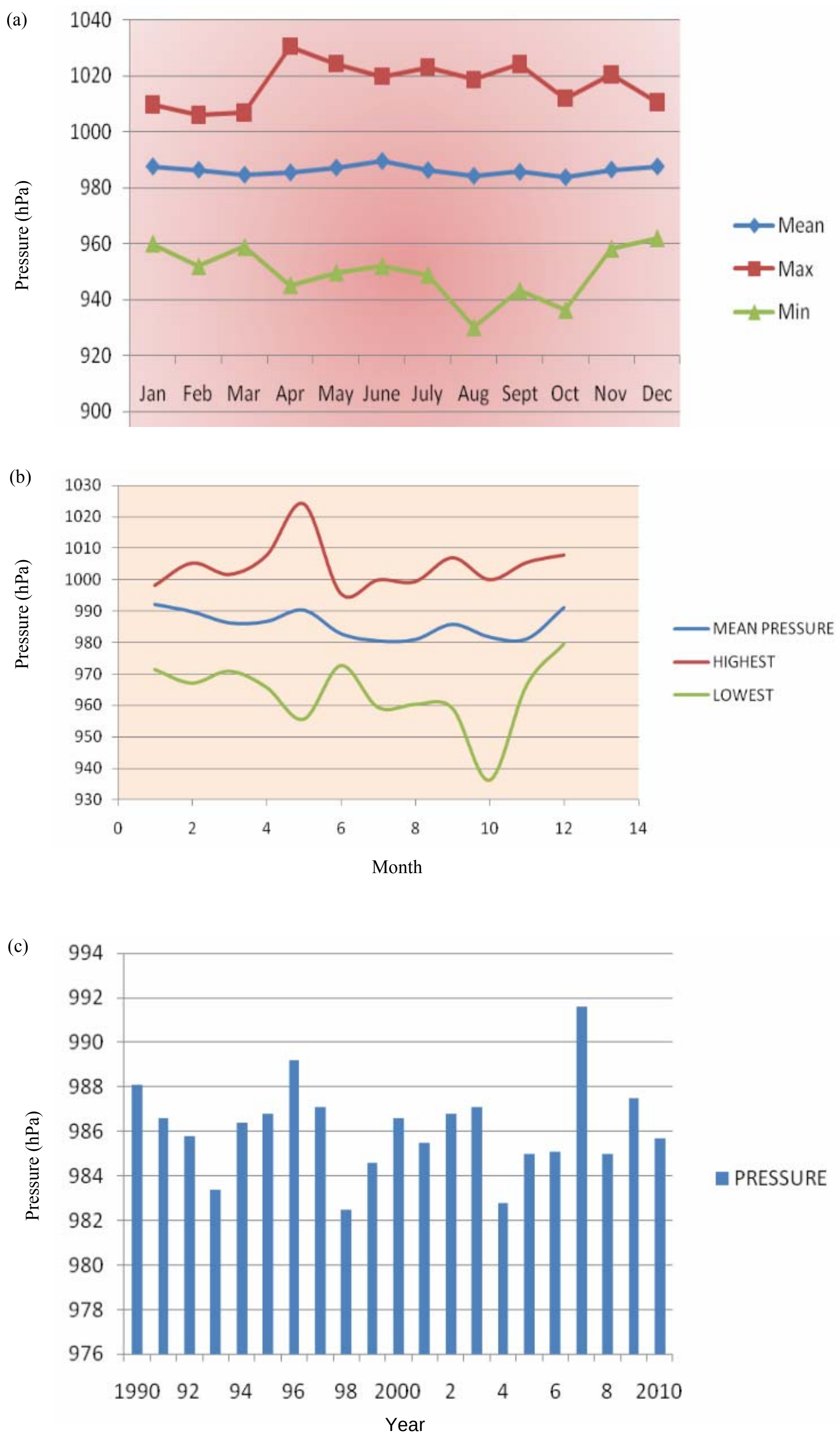
The ever recorded maximum temperature of Maitri is 12.5 °C on 3rd February 1996 followed by secondary maxima 10.3 °C during 1991. The lowest minimum temperature -38 °C recorded on 23rd July 2006 followed by secondary minima -36.2 °C during 2008. The cooling process becomes slow due to movement of blocking high. The mean monthly highest maximum temperature 3.3°C was recorded during January and mean monthly lowest minimum temperature - 21 °C recorded during August. The spring season starts with increase of solar insolation which causes melting of snow and ice commencing from August. Therefore latent heat released at the same temperature could be one of the reasons for the lowest temperature during August. The annual variation of mean temperature and mean monthly temperature during the period 1990-2010 is given in Fig. 3 (c) and Fig. 3(d) respectively. The annual variation of mean temperature at Maitri is 24.3 °C. The annual variation of temperature over Maitri clearly indicates marked warming during 1996, 2002, 2005, 2006 and 2007 followed by cooling episodes during 1993, 1995, 2000, 2004 and 2010. The year 2010 happens to be the coolest. The seasonal variation of mean air temperature is given in Table 1. The seasonal cycle clearly indicates that each season of year 2010 was warmer as compared to mean temperature 1990-2010 Table 1. The seasonal mean maximum air temperature is - 0.1 °C during summer whereas lowest seasonal mean temperature -14.6 °C reported in winter season. Seasonal cycle follows similar pattern as mean monthly long period curve (1990-2010). There is little variations of mean monthly temperature during winter season that is why winter at Antarctica is called a coreless winter. The seasonal variation of temperature at Maitri is indicative of abrupt change in solar insolation at the beginning and at the end of the dark period.

An unusual extreme maximum temperature -0.2 °C and highest msl pressure 1011.3 hPa was recorded on 25th August 1996 at Maitri. In the colder winter month abnormally such warm situations are possible, which is usually associated with rapid translation of warm oceanic air from north, low level inversion or substantial low level subsidence and due to passing of high pressure centers with ridges extending at higher latitudes.

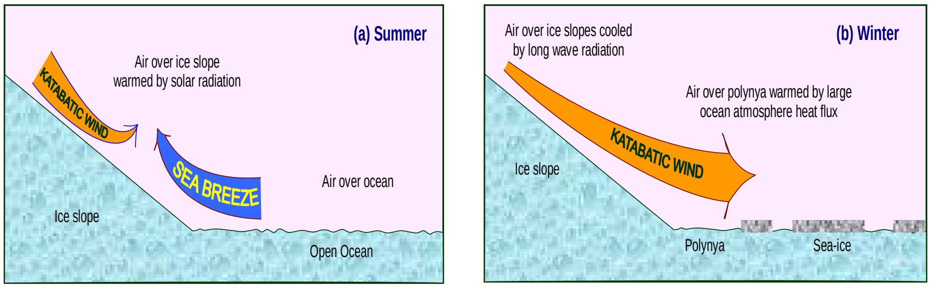
The surface temperature inversion over the Antarctic continent results from the radiative heat loss from the ice surface, particularly during the polar night of winter. Phillpot and Zillman (1970) found that the average strength of the surface temperature inversion over the Antarctic continent in winter was about 25 °C on the high plateau area of East Antarctica decreasing to about 5 °C near the coast. The upper air temperature influences weather phenomena over Schirmachar Oasis. The upper air inversion were reported during April to October at Maitri between two layers from surface to 850 hPa and between 800 to 750 hPa. The inversion layer found absent during summer due to 24 hrs available solar insolation. The tropopause during summer was warmer by 15-20 °C as compared to winter (Hosalikar & Machnurkar 1995). The strength of inversion varies from-day-to-day, as weather systems move and evolve.

6. Atmospheric pressure

The circumpolar troughs of low pressure extend around Antarctica mean latitude 63° S. Due to lack of



Figs. 4(a-c). (a) Mean monthly atmospheric pressure at Maitri (1990-2010), (b) Half yearly periodicity of atmospheric pressure at Maitri 2010 and (c) Mean annual atmospheric pressure at Maitri (1990-2010)



Figs. 5. (a&b). Feature of Katabatic winds (a) summer and (b) winter

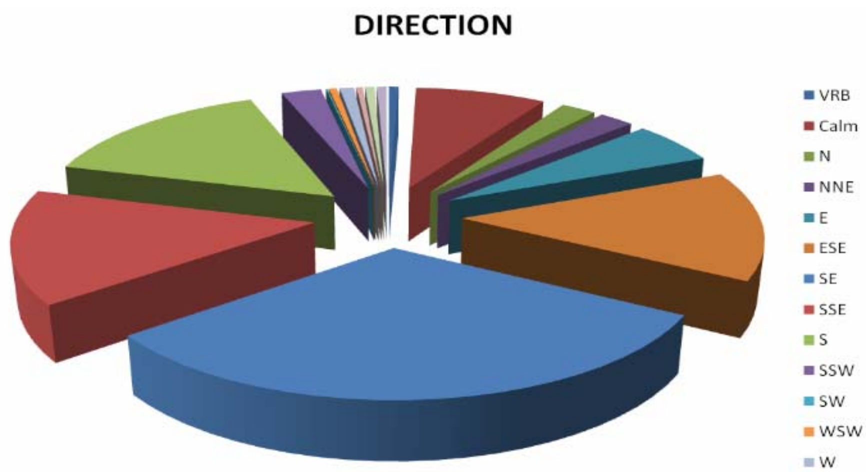


Fig. 5 (c). Wind rose diagram of Maitri station (Antarctic), 2000

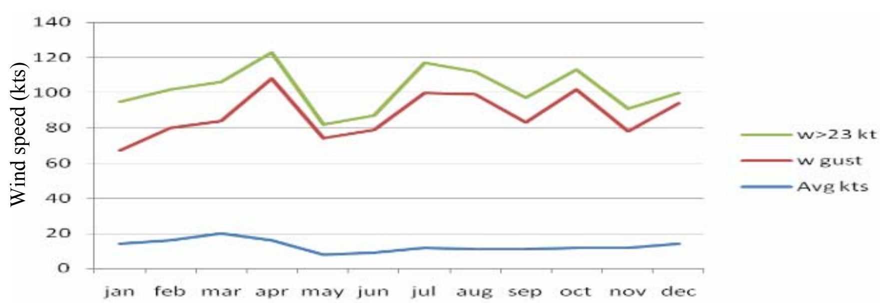


Fig. 5(d). Mean wind speed during 2010

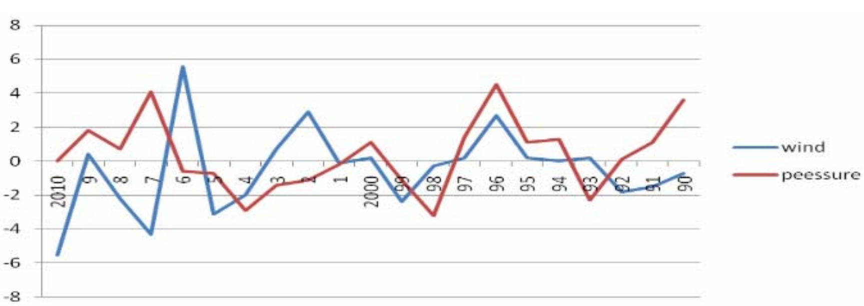


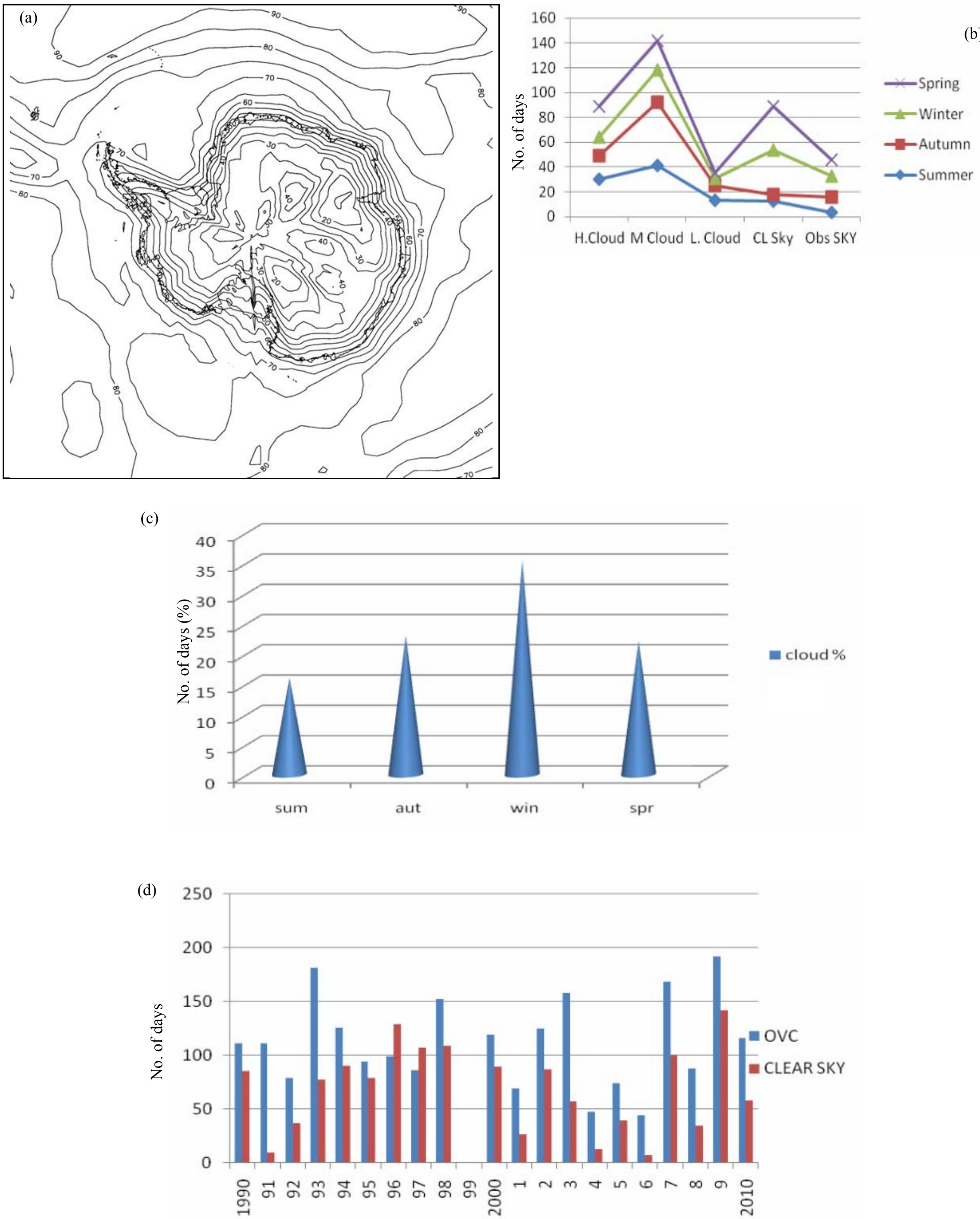
Fig. 5(e). Pressure and wind anomaly during 1990-2010 barrier zonal flow, high levels of cyclonic activity occurs around the Antarctica coast. Dakshin Gangotri and Maitri both lie between high pressure zones centered on pole and circumpolar trough of low pressures moving around Antarctica mean latitude. Therefore, atmospheric pressure at both the station is influenced by relative position and strength of these systems. The annual mean atmospheric pressure shows half yearly periodicity with lowest pressure during spring and secondary minima in March. The semi annual oscillation dominates variations of atmospheric pressure at Maitri [Lal (2006)]. It shows well defined maxima around summer and winter solstice which gives clear indication of semi annual oscillation with respect to position and strength of circumpolar trough [Figs. 4 (a&b)]. The semi annual oscillation is deepest in equinoctial seasons. The highest and lowest pressure occurred during May followed by secondary minima in October and maxima in September. The pressure pattern over Maitri has half year periodicity which is similar to other coastal Antarctica station. It allows contraction and extension of pressure trough along Antarctica and surrounding ocean. Due to the semi annual oscillation the pressure at Maitri shows half yearly wave pattern. The phase of semi annual oscillation reverses from pressure maxima during month March/ September.

At Maitri, mean seasonal pressure variation during 1990-2010 shows higher values during summer & winter and lower values in autumn & spring which is indicative of net transport of air from ocean during autumn and spring season. The high values of pressure in autumn during 2010 could be indicative of more peripheral movements of high pressure system (Table 1). The mean monthly latitudinal variation of axis of Antarctica trough also indicates similar fluctuations throughout the year which is main feature of mean circulation of southern hemisphere, the controlling factor of weather variation. The summer and winter month of 2010 had lower pressure than seasonal mean pressure during (1990-2010) which corresponds to higher temperature during summer in same period. The record of highest and lowest mean annual pressure occurred during the year 2007 and 1998 [Fig. 4 (c)] which corresponds to highest annual mean temperature and lower minimum temperature during these year.

The long period (1990-2010) mean annual atmospheric pressure of Maitri is 985.7 hPa whereas mean annual atmospheric pressure at Dakshin Gangotri is 985.0 hPa during the period 1984-89. The lowest mean sea level pressure of 935.0 hPa was recorded at Dakshin Gangotri on 30 July 1985 and lowest mean monthly pressure 930.0 hPa recorded on 9 August 2005 at Maitri. The highest mean sea level pressure 1030.5 hPa recorded on 29 April 1990 at Maitri.

7. Winds

In Antarctica, surface wind is one of the deciding factors for outside working and better planning activities for the day. Due to topography of the Schirmacher Oasis and pronounced stability of the boundary layer air mass, the simple rules of synoptic meteorology regarding the pressure to wind relationship are not adequate to explain the observed winds. The slope of the icy terrain of the Oasis is the strengthening factor of wind. The katabatic winds accompanied with either rise of temperature or fall of temperature due to advection of cold air towards the Schirmacher Oasis The feature of katabatic winds over Scirmachar Oasis is given in Figs. 5 (a&b). The winds in coastal region of East Antarctica are driven by mesoscale katabatic wind and synoptic scale system Schwerdtfeger (1984). The strongest winds are generally forced by offshore cyclonic vortices that move primarily around the coast from west to east, as a component of the semi-permanent trough of low pressure that encircles the Antarctic continent, in the appropriate location these depressions can reinforce the drainage flow towards the coast (Ball 1960). The unstable stratification, marked by turbulence and convective activity occurs in the surface layer of atmosphere during day whereas stable stratification and suppression of turbulence occurs during night. The nocturnal inversion resulted both in the frictional decoupling of the surface atmospheric layer and in local pressure gradients which had little or no relation to the synoptic pressure distribution. Kumar & Gupta. (2007) studied the development of katabatic flow at Maitri with distance and time on ice slopes, the mass of air involved, mixing within the flow and between the flow and the ambient air. The confluence zone east south east & south is a zone of convergence at the Maitri which enhance supply of radiative cooling of air near surface along coastal slopes as a result katabatic winds become stronger and more persistence. In mid day of summer season lower atmosphere of the Oasis is determined by thermal convection which dissipates by sudden onset of katabatic wind flow. The inclination angle of terrain and the distance at which inversion forms, control the speed of katabatic winds. These winds blow down an inclined surface under influence of gravity, their direction at Maitri is invariably southerly as the elevation increase towards south. Therefore, katabatic wind at Maitri has high directional consistency. The directional consistency and topography largely attributes to influence katabatic process. The variation in surface wind does not confirm always changes of synoptic situation, *i.e.*, passes of low pressure system (Thomas and John, 2003). The gravitational forcing of cold air mass on inclined terrain is an essential requirement for the formation and maintenance of the katabatic winds. The katabatic winds transport dry air from polar region. A case of katabatic



Figs. 6 (a-d). (a) Mean winter cloud amount (%) from ISCCP data (*Courtesy of the British Antarctic Survey*), (b) Seasonal Mean Frequency % of cloud observation at Dakshin Gangotri (1987), (c) Seasonal Mean Frequency (%) of cloud observation at Maîtri (1990-2010) and (d) Yearly mean cloudiness and clear sky condition over Maitri during 1990-2010 wind at Maitri was studied by Kulandaivelu & Dang, (2003). Maitri remained windy for 190 days during 2010 when wind was exceeding 23 knots or more. Gusty winds prevailed during month of April, July and October where as January was lowest windy month followed by May [Fig. 5 (d)]. For the period (1990-2010) the seasonal mean wind shows more windy winter season as compared to summer season (Table 1).

Srivastava *et al*., 2004, has analysed wind data of Maitri and studied katabatic wind flow over Maitri for year 1992. The surface winds mostly flow from SE sector with lower frequency of calm and variable wind [Koppar (1995) & Fig. 5 (c)]. These winds are usually accompanied by drifting or blowing snow. The mass of the snow picked up by the winds increases exponentially at fourth power of winds speed (Streten, 1990). The wind at Maitri has similar characteristics as most of the coastal stations at Antarctic, short period calm and light wind followed by a period of high events which corresponds to successive passes of low pressure system. There is strong symmetry of annual mean wind speed and annual mean surface pressure of Maitri [Fig. 5(e)] except 2007 where high mean pressure corresponds to low mean wind speed.

8. Clouds

The clouds are important component of earth climate system by virtue of their role in radiative process and hydrological cycle. Schwerdtfeger (1970) outlines some of the difficulties with surface cloud observations in the Antarctica because of blowing snow and lack of light during winter. The satellites have contributed significantly to the monitoring of cloud characteristic alongwith other parameters. King and Turner (1997) reported that stratiform cloud (stratus/nimbostratus/altostratus/cirrus) is the most common cloud type although cumuliform clouds are reported rarely. Moreover, in some cases over the continent localised instability can be quite severe and lead to mammatus and small cumulonimbus development, particularly where local convergence occurs in coastal environments or where cold air flows over relatively warm water or rock. The mean winter cloud condition over Antarctica is given in Fig. 6 (a).

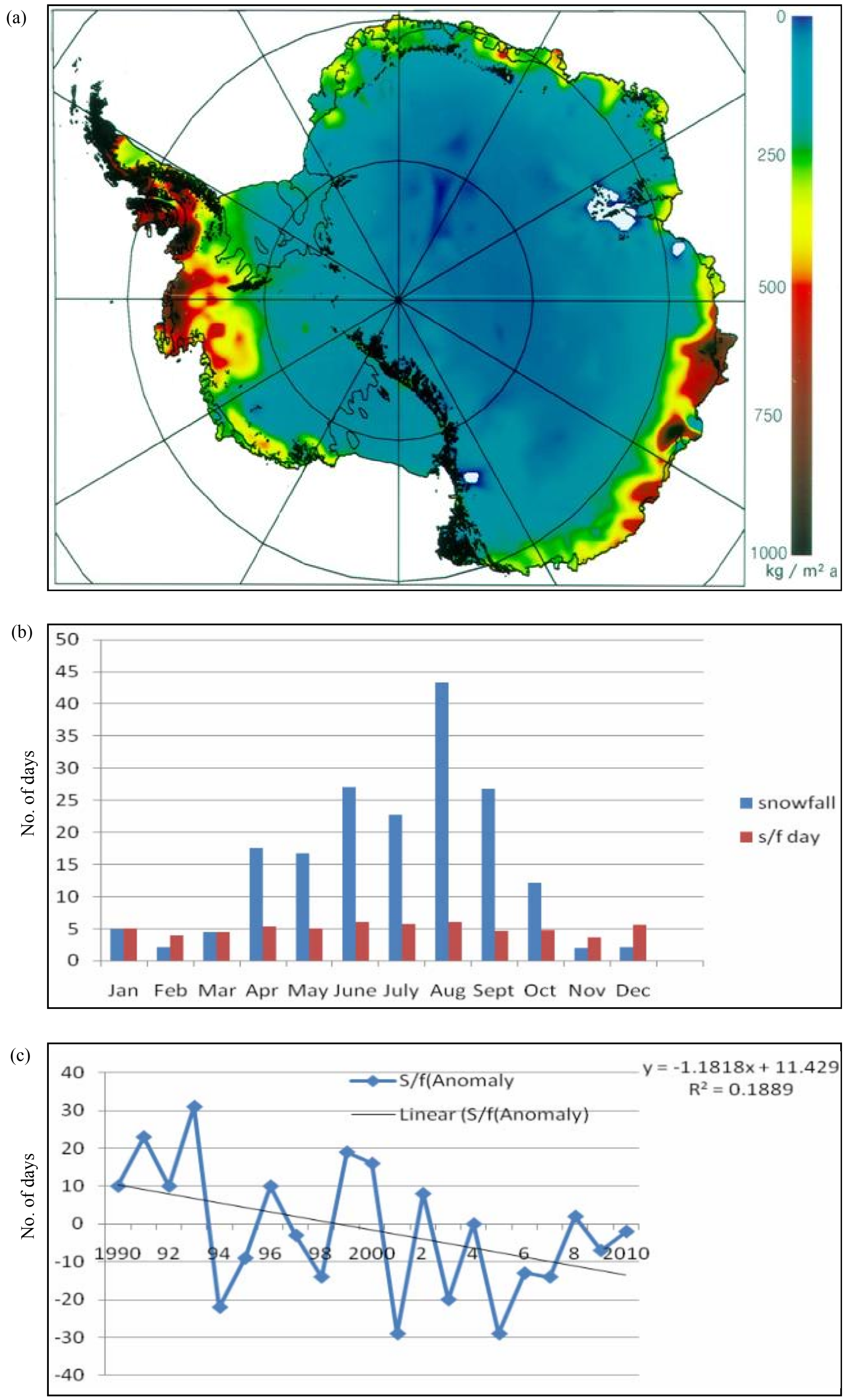
Cloud observations has been a part of study during each Indian scientific expeditions. It is very common phenomenon at most of the coastal Antarctica stations. Clouds occur under influence of low pressure system moving around Antarctic circle and their coverage changes rapidly as the system approaches towards the station. When any pressure system approaches, high clouds Cirrus (Ci) appears first as they become denser then cirrostratus (Cs) forms. It was observed that often stratocumulus overcast is so dense and continuous that the individual cloud layers are difficult to be distinguished. Isolated orographic clouds form when wind is southerly caused by low level waves due to Wohlthat mountain about 70 km south east of Maitri. Stratus clouds or stratocumulus often seen in summer but cumulus is very rare. Cirrus/cirrostratus clouds are often widespread and form at much lower level than in temperate region. Therefore, the clouds observed at Maitri are mostly Stratus, Altostratus, Altocumulus, Cirrostratus and cumulus. The polar stratospheric clouds are very high clouds brighter than the full moon and clearly visible at night or when the sun is low. These clouds form and disappear rapidly when water condensation occurs at high altitude, often caused by the presence of aerosol particles in form of chemicals in the atmosphere.

The mean cloudiness at Maitri and Dakshin Gangotri is 4.4 and 4.5 octa respectively. The annual mean 101 overcast day and 63 clear sky day was observed at Maitri. Koppar (1991 &1995) analyzed data of sixth and eleventh Indian scientific expedition to Antarctica and illustrated cloud observations of Dakshin Gangotri and Maitri [Fig. 6 (b]. It is seen that the spring is most appropriate season for cloud formation. The reason could be more evaporation due to melting of frozen ocean. The frequency of high clouds is more than other clouds during summer. However the frequency of clear sky is higher in winter and spring whereas higher frequency of medium clouds are observed during summer. Generally the cloud cover days during summer season are lower than other seasons [Fig. 6(c)]. August of 2009 was less cloudy. Cloud condition during last 21 year shows negative anomaly in 1992, 1993, 1995, 1996, 1997, 2001, 2004, 2005 and 2008 which indicates less number of overcast days during these years [Fig. 6(d)].

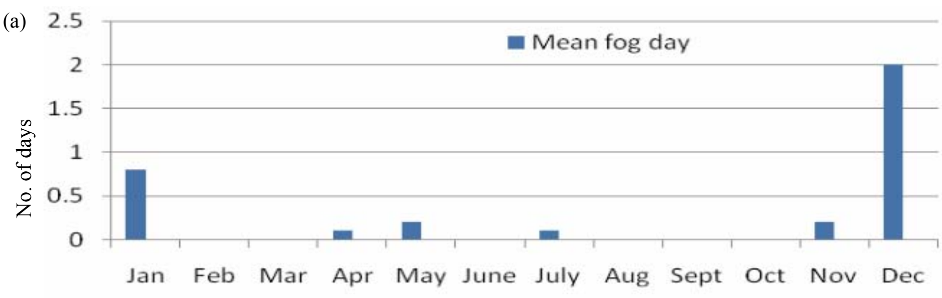
9. Weather over Maitri

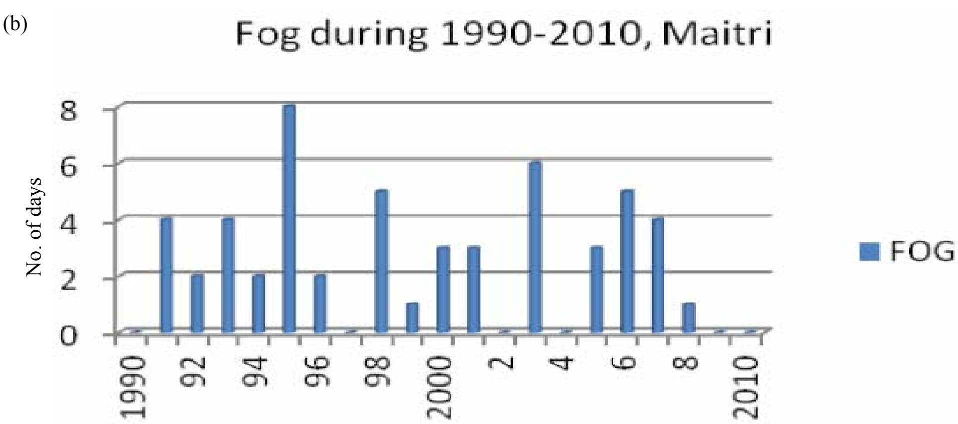
9.1. *Precipitation*

The Antarctica is envisaged as a land of ice and snow. Over the Antarctic continent, air is extremely dry. Air in the upper levels of the atmosphere circulates towards Antarctica from northern latitudes. By the time the air descends over the polar central plateau to reach the boundary layer of the atmosphere, which is immediately above the dome shaped ice cap, most of the moisture gets removed. For the continent as a whole, annual snow accumulation is equivalent to about 150 mm of water. Fig. 7(a) shows estimates of the mean annual accumulation of snow and it may be seen that the 50 mm water equivalent isopleth over central Antarctica accords well with the estimate of mean annual precipitation there



Figs. 7 (a-c). (a) Annual net accumulation (P–E) (kg / sq.m area mm water equivalent) over the Antarctic continent [From Vaughan *et al*. (1999)], (b) Snowfall (mm) & snowfall day during 1990-2010 and (c) Snowfall day anomalies during 1990-2010





Figs. 8(a&b). (a) Mean monthly Foggy day and (b) Foggy day during 1990-2010 at Maitri

of around 50 mm of water equivalent, given that wind speeds, and thus ablation, are relatively low over central Antarctica.

The precipitation occurs due to cooling of moist air masses above low level inversion. Due to the orographic lifting of warm air masses in association with synoptic scale systems more precipitation occurs in coastal Antarctica. The fronts associated with moving cyclones are responsible for snowfall activities over the Schirmacher Oasis. Heavy or moderate snowfall is indicative of active fronts leading edge of warm air masses being transported southwards. The strong temperature variants give precipitation in form of snow or mixture of rain and snow. Due to frequent movement of depression or trough more precipitation occurs especially when long waves are amplified and air is advected towards higher latitude. Interestingly, the blocking high give less precipitation, slight precipitation may occur due to medium clouds (As, Ns) associated with anticyclones. The precipitation at Maitri and Dakshin Gangotri is mostly in the form of snowfalls. There are on an average 88 days snowfall per year over Dakshin Gangotri and average a year 61 days per year snowfall occurs at Maitri. Due to heavy to very heavy drifting snow, highest snowfall recorded during winter season which causes more accumulation of snow. The mean maximum snowfall is 43.3 mm recorded in August during period from 1990-2010. Light to moderate precipitation occurs during summer season, the reason for lowest snowfall during summer period. On an average 2.1 mm snowfall only have occurred during December for the entire period from 1990-2010 [Fig. 7(b)]. Accumulation of the Snowfall at Maitri does not depend upon number of days but it depends upon mass transport of snow/ice pellet from southern latitude.

Precipitation mostly indicative of snowfall but rainfall is also very rare which occurs when mean temperature during summer rises several degree above the freezing level. In isolated cases, rain or drizzle have also been reported during summer months at Maitri (17th January 1991 & 2nd February 1996). The average monthly mean temperature was abnormally high during 1996. The highest day temperature 12.2 °C recorded on the 3rd February 1996 [Rasal & Mohar (1996)]. The rise of temperature accompanied with absorption of latent heat by ice pellet in lower level of atmosphere resulted precipitation at Maitri in form of water droplets. On basis of the snowfall anomaly, it appears that Maitri experienced less precipitation during last decade [Fig. 7(c)]. As per annual anomaly of snowfall day derived average over long period average 1990-2010, the tendency of decreasing trend is observed [Fig. 7(b)].

9.2. *Fog*

The clouds over oasis are characterized by cooling of rising air, their cooling over a humid surface below it's dew point temperature causes fog formation. This cooling may be as a result of radiation, mixing of warm and cool air masses or from warm moist air moving over colder surface. The occurrence of advection fog over Maitri and Dakshin Gangotri is a very common phenomenon. The induction of warm and moist marine time air masses moving towards interior colder surface of Schirmacher oasis causes development of low clouds which laid formation of fog over the surface. In general fog occurs due to advection of warm and moist air under influence of low pressure system from higher latitude over colder surface of coastal east Antarctica. The advection fog is quite frequent in peak summer. [Fig. 8(a)]. Fog does not affect Maitri every year. In recent decade during 2002, 2004, 2009 and 2010 no fog was reported at Maitri [Fig. 8(b)]. Very few studies are available on formation of fog over Maitri. The advection Fog is very common over Dakshin Gangotri [Lal (1987)]. Koppar (1989) has also observed 13 foggy days over Dakshin Gangotri.

(*i*) *8-9th January 1996*

Gajanand *et al*., (2007), studied advection fog over Maitri during 8-9th January 1996 which lasted for about 24 hrs. Due to induction of warm air masses from the southern ocean on 8th January, 1996 at Maitri, the temperature climbed up by 2 °C which fell by 3.7 °C after fog dispersal. The fall of mean sea level pressure about 3 hPa during fog followed by rise of pressure by 5 hPa on 10th January after lifting of fog. The sudden increase of temperature on 10th January caused to pickup strong katabatic winds to disperse the fog. The advection of sea fog from shelves ice at the exposed land area and the very low stratus cloud entering from the northern latitude are main reason for occurrence of fog at Maitri.

During 2000 following three different cases of fog episode were observed over Maitri.

(*ii*) *30th April 2000*

In this study it was observed that after cessation of blizzards due to passing a low pressure system, light wind followed by clear sky laid fog formation on 30th April 2000 the autumn month. The fog commenced at 0830 UTC, reducing surface visibility to less than 500 m which remained for 3 hrs. Initially a fall of temperature and gradual rise of temperature was observed later on.

(*iii*) *December 2000*

Two cases of fog were observed during peak summer on 8-9th and 12th December 2000. The fog on 9th December occurred at 0300 UTC due to advection of shallow fog towards Maitri from shelf ice. During this period the air temperature had fallen by 8 °C from -1 °C to -9 °C followed by rise of pressure. The rising trend of pressure on 8 & 9 clearly indicates passing of the low pressure system. In this case also fog dispersed due to increase of the wind speed. On 12th December 2000 fog occurred due to passing of very low stratus cloud on the ground level. The ground level movement of low stratus cloud from shelf ice towards the station causes visibility less than 150 m resulting in thick fog on the day over Maitri which lasted for 8 hrs. Kulandavelu, (2007). The strong southerly katabatic wind resulting from elevated ice plateau inclined towards south of the station cleared stratus clouds and thus fog dispersed.

In majority of the cases fog occurs due to relatively warm air from low latitude moving slowly over colder surface. The air loses its sensitive heat, so that relative humidity increases and the saturation temperature is reached to produce fog at the station. Fog dissipates under influence of increasing wind speed and corresponding increase in vertical mixing height of unsaturated air. The vertical depth of fog over Maitri occasionally goes up to 300-400 m. The solar heating of ground and formation of thermal plumes had less effect on the formation and dissipation of the fog episode at Maitri [Gajanand *et al*., (2007)]. The fog dissipates after the katabatic wind starts blowing from the interior of the continent.

The seasonal weather phenomena over Maitri are presented in Fig. 9. Precipitation occurs in form of snow or snow pallets which is more frequent in association with blizzards during winter. The precipitation occurred due to cooling of moist air above low level inversion. Due to orography lifting of moist air in association with synoptic scale system more precipitation occurred during winter season. Lowest precipitation occurs during autumn corresponding to less number of cyclonic disturbances affecting Maitri. Summer and winter season is most conducive of fog formation Fig. 8(a).

During the period under study, (1990-2010) fog did not affect Maitri every year. Maximum foggy days were observed during 1995 followed by secondary maxima during 2003. It appears that due to the warm episode during 2009 and 2010 no fog was reported.

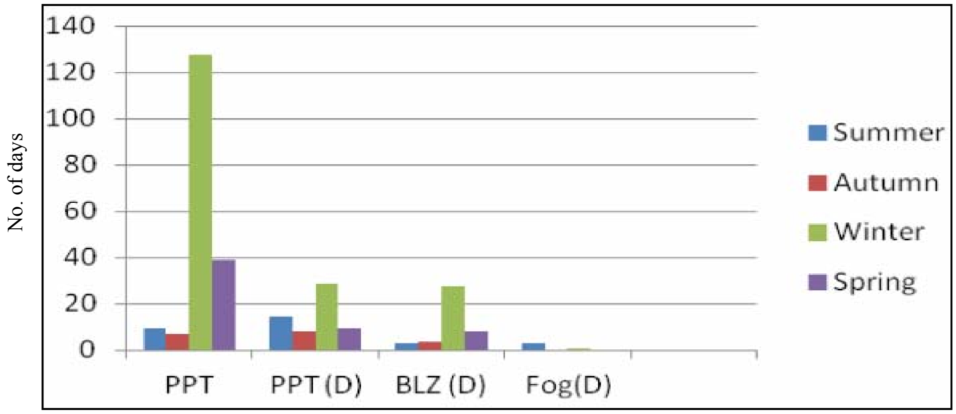


Fig. 9. Seasonal weather phenomena over Maitri (1999-2010). PPT – Precipitation, PPT(D) – No. of precipitation days, BLZ(D) – No. of Blizzards days, Fog(D) – No. of foggy days

10. Blizzards

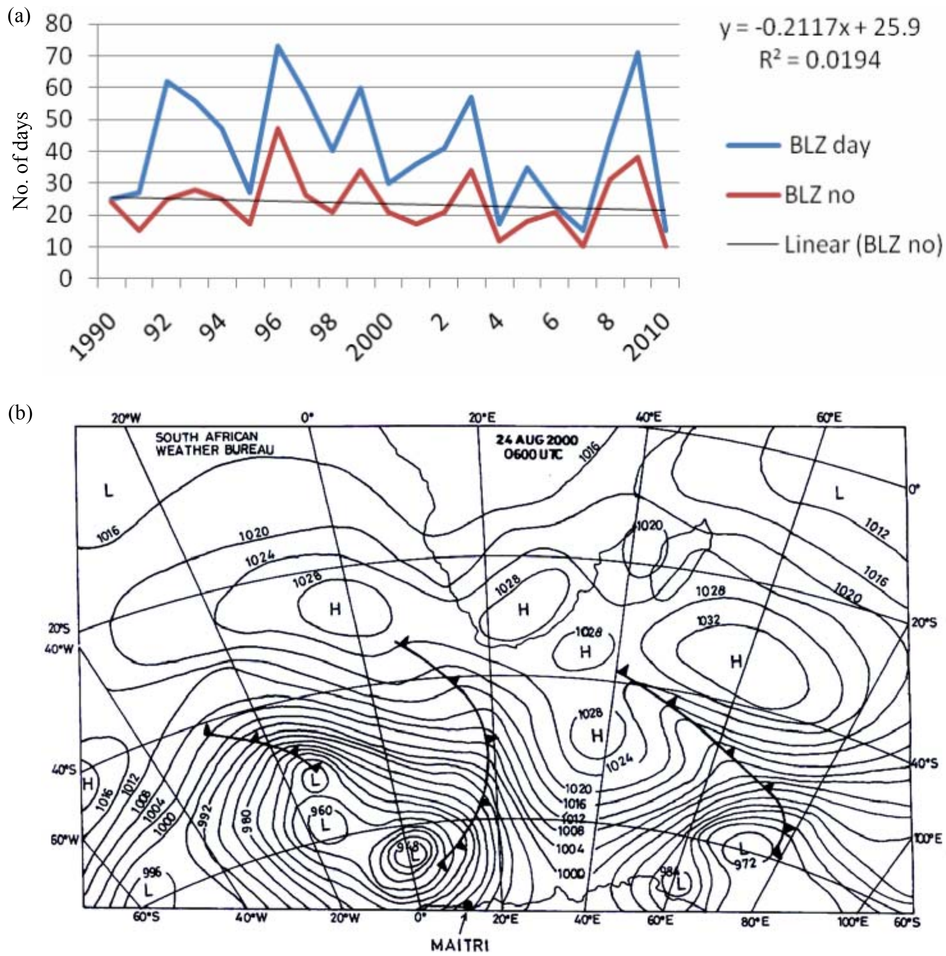
Antarctica is known as home land of Blizzards and is the windiest continent of the world. As winds increase in speed to above about 8 m/s (15 kt) they can cause any loose snow on the surface to begin to drift. If winds strengthen to exceed about 11 m/s (21 kt) and loose snow is present, then drifting snow may be raised above eye level thus disrupting outdoor activity and being defined as blowing snow for the purpose of international reporting of weather observations. Winds stronger than about 17 m/s (33 kt) can reduce visibility to only a few hundred metres, if there is sufficient loose snow in the vicinity. The word 'Blizzard' however, used quite loosely in the literature, means light drifting snow with clear skies to a snow storm accompanied with high winds. This is a typical Antarctic weather phenomenon occurring when drift snow is picked up and blown along the surface by the violent winds. Blinding conditions can result in making the objects invisible less than a few feet away. During blizzards surface wind may reach hurricane intensity with falling snow or disengagement of ice from the surface into the fine snow dust and blown to several hundred meters. In such situation visibility may reduce to almost zero. Localized blizzards are caused when the surface wind sweeps up loose snow, even if the skies above are clear and no snow is falling. A severe blizzard may last for a week at a time with high wind speeds.

Since the beginning of the Indian Antarctic expedition, the blizzards have been most attractive weather phenomena and were a part of study during each expeditions. Lal (1987) studied blizzards at Dakshin Gangotri during 4th Indian scientific expeditions. Lal & Ram (2009) studied climatology of blizzards. Kulandaivelu *et al.*, 2005 discussed the synoptic features of the blizzards for the year 1996 at the Maitri. Srivastava *et al.*, 2004 Studied two cases of blizzards - one during peak winter (June) and another during peak summer (December). It was observed that during summer turbulent mixing of surface and upper air masses took place as a result of which during blizzards rise of temperature over Maitri was observed but during winter, temperature and R. H. both decreased due to abundant fast snow dispersal into the atmosphere with increase in wind speed, lower down temperature and directional consistency of katabatic wind. Rasal (2003) described some synoptic features of blizzards over Maitri on the basis of one year Maitri data. These studies suggest that the blizzards at Schirmacher are usually warm, moist and are associated with eastwards moving cyclones situated to north or northeast of the station.

The number of blizzards and blizzard day during 1990-2010 over Maitri is given in Fig. 10 (a). Blizzard day and number of blizzards are well consistent. Annual non-uniformity of blizzard during the period concerned with warm or cold episode during the particular year is observed.

10.1. *Blocking high*

The term Blocking high is described as tropospheric high pressure system which remains at the station for several days in the area where zonal flow prevails. It is abnormally persistent quasi-stationary system that blocks movement of mid latitude jet stream and is triggered by Rossby wave (Masoon *et al.*, 2004). The high pressure plays a blocking role in slowing the cyclone and forcing it to move southwards closer to the coast and thus enhancing the impact of the cyclone (Morphy, 2003). Two cases of blocking high during 17-27 August 1996 and 22-29 August 2000 were studied by Kulandaivellu *et al.* (2005) when surface air temperature shoot up abnormally about 10° C or more.



Figs. 10 (a&b). (a) Annual variability of blizzards over Maitri during 1990-2010 and (b) Surface weather chart on 24 August 2000

(*i*) *17-27 August 1996*

The eddies and lows moving systems around coastal Schirmacher Oasis were blocked by a ridge ahead on 24^{th} August 1996 which was extended form mid latitude high pressure system situated in Indian Ocean region [Fig. 10 (b)]. It blocked movement of air masses from west to east. The high pressure developed in the realm of cold air which moves towards north or north east behind the eastward moving cyclone. A strong wind from northern latitude and rise of surface temperature by 20 °C was experienced at Maitri.

(*ii*) *22-29 August 2000*

On 24^{th} August 2000 a high with central pressure 1032 hPa and another high with a central pressure 1038 hPa were seen about 35° S/60° E and 50° S/40°E extending ridge upto 70° S. Three eddies associated with frontal system were also present. A strong low pressure area with central pressure 948 hPa was laying over 64° S/0° E. The sub tropical mid latitude high remained stationary for 10 days during this period. The sky was covered with Altostratus cloud during period from $23\text{-}29^{th}$ August. The eastward movement of the eddies blocked by the ridge is a reason for prolonged cloudiness. The approaching low pressure closed to the station, resulted strong winds 55 kt with gustiness 78 kt. This strong wind continued till 29^{th} August and blizzard prevailed for 4 days causing surface visibility to zero. The movement of the low pressure systems slowed down due to presence of ridge at 40 degree east. The surface temperature rose by 5 °C due to advection of warm and moist air from lower latitude toward east Antarctica coast.

Fig. 11. Monthly frequency (%) of blizzards over Schirmachar Oasis. Dakshin Gangotri 1984-1989 and Maitri period 1990-2010

10.2. *Circumpolar low*

The circumpolar trough of low pressure surrounding Antarctic continent, dominates the area between 60° S and 65° S. Frequent depressions move at speed about 20 to 30 kt in the vicinity of this trough resulting in very changeable and amazing disturbed weather conditions. Maitri is scored by a regime of persistent and powerful katabatic wind which is the result of cold and dense air rolling down the slope from the high plateau. The warm and moist air from the sub polar region approaching towards coastal Schirmacher Oasis regions rides over the cold dense air flow rolling down from the high interior plateau. They interact and cause moderate to severe snow fall which blows with the strong wind and thus causes occurrence of extremely severe blizzard or snow storm. The low pressure system in the circumpolar region when intensifies, wind attains gale force. Thus, blizzards at Maitri are associated with extra tropical storm which is preceded by snow fall.

On an average 51 blizzard occurred over Dakshin Gangotri for 115 days and about 21 blizzards affected Maitri for 47 days during the period. Maitri experienced about 7 blizzards a day with the maximum number of blizzard day during July. The station Dakshin Gangotri which lies near the coast experienced maximum number of blizzard during May (Fig. 11). The average wind speed during the blizzards is about 52 kts which exceeds 100 kts on several occasions. The longest duration of blizzards 168 hours recorded in June 1997. There were 12 such occasions when blizzards lasted for more than 72 hours.

The percentage frequency of blizzard over Maitri in month of May is highest followed by July and August whereas January experience lowest frequency of blizzards at Maitri. Dakshin Gangotri which is near the coast is affected by more number of blizzards during summer period than Maitri. At both of the stations the blizzards are associated with extra tropical system which is normally preceded by precipitation. At Maitri maximum 38 blizzards occurred in 1996 whereas minimum 10 blizzards occurred in year 2010. During the commencement of blizzards mean sea level pressure decreases and attains lowest values when extra tropical cyclone under whose influence the blizzards are activated across the latitude. Thereafter pressure rises continuously and maximum values reached when the cessation of blizzards starts. During blizzards moist and warm air is transported towards the Oasis which causes rise of surface temperature due to cyclone activities over the area. Frequency of the blizzards was very high in the temperature range of 0 °C to -15 °C of maximum temperature and -5 °C to -20 °C of minimum temperature (Lal and Ram, 2009).

Rasal, 2003 studied one of the longest & strongest blizzards affected Maitri during 19-24 July 1996 which lasted about 113 hrs with wind speed 63 kts during period. On 15th July 1996 there were a series of sub polar lows moving from west to east with well marked trough along 60° south on 17th July with a core pressure 964 hPa. (Fig. 12). Due to movement of low pressure systems fall of pressure by 24 hPa recorded upto 0000 UTC of 18th July.

The anticyclone around 48° S was acting as blocking high and pushing warm and moist air towards the Maitri caused continuous rise of air temperature to meet initial energy to initiate blizzards. Due to mixing of cold and

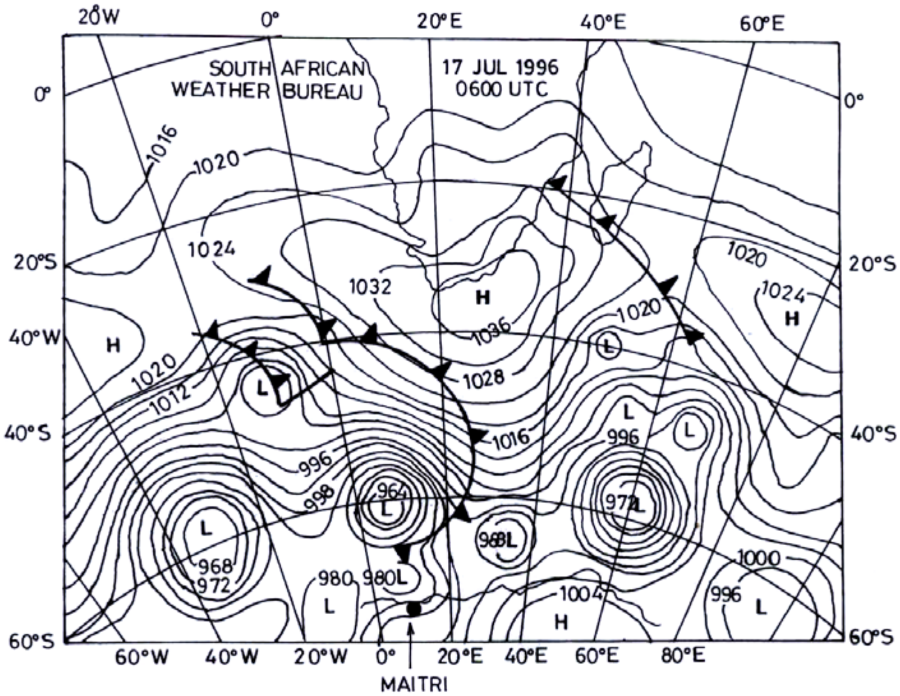
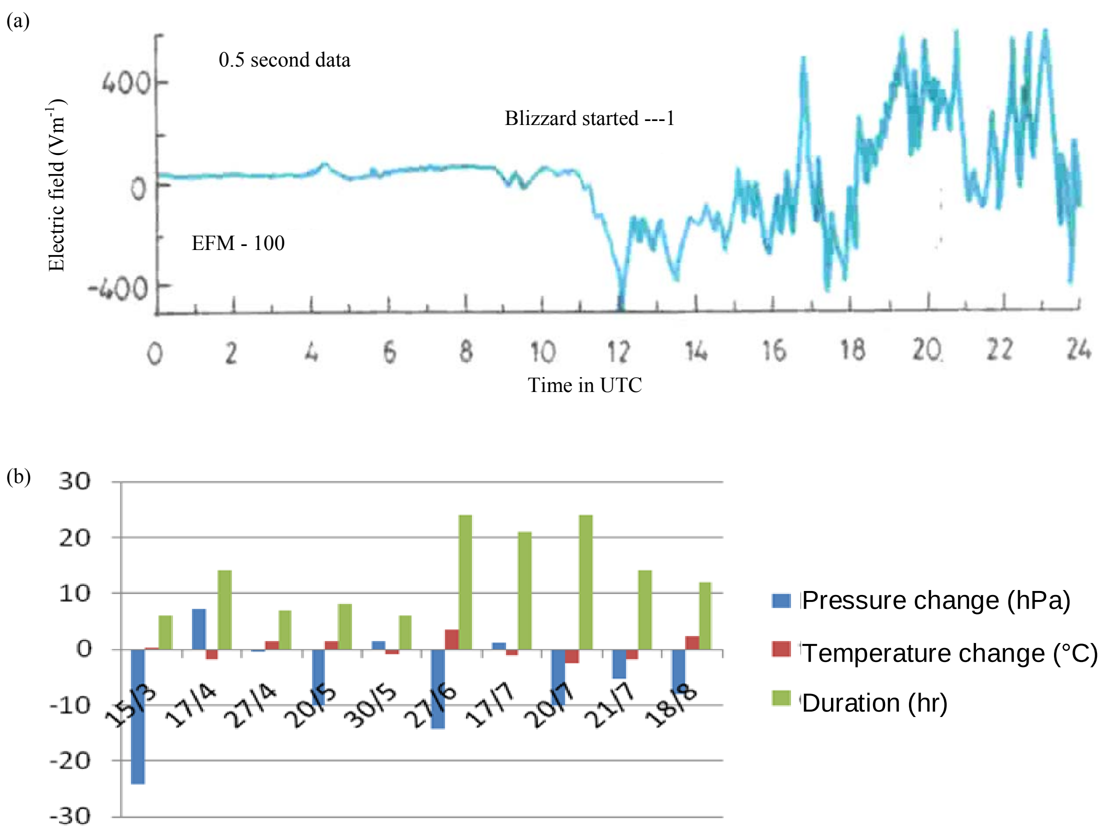
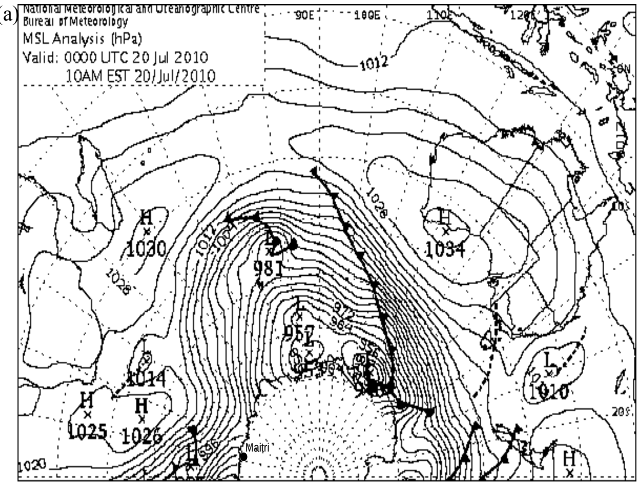


Fig. 12. Surface weather chart on 17th July 1996

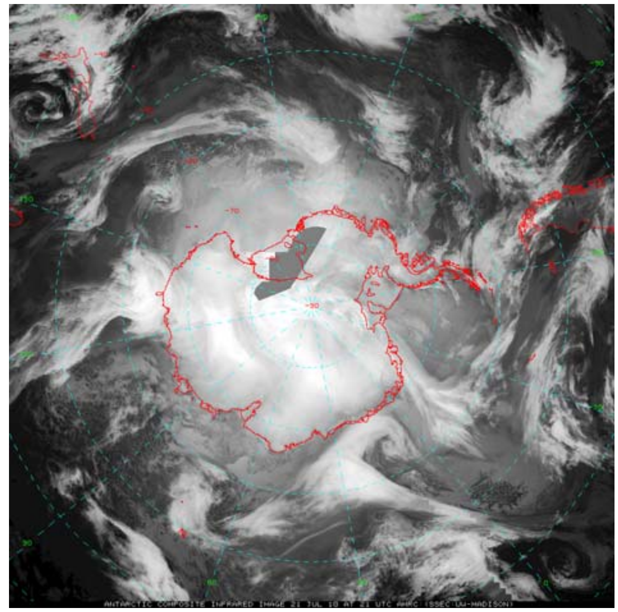


Figs. 13(a&b). (a) Electric field during the blizzards on 28th August, 2008 (/iigm.res.in) and (b) Intensity of blizzards

(a)



(b)



Figs. 14 (a&b). (a) Mean sea level pressure chart dated 20th July, 0000 UTC and (b) Antarctic composite IR Cloud imagery 21 July, 2100 UTC received from AMRC, SSEC, UW-Madison

dense air masses from the icecap region with warm and moist air mass from oceanic area caused snow fall. The snow fall drifted and blown by high speed wind gave a series of blizzards in Schirmacher Oasis over Maitri. Due to anticyclone little movement of the system was observed that resulted series of Blizzards over the station starting since 16th July to 19th July, 0600 UTC. The blizzards continued till 23rd and started receding since 24th July with rise in pressure and fall in temperature. The blizzards ended on 24th July at 0530 UTC. During this period maximum wind gust of 112 kts with wind speed 68 kts was reported on 23rd at 1010 UTC.

10.3. *Atmospheric electricity during blizzards*

During blizzard period tremendous rise of surface potential gradients was observed at Dakshin Gangotri which varied from 400-900 volts/m^2. In case of snow fall or fair weather surface potential gradient varies from 0-400 volts/m^2 (Lal, 1987). The variation of surface potential gradient depends upon strength and number of Blizzards day. The southern polar ionosphere caps also produces electric field which make change in air earth current, it was observed that the electric field and current density turns zero before few hours of onset of blizzards. A fluctuating electric field was observed during the blizzards on 28th August, 2008 before few hours of onset of blizzards at Maitri (/iigm.res.in).

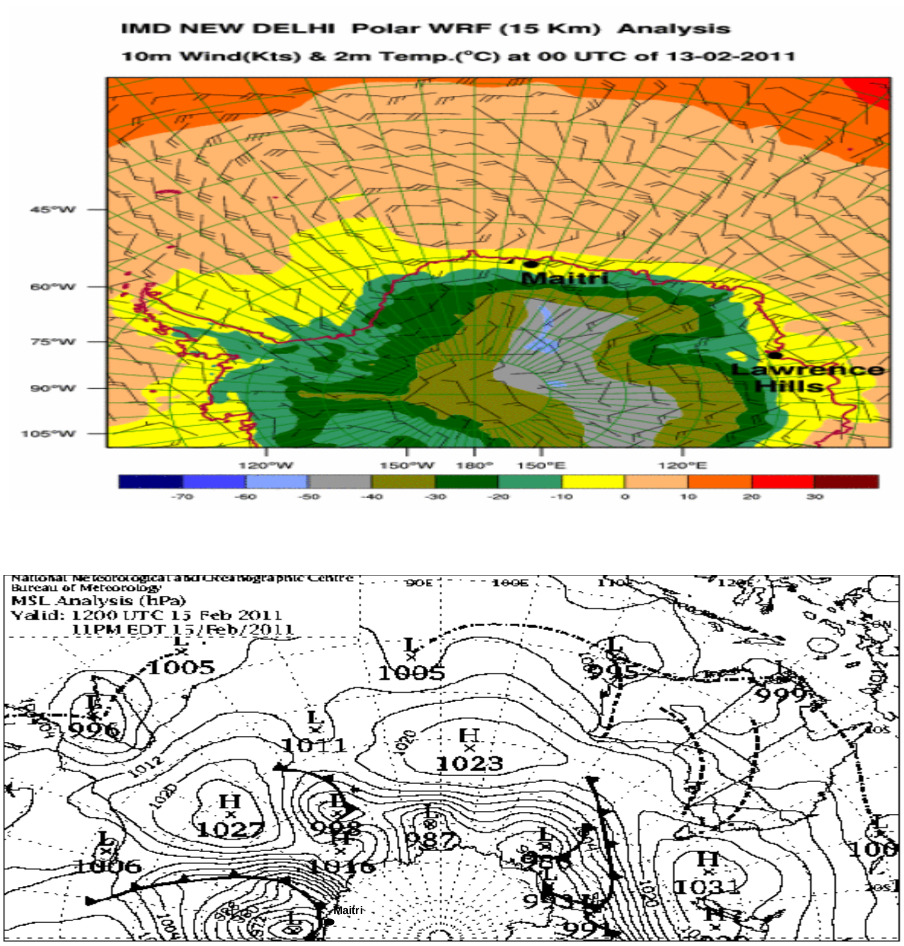
10.4. *Blizzards during 2010*

One blizzard each in March, June and August, two each in April, May and three in July, in total ten blizzards have been reported at Maitri during 2010. Although longest duration of blizzards was reported in June the peak winter month but more intense blizzard was reported in March associated with pressure fall of 24 hPa. The maximum wind gust 102 kt during blizzard in March was observed just within 6 hours. Blizzards do not always accompany with fall of pressure or rise of surface air temperature but reverse case may occur [Fig. 13(b)]. This year blizzards were not reported during summer and autumn season but they were reported during winter and spring season only. The blizzards during winter were not as intense as that of autumn. Therefore the year 2010 was very unusual year since last 21years as far as blizzard is concerned.

Three blizzards which occurred during 17 July -22 July 2010 have been examined. All these blizzards were associated with moving low pressure near Schrimacher Oasis [Figs. 14(a&b)]. First spell of blizzard was reported on 17th but due to influence of high pressure systems, no blizzard was reported on 18th and 19th. On 20th July again Maitri came under influence of warm front associated with low pressure system as a result of which the blizzards commenced at 0000 UTC of 20th and continued

(a)

(b)



Figs. 15(a&b). (a) Polar WRF analysis of 13th Feb. 2011 and (b) Mean level analysis chart of 15 Feb. 2011 (AMRC, SSEC, UW-Madison)

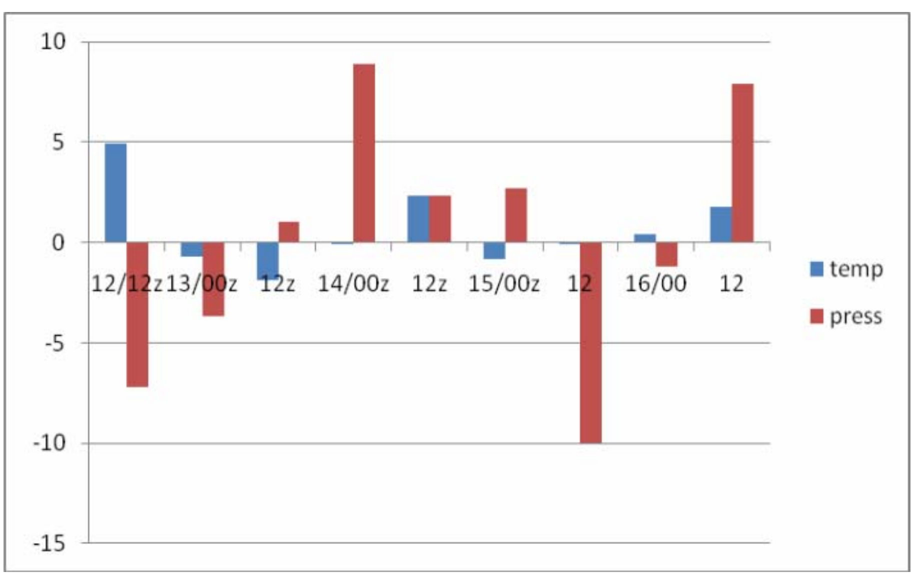


Fig. 16. Change of temperature & pressure during blizzards

till 22nd. During this period two spells of blizzards on 20th and 22nd were reported with maximum wind gust of 64 kts and 88 kts respectively with lowest pressure 960 hPa recorded on 22nd 0900 UTC.

10.5. *Blizzards during February 2011*

Eight low pressure systems were observed moving around coast of east Antarctica during the month of February, out of which only one blizzard affected Maitri. Under influence of a high pressure system on 11th, warm and moist air masses inducted towards the station and caused gradual rise of temperature on 13th February. The blizzards commenced from 0200 UTC of 13th and lasted till 1315 UTC. Since last 12 hrs the rise of pressure at the station by 7.9 hPa was observed on 14th at 0000 UTC which is indicative of passing peripheral of high pressure systems. After cessation of blizzard on 13th at 1315 UTC another spell of blizzards commenced on 15th, 0808 UTC under influence of a trough of low pressure [Figs. 15(a&b)] resulted in fall of pressure and temperature. The blizzards remained till 15th, 1900 UTC with lowest pressure 977.4 hPa recorded on 15th at 0900 UTC associated with significant pressure fall by 17.3 hPa and mean wind speed 36 kts followed by sudden gust 52 kts (Fig. 16).

11. Conclusion

(*i*) The detection of weather system and weather forecasting for Antarctica is a challenge. Satellite imagery & weather charts are only means at Maitri to predict arrival of frontal bands. The precipitation may be estimated as how active a front is? The type of clouds, temperature and pattern of circulation approaching towards stations gives clear indication for prediction of blizzard preceded by snowfall. It is possible to predict near surface temperature, from flow of warm air from ocean and cold air advection from the pole. Eastward moving extra tropical lows move frequently around Antarctica Circumpolar trough. The system pushes relatively warm, moisture leaden air masses towards the station which causes formation of fog, clouds which may lead to precipitation.

(*ii*) The gravitational forcing of cold air masses on the inclined ice slope is an essential requirement for formation and maintenance of katabatic winds which is highly directional. The wind becomes stronger due to eastwards moving low pressure systems. These winds become stronger and more persistent due to radiative cooling of air in confluence zone.

(*iii*) Under the influence of extra tropical sub polar lows the warm and moist air masses from lower latitude moves towards Schirmacher Oasis which interact with cold and dense air masses from high interior plateau which causes moderate to severe snowfall accompany with strong winds in association of severe blizzards.

(*iv*) The variation of temperature and pressure at Maitri during blizzards depends upon season In general, the surface pressure rises before onset of blizzards and then falls rapidly under influence of trough of low pressure system and severe wind events. Surface temperature increases as a system approaches and advection of warm air. Cloud approaches over the station ahead of the system. Due to dispersal of fast snow with high wind speed during blizzard temperature decreases during summer.

(*v*) The high pressure ridge plays a blocking role in slowing the movement of the system and forcing it to move southward closer to the Schirmachar oasis and thus enhancing the impact of cyclones for a longer period at the station.

(*vi*) The change in atmospheric electric field is an important pre indication for any forecaster to forecast commencement of blizzards.

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