

*Research Paper***Progress in Meteorological Studies Around Indian Stations in Antarctica**

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(Received on 26 June 2016; Accepted on 25 November 2016)

The study of climate of Antarctica and its role in the Earth system is critically important as the region experiences change that has global implications. The climate of the continent and the surrounding ocean are closely coupled to other parts of the global environment by the ocean and the atmosphere. Subjects of immediate interest are forecasting of weather and climate and understanding the effects and likely impacts of climate change. India Meteorological Department is taking part in Indian Scientific Expeditions to Antarctica since the very first expedition during 1981-82. The meteorological data collected at Maitri station for the period 1990-2015 have been analyzed. The long term analysis of temperature record showed a cooling trend at Maitri station. The trend analysis of pressure, wind and blizzards during the period 1990-2015 is also discussed. Recently, the India Meteorological Department has established manned permanent meteorological observatory at Bharati station with the objective to collect data on meteorological parameters, solar radiation and ozone so as to understand the Antarctic atmospheric processes and dynamics. WMO has enlisted Meteorological Observatory at Bharati, and assigned WMO Index number 89776. A GPS-based ozonesonde system has also been installed at Bharati for measurement of vertical profile of ozone. IMD provides weather forecast of Maitri and Bharati stations.

Keywords: Antarctica; Blizzard; Temperature; Pressure; Wind**Introduction**

Antarctica is an important part of our climate system and its sensitivity to climate changes, however, very few meteorological measurements are available. In order to address this issue, the World Meteorological Organization (WMO) strongly recommended that all research station should set up a meteorological observatory and data be provided through the Global Telecommunication System.

IMD's Antarctic Meteorological Programme continues to be an integral part of the Indian Scientific Expedition to Antarctica since the very first expedition during 1981-82. During 2nd expedition (1982-83), surface meteorological observatory was established at DakshinGangotri on an ice-shelf about 20 km from the coast. A Permanent station "DakshinGangotri" and a year round meteorological observatory was established during the third Indian expedition in 1983-84. This was the first time the Indian team started over wintering in Antarctica to carry out scientific

programme. In February 1983, ozone soundings were initiated. During 4th expedition (1984-85) trial Data Collection Platform (DCP) was commissioned for down loading INSAT IB data and during 5th expedition (1985-86), Data Collection Platform (DCP) was made fully functional. Measurement of global solar radiation was started during 1984-85. Observational program continued till Jan 1990 at DakshinGangotri until this station was decommissioned. DakshinGangotri is now non-functional due to its complete burial under the ice.

The Second station "Maitri" was established in 1989. Meteorological observation Programme of IMD was started from January, 1990 (from 9th expedition) and is continuing till date without any break. Automatic weather station was setup at Maitri during 26th expedition. Recently IMD has implemented Polar WRF model for Maitri and Bharati region at the horizontal resolution of 15 km using initial and boundary conditions of the IMD GFS T-382. Daily Forecasts for next 48 hours are produced based on available

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observations, satellite images of NOAA and synoptic charts provided by Weather Service of South Africa.

Maitri is located in the valley of central part of Schirmacher Range, Dronning Maud Land, East Antarctica. The Schirmacher Range lies between the Wolthat Mountains about 80 km to the south and the tip of the shelf ice that is about 100 km to the north. The northern boundary of the Schirmacher oasis has an abrupt and steep fall towards the shelf ice. Maitri is affected by the eastward moving depressions that are synoptic scale frontal systems. These systems move in the circumpolar trough zone that lies between 60° and 66° S meandering north and south between seasons. The large amplitude cloud bands in association with these systems move across the station, producing dramatic variation in cloud cover. The cyclonic circulation associated with these low-pressure systems is frequently seen on the 500 hPa chart. These systems bring warm and moist air to the coastal areas of the Antarctic continent from northern latitudes. Therefore, when a depression approaches the station, pressure starts falling continuously and temperature starts rising. The rise in temperature, which can be of the order of 10°C during a blizzard, is also due to the fact that the low level inversion is broken because of turbulence caused by increase in wind speed. After the system moves away, often pressure increases steeply, temperature falls, wind becomes light or calm and the sky clears. On some occasions when small low pressure system move at relatively higher latitudes, the skies are overcast with stratus clouds and calm or light wind prevails. Such situations result in heavy snowfall at the station.

Antarctica is mainly divided into three regions namely, West Antarctica, East Antarctica and Antarctic Peninsula. A mountain range known as Transantarctic Mountains in Antarctica extends across the continent from Cape Adare in northern Victoria Land to Coats Land with some interruptions in between. These mountains divide East Antarctica and West Antarctica. Sharp contrast in temperature trends are observed by many researchers in East Antarctica and West Antarctica. The southern hemisphere (SH) annular mode (SAM), also known as Antarctic Oscillation (AAO) is the principal mode of variability of the SH extra-tropical atmospheric circulation (Thompson and Wallace, 2000). The SAM

is defined as the zonal mean atmospheric pressure difference between the mid-latitudes (~40°S) and high latitude (~65°S) (Marshall, 2003). SAM alters the north-south movement of westerly wind belt that circles the Antarctic. During positive phase of SAM, pressures are lower than normal over Antarctica, and westerly winds are stronger than normal over the Southern Ocean.

Observations and Analysis

The surface meteorological observation data, i.e. maximum and minimum temperature, mean sea level pressure, wind collected by the India Meteorological Department at Maitri for the period 1990-2015 have been analyzed in this paper. The observers also keep record of blizzards at Maitri. The trend in frequency of Blizzards and their maximum duration is also examined. The definition of blizzard may vary from region to region (e.g., Bluestein, 1993; Wild, 1995; Branick, 1997). The following criterion is used by IMD to define the blizzard:

1. Blowing snow with or without snowfall.
2. Visibility less than 1 km
3. Wind speed greater than or equal to 23 kts.

Depending on the situation to call a meteorological condition 'a blizzard', sometimes any one of the above criteria is waived off. For example, copious snowfall is recorded for two days at a stretch followed by winds, as low as 10 to 15 knots can cause a severe blizzard with visibility less than 10 meters as the area covered by snowfall sometimes exceed several hundred square kilometers in Antarctic regions. At times even in very high winds (around 60 to 70 kts) the visibility may not decrease to 1 km level due to little snowfall or very low temp. Such cases are also considered as blizzard. Even light to moderate winds upto 15 knots can cause moderate to intense blizzards if fresh snow is present on the ground. Such blizzards sometimes last for periods beyond 12 hours as the ground level snow is swept across the station from far off places, as far as 200 km continuously. Visibility of less than 10m is quite common during such blizzards. Reasonably good vertical visibility is an indicator of such blizzards.

Results and Discussion

Surface Air Temperature Trends

The air temperature of Antarctic is not controlled mainly by insolation. The very slant angle of solar radiation (low angle of incidence), very high albedo of snow/ice surface, low atmospheric turbidity, absence of vegetation and no major landmass nearby makes the Antarctica a very cold region on the Earth. During the dark period in the austral winter when sun does not rise above the horizon, there continues to be heat loss to space, but there is no input insolation. This causes temperatures to drop to their lowest point of the year. Furthermore the air in Antarctica is very dry and because of this very little heat emitted by ground is retained by the atmosphere. Temperature is influenced more or less by the heat transport mechanisms, wind and weather phenomena which perturb radiation. Persistent clear sky with light wind also lead to lower temperature of Antarctica region. On cloudy days, diurnal variation of temperature was found to be very low as compared to that on clear sky days as expected. Similarly night temperature used to drop considerably during cloud free nights.

Turner *et al.* (2005) examined surface temperature trends from 19 Antarctic stations with long records. The spatial pattern of temperature change can be broadly summarized as rapid warming at stations on the Antarctic Peninsula and little change, or modest cooling at stations along the coast of East Antarctica. Nicolas and Bromwich (2014) observed statistically significant annual warming in the Antarctic Peninsula and virtually all of West Antarctica, but no significant temperature change in East Antarctica during 1958-2012. There is sharp contrast in temperature change on either side of the Transantarctic Mountains which divides East and West Antarctica. Several researchers examined the surface air temperature data of past several decades and observed that the Antarctic Peninsula and Western Antarctica are among the most rapidly warming regions of southern hemisphere (Turner *et al.*, 2005, Chapman and Walsh 2007, Steig *et al.*, 2009, Bromwich *et al.*, 2013, Nicolas and Bromwich, 2014). In contrast, East Antarctica has experienced an insignificant, cooling trend (Schneider *et al.*, 2012, Nicolas and Bromwich 2014). Smith and Polvani (2016) also observed annually averaged warming of

the Antarctic Peninsula and West Antarctica while very small trends over East Antarctica. They further found that this asymmetry is because of highly significant warming of West Antarctica in austral spring and a cooling of East Antarctica in austral autumn. This large spatial asymmetry in temperature trends between West and East Antarctica is not yet understood clearly. Some researchers have attributed the cooling of East Antarctic and the warming of the Peninsula to positive trend in the Southern Annular Mode (Thompson and Solomon 2002, Nicolas and Bromwich 2014). Nicolas and Bromwich (2014) examined the influence of the southern annular mode (SAM) on Antarctic temperature trends. They suggested that the trend of the SAM toward its positive phase in austral summer and fall since the 1950s has had a statistically significant cooling effect not only in East Antarctica but also in West Antarctica (only in fall). Smith and Polvani (2016) examined the relationship between the SAM and Antarctic temperature trends and conclude that SAM is most likely contributor to the observed temperature trends in austral autumn but natural climate variability can be likely contributor to the recent warming of West Antarctica and of the Peninsula.

Monthly mean variation of maximum, minimum and average surface air temperature is shown in Fig. 1. The surface air temperature over the Maitri has a seasonal variation with peak observed during local summer (December and January). The peak during summer is due to solar energy warming up the surfaces. The temperature gradually decreases from January onwards up to August. From August to September temperature rises slightly and thereafter increases sharply from October. The surface air

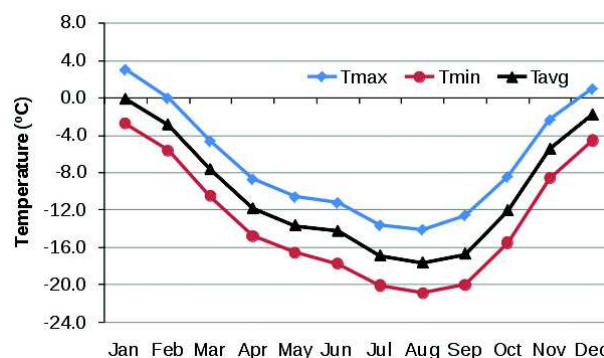


Fig. 1: Monthly mean (1990-2015) variation of maximum, minimum and average temperature

temperature rises slightly from May to June. This may be due to the frequent movement of extra-tropical low pressure systems which causes the warm and moist air drawn from lower latitudes and mixed with dry and cold continental air thus causes increase in temperature. Generally during the blizzard period, a rise in the temperature was observed due to the same reason. The highest mean monthly maximum and minimum temperature is found in January. The lowest maximum (-14.1°C) and lowest minimum temperature (-20.9°C) is witnessed in August. There are incidences when the surface air temperature enhances due to the presence of a blocking polar high, it is observed primarily during local winter season. The average annual temperature is around $-10 \pm 0.8^{\circ}\text{C}$. The winter air temperatures are observed in April and stay around -12°C to -17°C during the succeeding months. By the temperature regime, the winter season continues for six months from April to September. July/August is the coldest month with mean temperature around -17°C . Summer is warm and continues for two months from December to January when average monthly temperature is close to zero. The highest temperatures are recorded during the summer solstice. During this period, rapid snow and ice melting occurs and numerous relief depressions are filled with water. Based on the temperature, two other seasons can be categorized as spring (October-November) and autumn (February-March).

Long-term data for the period 1990-2015 available from Maitri is used to study the temporal trend in maximum, minimum and average temperature (Figs. 2, 3, 4A and 4B). The trends were computed using a standard least-squares method, with the Mann Kendall test used to calculate the significance levels. Statistically significant trend at $-0.053^{\circ}\text{C year}^{-1}$ over

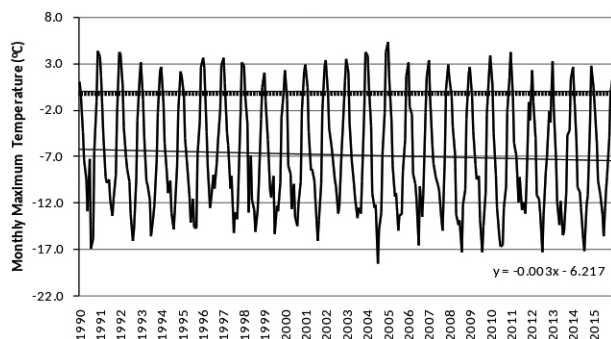


Fig. 2: Long-term variation in Monthly mean maximum temperature (1990-2015)

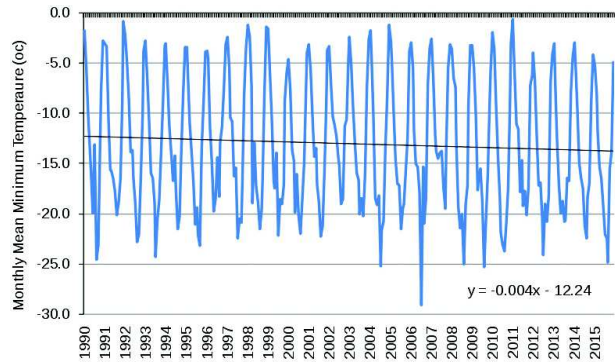


Fig. 3: Long-term variation in Monthly mean minimum temperature (1990-2015)

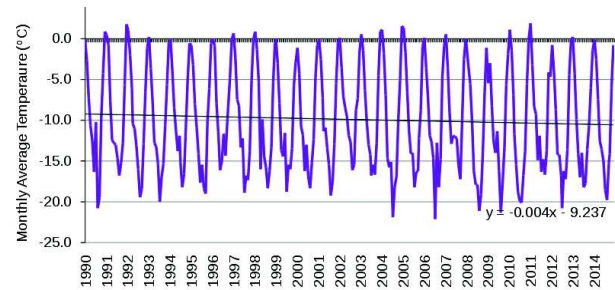


Fig. 4: (A) Long-term variation in Monthly mean average temperature (1990-2015)

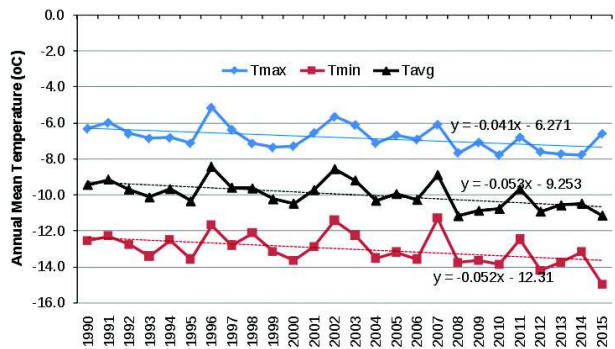


Fig. 4: (B) Long-term variation in annual mean temperatures (1990-2015)

1990-2015, a figure that is significant at the $<5\%$ level. The temperature trends observed at Maitri are similar to that observed at neighboring Russian station Novolazarevskaya during 1990-2015.

Mean Sea Level Pressure Trends

The mean monthly variation of mean sea level pressure during the period 1990-2015 is depicted in Fig. 5. Annual variations of atmospheric pressure, similar to the other Antarctic stations have two maximums (in June and January) and two minimums (in March and

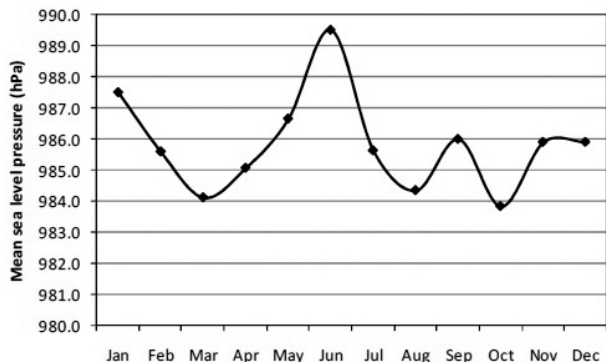


Fig. 5: Monthly variation of mean sea level pressure (MSLP)

October). One peak in the month of June has mean value of 989.5 hPa and the other in January with value of 987.5 hPa. The MSLP pressure fell to a low value of 984 hPa in March and then steadily increases till June.

Monthly mean sea level pressure (MSLP) trend for the Maitri during 1990-2015 is depicted in Fig. 6. A consistent decrease of pressure at Maitri of $-0.002 \text{ hPa year}^{-1}$ was observed during 1990-2015 at Maitri. Turner *et al.* (2005) observed decreases in pressure

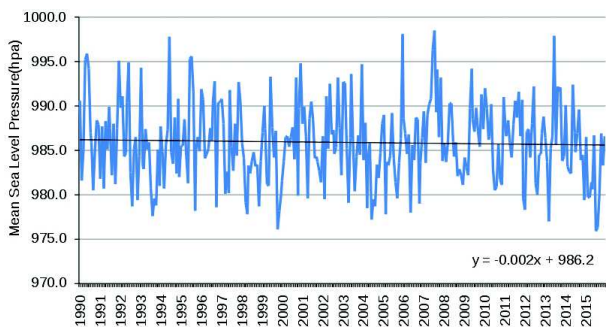


Fig. 6: Long-Term variation of monthly mean sea level pressure (MSLP)

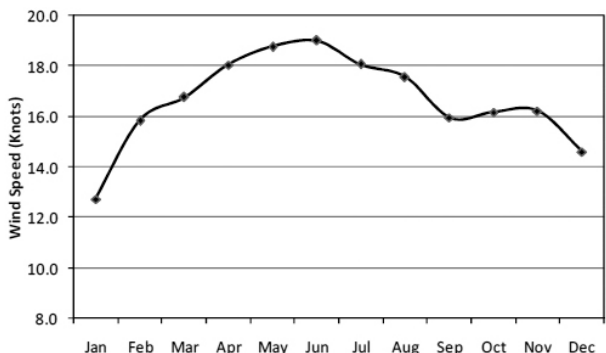


Fig. 7: Monthly variation of mean wind speed (knots)

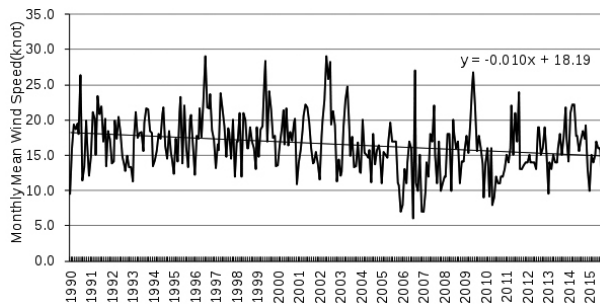


Fig. 8: Long-Term variation of monthly mean wind speed (knots)

in all sectors of the Antarctic, with the most negative trends being at Molodezhnaya (statistically significant at the 1% level) and Mirny station.

Surface Wind Speed Trends

Antarctica is a dome of ice with a 4000m high plateau in its interior sloping towards its perimeter at coast. The surface wind at Maitri is mainly katabatic in nature predominantly from south-east direction. The katabatic wind refers to cold and relatively dense air near the surface moving downhill due to gravity. As the cold heavy wind moves towards sea, it gathers speed to very high value. The winds at Maitri are predominantly easterly and south-easterly. The confluence zone east, south-east and south is a zone of convergence at Maitri which enhance supply of radiative cooling of air near surface along the coastal slopes as a result katabatic winds become stronger and more persistence (Kumar and Gupta, 2007). The winter months are the windiest months at Maitri with mean wind speed around 18 knots (Fig. 5). Minimum mean wind speed is observed during summer ranging from 12 to 14 knots. The weak winds during summer are due to less cyclonic activities. The trends in near-surface wind speed for the Maitri is presented in Fig. 10. Declining trend of $0.13 \text{ knots year}^{-1}$ is observed at Maitri for the period 1990-2015. The declining trend in mean wind speed can be attributed to decreasing trend in the frequency of cyclonic disturbances affecting Maitri station. Further, A decrease in wind speed would result in a more stable boundary layer and colder conditions at the surface, which would explain the trend towards colder surface air temperature.

Long Term Variation in Frequency of Blizzards

Blizzards at Maitri are usually warm, moist and are

associated with eastward moving cyclone situated north or northeast of Maitri station (Rasal, 2003). Mainly the blizzards are observed during June to September. Tyagi and co-workers (2011) found that due to cyclonic activities, warm air masses are transported toward Schirmacher Oasis which causes rise of temperature at Maitri. The longer duration of blizzard depends on slow moving blocking anticyclone situated east of Maitri station at lower latitude. The blocking high is the high pressure system which remains at the station for several days in the area where zonal flow prevails. This high pressure system plays a blocking role in slowing the cyclone. The long term variation in frequency of blizzards and duration of longest blizzard is presented in Figs. 9 and 10, respectively. The frequency of blizzards is decreasing at a rate of 0.29 blizzards year⁻¹. Durations of longest blizzard is also found to be decreasing.

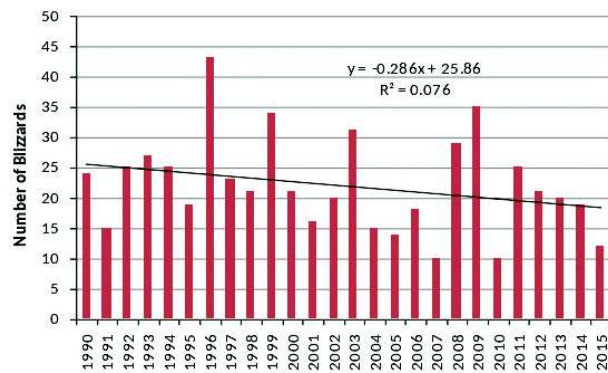


Fig. 9: Frequency of Blizzards at Maitri during 1990-2015

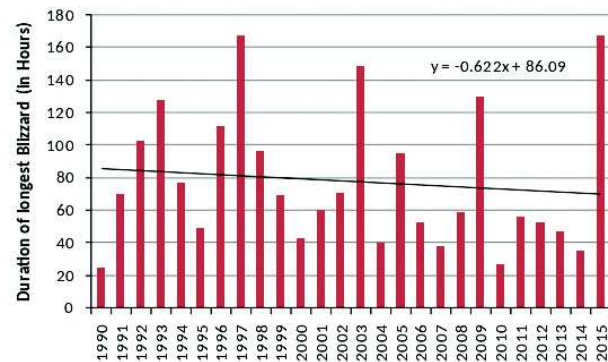


Fig. 10: Longterm variation of the duration of longest Blizzard each year

Conclusions

This paper has examined the temporal variability and change in some of the key meteorological parameters

around Maitri station. The temperature trends showed cooling over Maitri during 1990-2015 which is consistent with the trend at nearby Russian station Novolazarevskaya during the same period. The wind speeds at the station have decreased at a statistically significant level. A decrease in wind speed would result in a more stable boundary layer and colder conditions at the surface, which explains the trend towards colder surface air temperature. The clear decrease in mean sea level pressures at the Maitri station over the period 1990-2015 of the station data is indicative of the SAM moving towards a high-index state in recent decades.

Acknowledgement

Authors express their gratitude to Director General of Meteorology for encouragement and providing all facilities to carry out this study.

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