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A short term characterisation of wind and temperature over Maitri, East Antarctica

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सार – वैशविक जलवायु में ध्रुवीय जलवायु विज्ञान के गहरे प्रभाव के कारण जलवायु परिवर्तन अध्ययन में ध्रुवीय विज्ञान का महत्व बढ़ता ही जा रहा है। शोध से पता चला है कि एंटार्कटिक जहाँ किनारों पर गर्म हो रहा है वहीं बीच के भागों में ठंडा हो रहा है। एंटार्कटिक का पूर्वी भाग ऊँचाई अधिक होने के कारण उसके पश्चिमी भाग की अपेक्षा जलवायविक रूप से अधिक ठंडा है।

इस शोध पत्र में मैत्री में पवन और तापमान के लघु अवधि को अभिलक्षित करने का प्रयास किया गया है। शीत ऋतु के साथ अधिकतम और न्यूनतम तापमानों में कमी की प्रवृत्ति देखी गई जिसके फलस्वरूप अधिकांश परिवर्तन हुआ। पवन की दिशा ग्रीष्म ऋतु और शरद ऋतु में दक्षिण–दक्षिण–पूर्वाभिमुखी तथा शीत और शरद ऋतु में दक्षिण–पूर्वाभिमुखी और शरद ऋतु में अवरोही पवनों की आवृत्ति अधिकतम रही। शीत ऋतु में पवन की गति में बहुत विविधता रही। पवनों में पवन को ठंडा करने वाले तापमानों में बड़ा योगदान पाया गया और परिवर्तन की यह प्रवृत्ति ऋतुओं के संक्रमण काल में अधिक सुस्पष्ट रही है।

ABSTRACT. Polar Science is gaining increased importance in Climate Change studies because of the profound influence Polar Climatology has on the Global Climate. Research shows that Antarctica seems to be warming around the edges and cooling at the center at the same time. East Antarctica is climatologically colder than west Antarctica because of its higher elevation.

A short term characterization of wind and the temperature over Maitri is attempted in this paper. Maximum and Minimum temperatures showed a tendency to decrease with winter contributing the most to the change. The Wind Directions were predominantly South-South-Easterly in summer and autumn and South-Easterly in winter and spring, with katabatic winds showing the maximum frequency in autumn. The wind speeds were found to be most variable in winter. Greater contributions to the wind chill temperatures were found from the winds, with the tendency for change being more prominent in the transition seasons.

Key words – Maitri, Antarctica, Climate change, Polar climatology, Wind Chill Temperature (WCT).

1. Introduction

Polar Regions have a profound influence on the Global climate. The enormous ice covered Polar Regions act as a global thermostat that regulates the Earth's climate system. The Polar Regions are known as the planet's heat sinks, because the equator - poleward temperature gradient in both the hemispheres is the basic driving mechanism of the large scale global circulation of the atmosphere. Studies of these heat sinks are equally important as the studies of the heat sources to understand the meteorology of the planet. Most climate models predict that changes in global temperatures will be first reflected at the poles. This is primarily due to the fact that Carbon Dioxide, one of the key green house gases linked to global warming, has its greatest absorption of Infrared Radiation at sub-zero temperatures. Presence of limited amounts of water vapour in the polar atmosphere due to extremely low temperatures means Carbon Dioxide can exert greater influence on the atmosphere in Polar Regions as compared to the other more moist regions of the globe. However, researchers found that the results of the Global models showed some inconsistency, because though parts of Antarctic Peninsula showed signs of warming, a larger part of continental Antarctica showed signs of cooling. Antarctica's climate is difficult to study partly because though the continent is vast, the observations are sparse and to some extent because, the cold and dry atmosphere of Antarctica is very different from that of the other continents.

Due to the climate extremes and its isolation, Antarctica remains the Earth's only continent without a native human population. However, a number of

Governments of countries that are signatories to the Antarctic Treaty maintain permanent research stations throughout Antarctica and in its surrounding oceans. These stations are operated either on seasonal (summer) basis or round-the-year. Although the first Indian expedition to Antarctic was flagged off from Goa in 1981, India was admitted to the Antarctic Treaty on 19th August 1983 and the first research station Dakshin Gangotri was built in 1983 during the third Antarctic expedition. Dakshin Gangotri, (Latitude 70° 05′ 37″ S, Longitude 12° 00′ 00″ E) was located on ice-shelf on Princess Astrid Coast, Central Dronning Maud Land, East Antarctica. In 1989-90 it was decommissioned due to excessive snow cover and is now being used as a supply base. India's second permanent research station, Maitri (Latitude 70° 45′ 57.7″ S, Longitude 11° 43′ 56.2″ E) was setup in 1989 on the rocky mountainous region Schirmacher Oasis, East Antarctica (Fig. 1). The oasis also contains one more permanent research station, Novolazarevskya a Russian station and barely 5kms from the Indian station. Climatic conditions on Schirmacher Oasis are relatively milder compared to the rest of Antarctica. A third permanent Indian base over Antarctic is also being planned. Tentatively named "Bharati', that is being setup on the Larsennum hills on the eastern coast of East Antarctica, is expected to be functional by 2012.

Antarctica is divided climatologically into three main parts, Antarctic Peninsula, West Antarctic and East Antarctic. Much research has been done to investigate the surface temperature changes over Antarctica. The Intergovernmental Panel on Climate Change, IPCC Fourth Assessment Report (2007) states that "Observational studies have presented evidence of pronounced warming over the Antarctic Peninsula, but little change over the rest of the continent during the last half of the 20th century". A number of studies have highlighted significant warming over the Antarctic Peninsula (Comiso 2000, Vaughan *et al.* 2003, Turner *et al*., 2005). However temperature changes were noted to be inconsistent over the other parts of the continent. It is difficult to arrive at a mean value for the trends over Antarctic as a whole because of the limited number of observations that have to be extrapolated over unrealistically large distances. So a number of researchers have used the station data to examine trends in climatic parameters. Turner *et al.* (2005) examined the near surface temperature trends for 19 stations annually and seasonally and found that excluding the Antarctic Peninsula the rate of warming is much more variable over the rest of the continent. Though most of the researchers have claimed a lot of cooling over the higher altitudes of East Antarctica, they found Novolazarevskya, (Russian Station) in East Antarctica, warming at a statistically significant rate in all the seasons and having the largest wind speed decreases in the winter season.

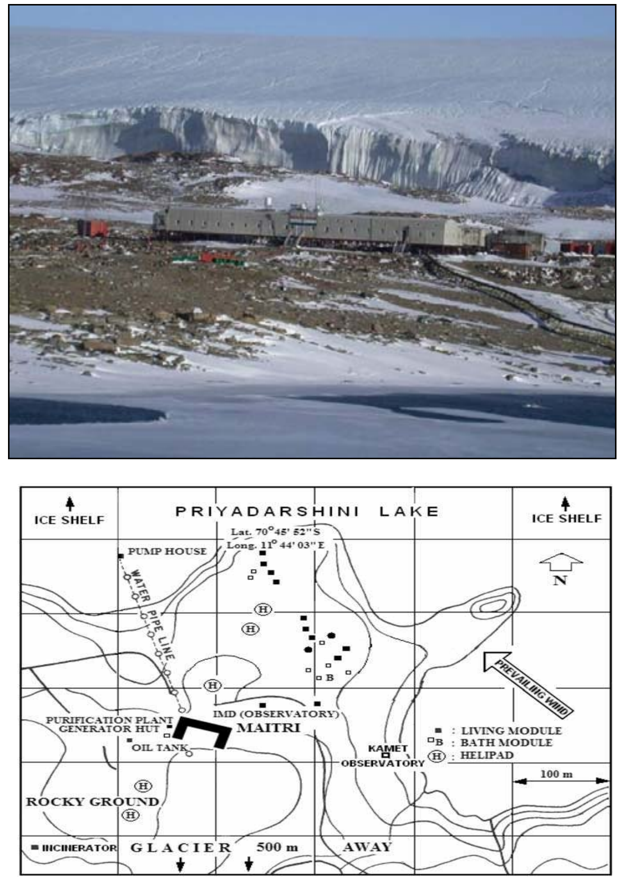


Fig. 1. Map showing location of Maitri

The Indian research base, Maitri is in a valley between continental ice and ice shelf located on a narrow hill range (Fig. 1). The altitude of Maitri is 117m above sea level. There is little mesoscale activity that affects the station, but they are generally affected by eastward moving depressions that are synoptic scale frontal systems. One of the main objectives of the scientific programme at Maitri is to build up a dataset for the climatology of Antarctica and for this a meteorological observatory was setup at Maitri in January 1990. Under IMD's modernization drive, an Automatic Weather Station (AWS) has also been setup at Maitri during the 26th Indian Antarctic Expedition (Ranalkar *et al*., 2008).

Annual Antarctic Expeditions from India are sent through the Department of Ocean Development (DOD) and the National Centre for Antarctic & Ocean Research (NCAOR) and the India Meteorological Department (IMD) has been continuously participating in all the expeditions with suitably designed meteorological programmes. The research findings of the summer and winter components of the expedition are presented in the

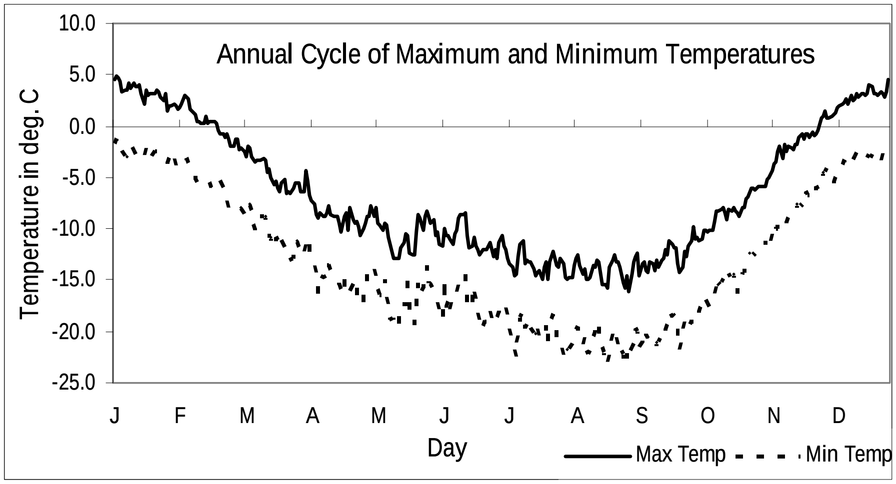


Fig. 2. Mean daily maximum and minimum temperatures (1990 - 2010)

form of scientific reports to NCAOR by each Expedition team (Hosalikar and Machnurkar, 1998). In the absence of substantially long term records of Maitri, (WMO recommends at least 30 years of data for trend assessment) most of the research findings reported over Maitri are limited to individual years (Srivastava *et al*., 2004) or a few case studies (Kulandaivelu and Dang, 2003 & Kulandaivelu *et al*. 2005). There are however few studies (Lal, 2006) that have attempted to characterize the climatology of Maitri. Lal, (2006) while investigating the short period climatology of Maitri found a decadal cooling of 0.26° C in the annual mean surface air temperature values at Maitri stations. It would be interesting to know which season contributes the most to observed trends in a given meteorological parameter. Since weather over Antarctica is strongly dependent on the temperature and winds, this paper attempts a short term characterization of temperature change tendency and wind variations over Maitri at seasonal scales. Antarctica is well known for its ferocious winds and blinding blizzards. Life threatening wind-chill temperatures is an ever present danger in Antarctica which makes outdoor activity virtually impossible in the winter months. Seasonal tendencies in the Wind chill factor, which is crucial for the operational outdoor activities, are also investigated. Section 2 discusses the data and methodology, section 3 elucidates the results and discussions, main conclusions from the study are highlighted in section 4.

2. Data and methodology

Since 1990 all meteorological observations are being recorded at Maitri. These include surface pressure, winds, temperature, precipitation, weather phenomena, clouding and total global solar radiation. The synoptic data for the period 1990 - 2004 were obtained from the archives of National Data Centre, NDC Pune. For the period 2005 - 2010 data for Maximum and Minimum Temperatures were obtained from http://www.tutiempo.net/en/Climate/MAITRI. The Maximum and Minimum Temperatures are recorded twice in 24 hours at Antarctica, at 0000 UTC / 1200 UTC. The daily Maximum and Minimum Temperature series were constructed for the period 1990-2010. The tendency of temperature change was investigated at the annual and seasonal scales. The seasons are defined as summer (December to February), Autumn (March to May), Winter (June to August) and Spring (September to November). Wind direction at Maitri is a significant feature of weather as it serves as a sure indicator of the ensuing weather. Wind roses are used to project the dominant wind direction and fractional frequency of the wind speed for the period under study (1990 - 2004). The wind roses are calculated for each season. The daily three hourly synoptic observations of dry bulb temperature and wind speeds recorded at Maitri for the period 1990-2004 were used for studying the tendency of change in the Wind chill factor. Wind Chill Factors are calculated differently in different parts of the world. The first wind chill formulae and tables were developed by Paul Allman Siple and Charles Passel working in the Antarctic before the Second World War. In November 2001, the National Weather Service of the U.S and Canadian Weather came up with a revised wind chill index which is as follows:

$$\text{WCT} = 13.12 + (0.6215*T) - (11.37*V^{0.16}) + (0.3965*T*V^{0.16})$$

Where,

WCT is the Wind Chill Temperature,

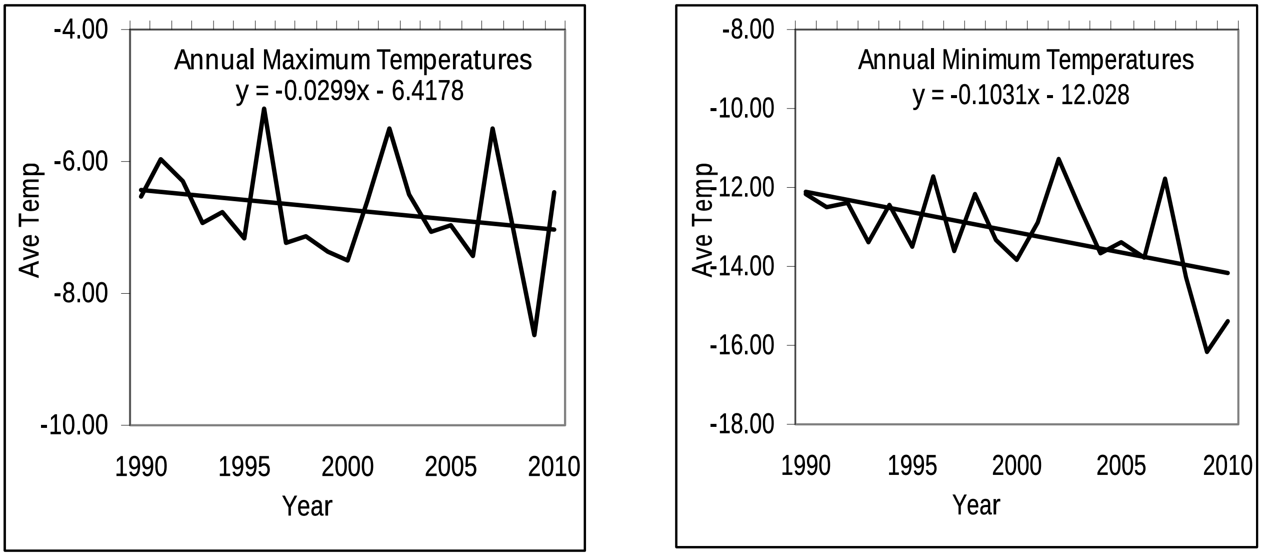


Fig. 3. Temperature change in the annual maximum & minimum temperatures

T is the ambient Air temperature in °C and

V is the wind speed in km/hr.

Based on this formula the wind chill temperature was calculated for each synoptic hour for all the days of the period under study. The individual WCT were then combined to form a seasonal series and the tendency of change across the period of study was evaluated. Since Wind chill depends on the temperature and wind speed, the tendency of change in the corresponding air temperature and wind speed were also evaluated at the same time scale to assess what contributes to the change in WCT. The tendency for change was evaluated using the ordinary least square regression method.

3. Results and discussions

3.1. *Surface temperature variations*

Fig. 2 shows the mean daily distribution of Maximum and Minimum Temperatures over the year (mean values from 1990 - 2010). The graph illustrates how cold the temperatures are all round the year at Maitri. Investigations into the daily time series of the observed values of both Maximum and Minimum Temperatures revealed a wide range of variation (approximately 20° C). The highest ever recorded Maximum Temperature at Maitri was on 03 Feb 1996 at 12.5° C and the lowest ever recorded was on 23 Jul 2006 at -38.0° C as on date. The mean diurnal temperature range is approximately 6-7° C. Plots illustrating the inter-annual variability of the annual Maximum and Minimum surface temperatures are shown in Fig. 3. The temperatures show a high degree of inter-annual variability which is a characteristic feature of Antarctica. Both, the Maximum and Minimum Temperatures over the period considered, showed a tendency to decrease with Minimum Temperatures decreasing at a faster rate. Maximum Temperatures showed a tendency to decrease at the rate of 0.3° C / decade whereas Minimum Temperatures showed a tendency to decrease at the rate of 1.0° C / decade.

The primary circulation feature that affects Antarctica is the Antarctic Oscillation or the Southern Annular Mode (SAM). Researchers have shown that the changes in the SAM can affect the temperatures over Antarctica (Marshall, 2007). A positive phase of SAM can strengthen the prevailing circumpolar westerlies over Antarctica and thereby isolate the interior of the continent which could lead to an effective cooling. SAM is known to exhibit strong seasonality and therefore though the temperatures over Antarctica especially East Antarctica are very cold throughout the year, they were further investigated on a seasonal scale. Fig. 4 illustrates the inter-annual seasonal tendencies shown by both the Maximum and Minimum Temperatures. The tendencies shown by the Maximum Temperatures were not uniform over the seasons. It was found to be increasing in the Summer and Autumn season and decreasing in the Winter and Spring seasons, with the rate of decrease being steepest in Winter, almost 1.1° C / decade. However the tendencies showed

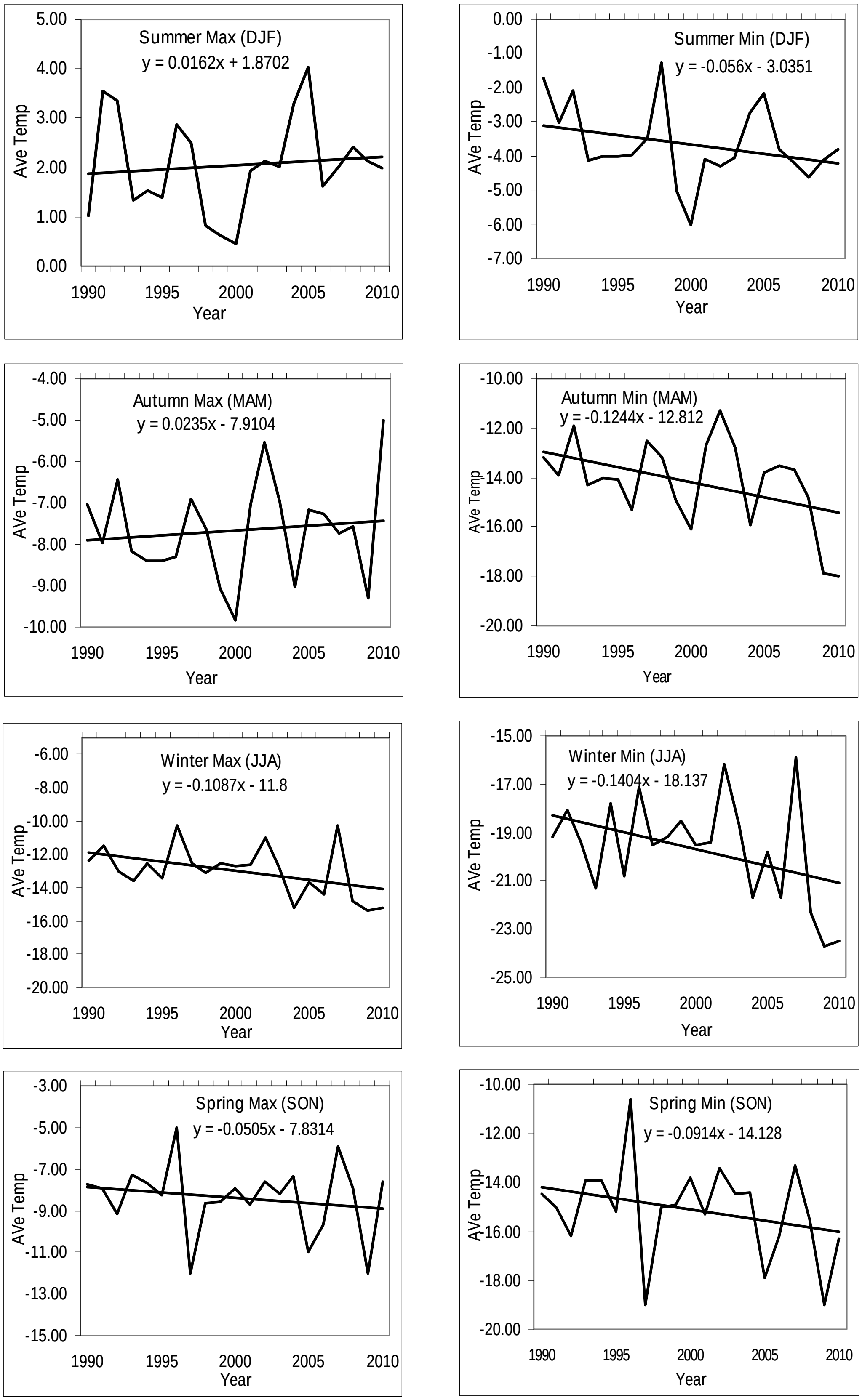
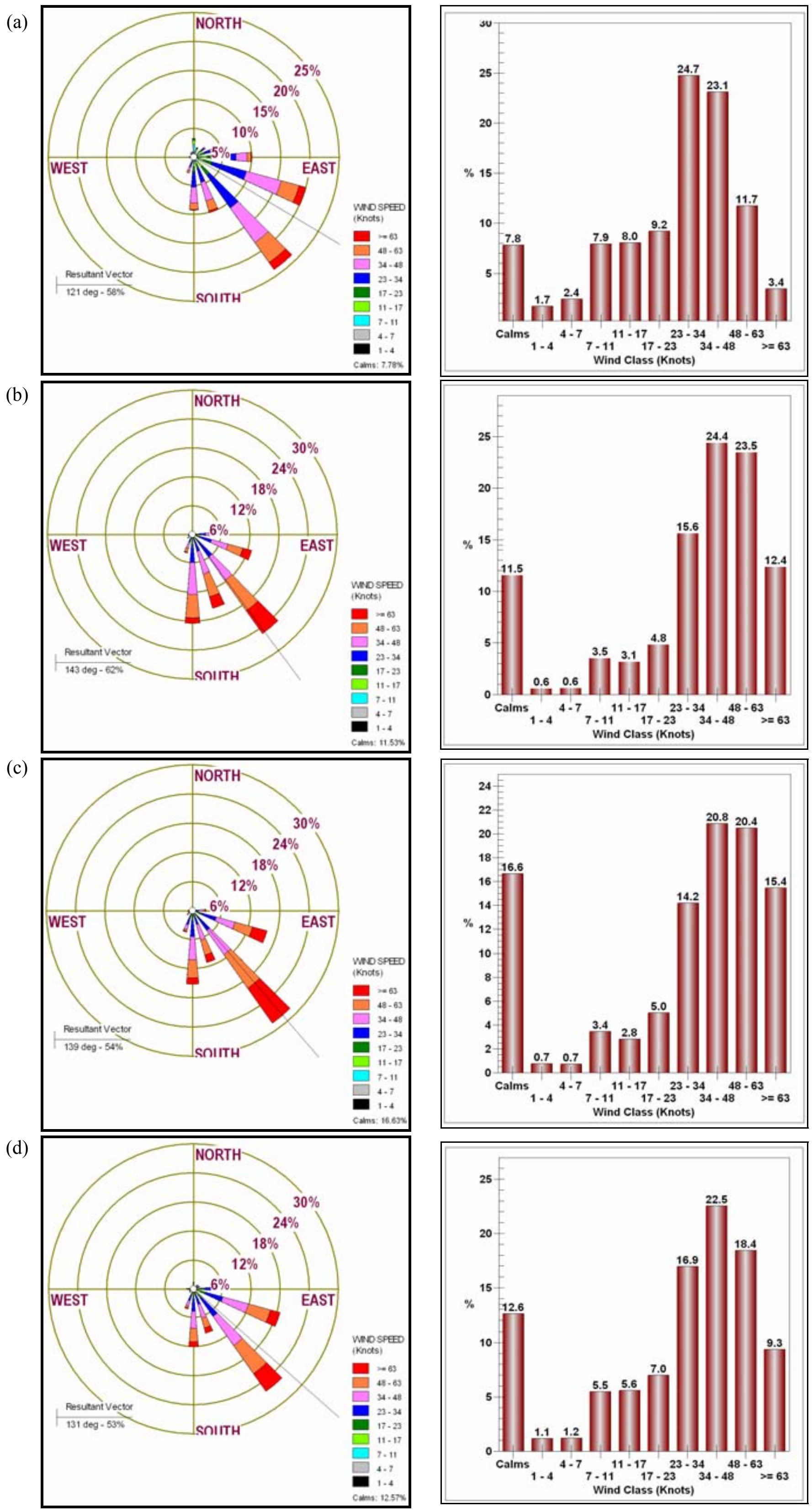


Fig. 4. Seasonal temperature change in maximum and minimum temperatures



Figs. 5(a-d). Wind rose and frequency distribution of wind speeds over Maitri, (a) summer season, (b) autumn season, (c) winter season and (d) spring season

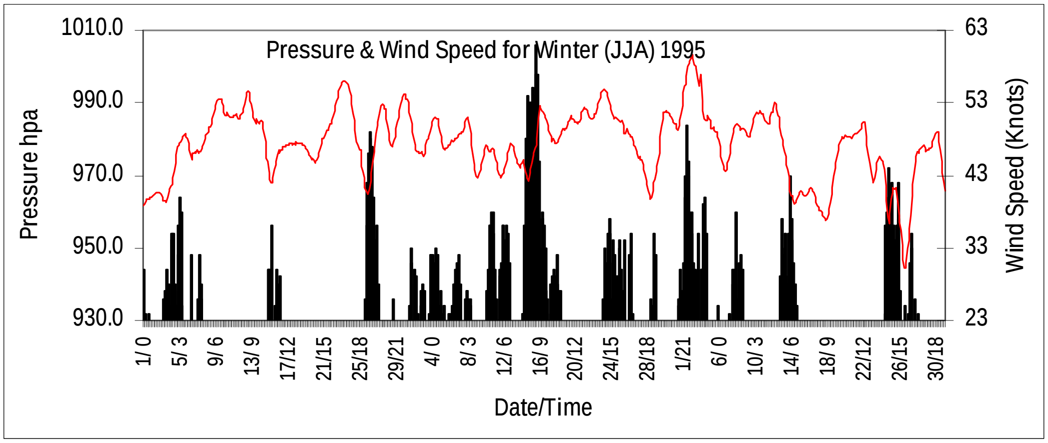


Fig. 6. Daily distribution of surface pressure and wind speed

by the Minimum Temperatures were more consistent across all the seasons. The Minimum Temperatures showed a decreasing trend in all the seasons with autumn and winter seasons showing steeper rates of decrease. The winter season showed the maximum decrease in Minimum Temperatures at the rate of nearly 1.4° C / decade.

Apart from being the coldest continent on Earth, Antarctica is also known to be the windiest continent on Earth. The winds over the continent play an important role in shaping the weather patterns over the Antarctica. The subsequent sections investigate the winds over Maitri for the period under study.

3.2. *Surface wind regime*

The daily surface winds at Maitri were analysed for the period under study. Wind roses were constructed for each season to depict the distribution of the wind speed and wind direction. Figs. 5(a-d) show the seasonal wind roses and the percentage frequency of the wind speeds in each season. Wind directions at Maitri are predominantly South-Easterly. Though Antarctic winds are known for their strong directional constancy, they are also strong indicators of the synoptic systems that can affect the station. Different synoptic situations give rise to the varied wind directions over Maitri.

In summer as noted from the wind rose diagram [Fig. 5(a)], the most preferred wind directions were East-South-East (20%) and South-South-East (25%) of the occasions. The southerly winds which are the katabatic winds were the least frequent in summer (10%). In autumn [Fig. 5(b)] the most frequent wind direction is South-South-East (24%) of the occasions. However the katabatic winds which are driven by the polar anticyclone showed the greatest frequency in autumn (18%). In winter [Fig. 5(c)] the most predominant wind direction is South-East (nearly 30%). The katabatic winds occur on nearly 14% of the occasions. In Spring [Fig. 5(d)], the principal wind direction is South-Easterly (25%) followed by East-South-Easterly winds (18%). The katabatic winds occur on 12% of the occasions. Winds over Antarctica are caused by heavy cold air located over the Antarctica Plateau falling under gravity towards the sea. As air falls it gathers speed and wind speeds can reach very high values. As noted from the wind roses and the corresponding histograms, the most frequent class of wind speeds is 23-34 knots for the summer season and 34-48 knots for the remaining seasons. The frequency of calm winds and storm winds ($\geq$ 63 knots) is the highest in winter months at 16.6% and 15.4% respectively.

At Antarctic Research stations outdoor activities are directly dependent on the weather conditions which can deteriorate rapidly. Winds are known to cause two critical problems in Antarctica, localized blizzards and wind chill which can be life threatening. Though on an average 21 blizzards occur over the year at Maitri (http://www.metmaitri.ind.in/blizard.html), the most number of blizzards occur in the winter season associated with moving extra tropical cyclones from west to east between 60 °S & 70 °S along the coast. Lal R.P. while investigating the short term climatology of Maitri concluded that the maximum occurrence of blizzards is in the month of August. This was also noted by the first author of this manuscript who was a member of the fourteenth expedition (1995 - 1996) to Antarctica. One of the strongest blizzards (14^{th} July 1995/1600 hrs - 15^{th} July 1995/0710 hrs) experienced by the first author during the winter period is depicted in Fig. 6, alongwith the daily

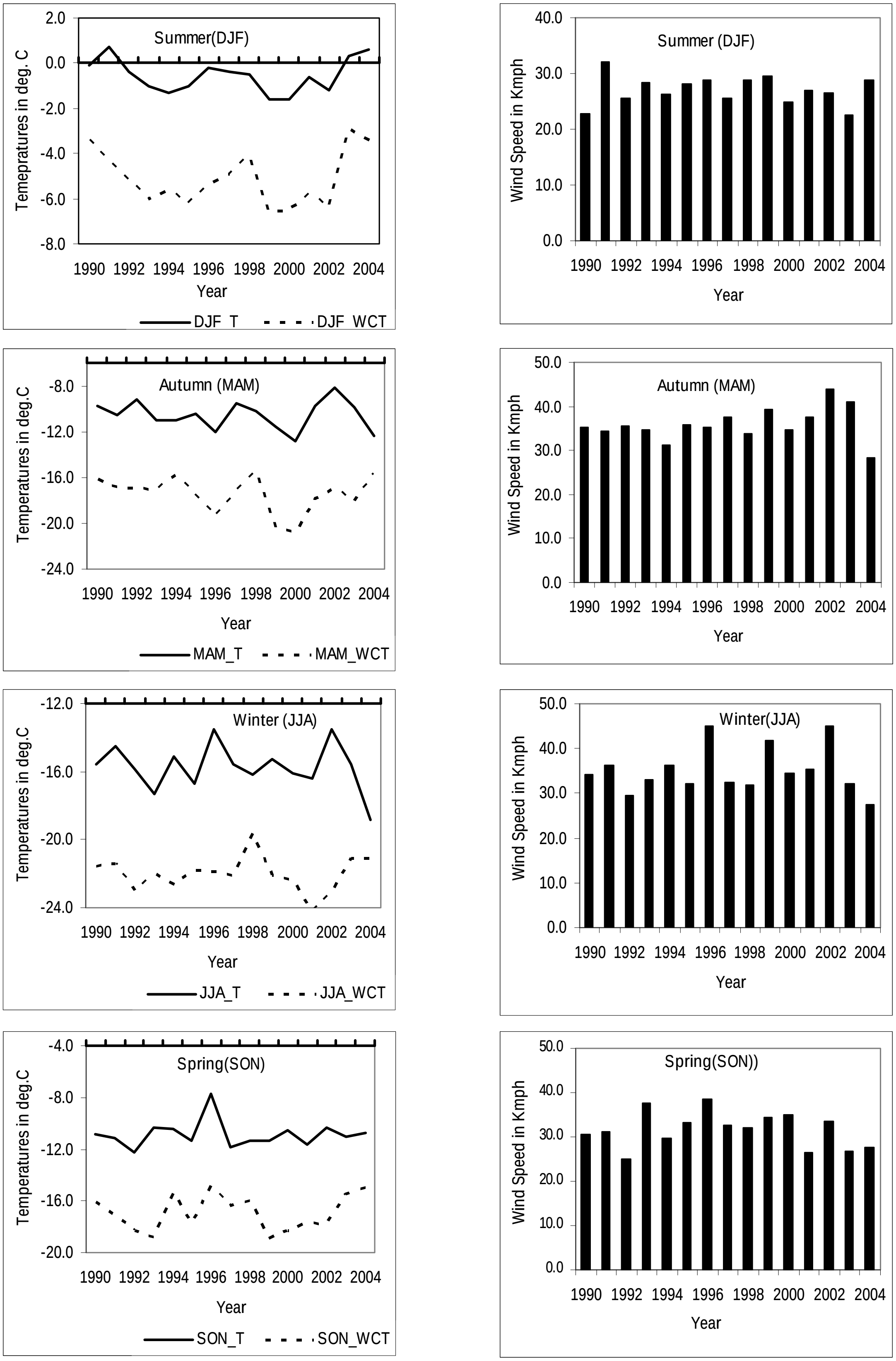


Fig. 7. Seasonal tendency of change in dry bulb temperature, wind chill temperature and wind speed

TABLE 1

Seasonal tendency for change in the mean *T*, W and WCT

Season	Dry bulb temperature tendency (T° C)	Wind speed tendency (W Kmph)	Wind chill temperature tendency (WCT° C)
Summer (DJF)	-0.0082	-0.0596	0.0057
Autumn (MAM)	-0.0879	0.2107	-0.0357
Winter (JJA)	-0.0064	0.0554	-0.0582
Spring (SON)	0.0436	-0.1350	0.0079

distribution of surface pressure and wind speed. The average surface wind speed during the blizzard was 52 kts reaching a maximum of 61 kts. A wind gusting to 90 kts with heavy drifting snow was also observed (Hosalikar and Machnurkar, 1998).

Wind chill is caused by the combined effect of wind speed and temperature which produces conditions that would be much colder than the actual temperatures and is the most debilitating factor of all Antarctic expeditions. Since over Antarctica almost all the year round the air temperatures are either near freezing or sub-zero, the next section examines the 'Wind Chill Temperatures' (WCT) over Antarctica in the different seasons.

3.3. *Wind chill temperatures*

The Wind Chill Temperatures are generally lower than the actual air temperatures when the wind speeds are higher than a certain threshold value (approximately 5 kmph). Taking into account the affect of wind in the perception of temperatures an attempt has been made in this section to quantify the wind chill in the different seasons at Maitri. The plots (Fig. 7) illustrate the average seasonal dry bulb temperatures and the derived equivalent Wind Chill Temperatures over the years (1990 - 2004). The corresponding seasonal means of the wind speeds for each year are also depicted. The average decrease in the perceived temperatures is the least in the Austral Summer (4.5 on an average) and the Maximum in Austral Winter (6.9 on an average). In the summer months the mean range of decrease in the perception of temperatures as noted from the graphs is of the order of 3-5° C from the actual temperatures. For the spring season, it is in the range of 4-8° C. For the autumn and winter seasons, the range of decrease in perceived temperatures when compared to actual temperatures is higher (3-10° C).

The affect of temperature and wind speed on Wind Chill Temperatures (WCT) were further investigated by working out the mean seasonal tendency for change in all the parameters. The results are presented in Table 1. It was found that the magnitude of change in WCT is greater in autumn and winter as compared to Spring and Summer. The WCT changes showed a negative tendency in autumn and winter and a small positive tendency in Spring and Summer. As compared to the tendency of dry bulb temperature to decrease in all seasons except Spring, the magnitudes of change in wind speeds were greater. The wind speeds showed a tendency to decrease in Spring and Summer. So the analysis showed that the mean seasonal tendencies in WCT are more influenced by the change in wind speeds.

4. Conclusions

From the analysis it is observed that the annual Maximum and Minimum Temperatures showed a tendency to decrease during the twenty year period of observations at Maitri, with Austral Winter being the chief contributor to the annual trends. Though the Maximum Temperatures showed seasonal inconsistency, the Minimum Temperatures consistently showed a tendency to decrease in all seasons. The average wind direction over Maitri was found to be in the range of 121 degree to 143 degree in the different seasons. The katabatic winds were found to be a maximum in their frequency of occurrence in autumn followed by winter. The wind speed frequencies were found to be the most variable in winter with storm class (≥ 63 knots) frequencies the maximum in winter. The Wind Chill Temperatures also showed the maximum tendency to change in Austral Winter. The greatest contribution to tendency in Wind Chill Temperature was found to be from the corresponding wind speeds. Larger magnitudes of wind speed tendency for change (both negative and positive) were found to occur in the transition seasons and was found to induce an opposite change tendency in Wind Chill Temperatures.

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