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Diurnal and Seasonal Variation in the Surface Layer Parameters Observed at Maitri Station, Antarctica

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Abstract

Surface layer parameters at Maitri station show a marked diurnal variation during the short austral summer. The diurnal effect in the surface temperature regime is due to the daytime heating provided by solar insolation. The surface layer over Maitri remains thermally stratified during the hours of minimum solar insolation, the so-called nighttime period. The surface wind regime also depicts a considerable diurnal influence alongwith the temperature regime particularly during summer months. The diurnal effect in the surface wind regime is due to the katabatic wind component. The diurnal variation in temperature and wind is observed to be maximum during summer months and decreases as winter advances. Same is the case with the surface heat flux which changes sign from positive (daytime) to negative (nighttime) during summer months in accordance with the atmospheric stability. In winter months the diurnal effect in surface layer parameters is altogether absent because of longer- term cooling in the absence of solar radiation.

1. Introduction

The evaluation of turbulent fluxes in the surface layer are important for the characterisation of the atmospheric boundary layer (ABL). The surface layer turbulent heat fluxes constitute a significant component of the surface energy balance. These parameters are of great importance in designing and maintaining air-strips in areas of seasonal snow cover. The Antarctic surface layer is unique due to the prevalence of snow, long day and night conditions and the katabatic flow of winds along the ice-slopes (Ball, 1956; Manins and Sawford, 1979; James, 1989; King, 1989; Streten, 1990; Gallee and Schayes, 1992).

Studies of the transfer of heat and momentum in the lowest layers of the atmosphere under extreme conditions of stability and instability have been carried out in the polar regions (Dalrymple *et al,* 1966; Heinemann and Rose, 1990; Joffre, 1982; Liljequist, 1957; Martison and Wamser, 1990; Maykut, 1978; Kottmeier and Engelbart, 1992; Radok, 1973; Naithani *et al,* 1995). Extreme stability is found over the polar land masses during winter darkness, while extreme instability is observed with less regularity during short summer. The seasonal and diurnal variation in the surface temperature and wind regime have been reported by various workers over different parts of Antarctica (Wendler *et al*., 1988; Streten, 1990; Ishikawa *et al,* 1990; Parish *et al.,* 1993). Diurnal influence in the surface layer parameters during summer over Maitri have already been reported by Naithani *et al.* (1995). In this report we present the diumal variation in surface layer parameters for different months representing different seasons at Maitri station.

Surface layer parameters have been evaluated using the measurements made at three levels on the 28 m tower. The turbulent heat flux has been calculated using the flux profile relationship given by Businger *et al,* (1971). Diumal variation of turbulent parameters have been calculated for five clear sky days in each of the months starting from January to May, 1995 (representing the summer, transition and winter seasons) and the average of these parameters is discussed in this paper.

2. Instrumentation

The mean wind and temperature profiles were measured using the sensors mounted on 28 m micro-meteorological tower at three levels, i.e., at 1.8, 4.5 and 11.3 m, respectively. The air temperature and humidity were measured using the PT 1000 thermometer, a sensitive humicap sensor, respectively. The wind speed and wind direction were measured using a cup-anemometer and a sensitive rotating arm wind vane, respectively. The accuracy in measuring temperature, wind velocity and direction are 0.1 °C, 0.1 m/s and ±2°, respectively. A pyranometer has been used to measure the solar radiation which was mounted on a separate mast. The measurements were made using Moll-Gorczynski thermoelectric pyranometer, and was calibrated by the India Meteorological Department, Government of India, as per world radiometric reference.

The temperature sensors were housed in a well insulated shields in the form of an umbrella over the top of the housing to protect them from direct exposure. The reflected component of radiations in the ice free zones in summer is minimum; however, care has been taken in the design of the shield to keep these effects minimum. In the winter period, when the Schirmacher region is covered with snow, the albedo is high but the Sun is no longer above the horizon. Each sensor has been calibrated as per the standards maintained by the India Meteorological Department, Government of India.

The instrumented tower is located in the SE direction (up-wind) of the instrumentation hut (housing the data logger and other system electronics) at a distance of 110 m. The south-east direction being the prevailing topographical wind direction, the observations are unaffected by the station buildings and other structures. The wind speed and direction sensors were mounted on 1.5 m booms extending in the SE direction, while the temperature and humidity sensors were mounted in the southward direction. However, no effort has been made to eliminate the shadowing effect due to the supporting tower, since winds from this sector are always low; perhaps, the shadowing effects may not matter much. The wind velocity and direction sensors are fitted with 10 watt heater elements to combat icing and riming problems. The data has been recorded by a microprocessor based data-logging system connected with the sensors.

3. Data Collection and Quality Control

The data-logger was programmed to calculate the mean value of each channel over a desirable period. The data was accessed after every one second and was stored to calculate averages over a period of 1 minute and 10 minutes. For the present study, 10 minute averaging was recorded after every half an hour. Since the cup-anemometer read about 5% above the 'true' wind speed for wind speeds exceeding about 5 m/s (Izumi and Barad, 1970), this factor has been taken care of in data analysis. The solar radiation measurements were recorded on a strip chart recorder.

The data used in the present study pertains to January, 1995 to May, 1995. Efforts were made to avoid the data for wind >12 m/s from any direction (because for very high near-surface winds strong surface inversions do not persist and the atmosphere tends towards neutral stability). Although, the instruments during the period of west and northwest winds were in the wake of the tower. But, the low winds during that period assured that the effect of the tower could be easily neglected.

4. Heat and Momentum Flux Profile Relationships

The fluxes of sensible heat and momentum are defined as :

$$Hs = - \rho C\rho \ Kh \quad (\partial \Theta / \partial z) \qquad ...(1)$$

$$\tau = - \rho Km (\partial u / \partial z) \qquad ...(2)$$

where, p is the density of air (gm m^{-3}), Cp is the specific heat at constant pressure (cal/gm/K), u is the horizontal velocity, Θ is the potential temperature, and $Kh=k.u^*.z/\phi_n$; $Km=k.u^* .z/\phi_m$ are the eddy diffusivity of heat and momentum, respectively.

The vertical wind shear and temperature gradient as defined by Monin and Obukhov(1954) are:

$\partial\Theta/\partial z = (u^*/kz)\, \phi_n(z/L)$ ...(3)

$\partial\Theta/\partial z = (\Theta^*/kz)\, \phi_m(z/L)$ ...(4)

The scaling length for surface layer turbulence, called the Obukhov length, is defined by the relation:

$L = (Tu^{2}*)/(gk\Theta^*)$ ...(5)

where, $u^* = \sqrt{(\tau/\rho)}$ is the friction velocity, $\Theta^* = \overline{-W'\theta'}/u_*$ is the scaling temperature (primes denotes the deviation from the average), ϕ_m and ϕ_n are the normalised vertical wind shear and the potential temperature gradient respectively. The overbar denotes an average over the observational runs of 10 minutes in our study.

The functions ϕ_n and ϕ_m for unstable and stable conditions are given as:

$\phi_n(z/L) = 0.74(1 - 9(z/L))^{(-1/2)}$ (unstable) ...(6a)

$= 1 + 5(z/L)$ (stable) ...(6b)

$\phi m(z/L) = (1 - 15(z/L))^{(-4/4)}$ (unstable) ...(7a)

$= 1 + 5(z/L)$ (stable) ...(7b)

where z/L is the atmospheric stability parameter and can be calculated in terms of Richardson number, Ri through the relations (Panofsky and Dutton, 1984)

$z/L = Ri,\ Ri<0$ ...(8a)

$= Ri/(1-5Ri),\ Ri>0$ ...(8b)

where Richardson number may be given as

$Ri = (g/\bar{T})\, (d\Theta/dz) / (du/dz)^2$ ....(9)

where $(g/\bar{T})$ is the buoyancy parameter and $\bar{T}$ is the average temperature.

5. Results and Discussion

The turbulent heat fluxes, derived from surface-layer parameters for different temperature gradients are presented in Figure 1. The fluxes have been calculated for the eddy diffusivity values suggested by Mahrt and Schwerdtfeger, (1970) for the Antarctic surface layer. The error bars indicate the scatter at 1-sigma (one standard deviation) level. Figure 2 gives a composite depiction of various surface-layer parameters throughout the course of a day for different seasons. Care has been taken in selecting the days for estimation of diurnal variation in fluxes. The data has been considered only for those days when the wind speed was less than or around 12 m/s. It is important to note that at higher

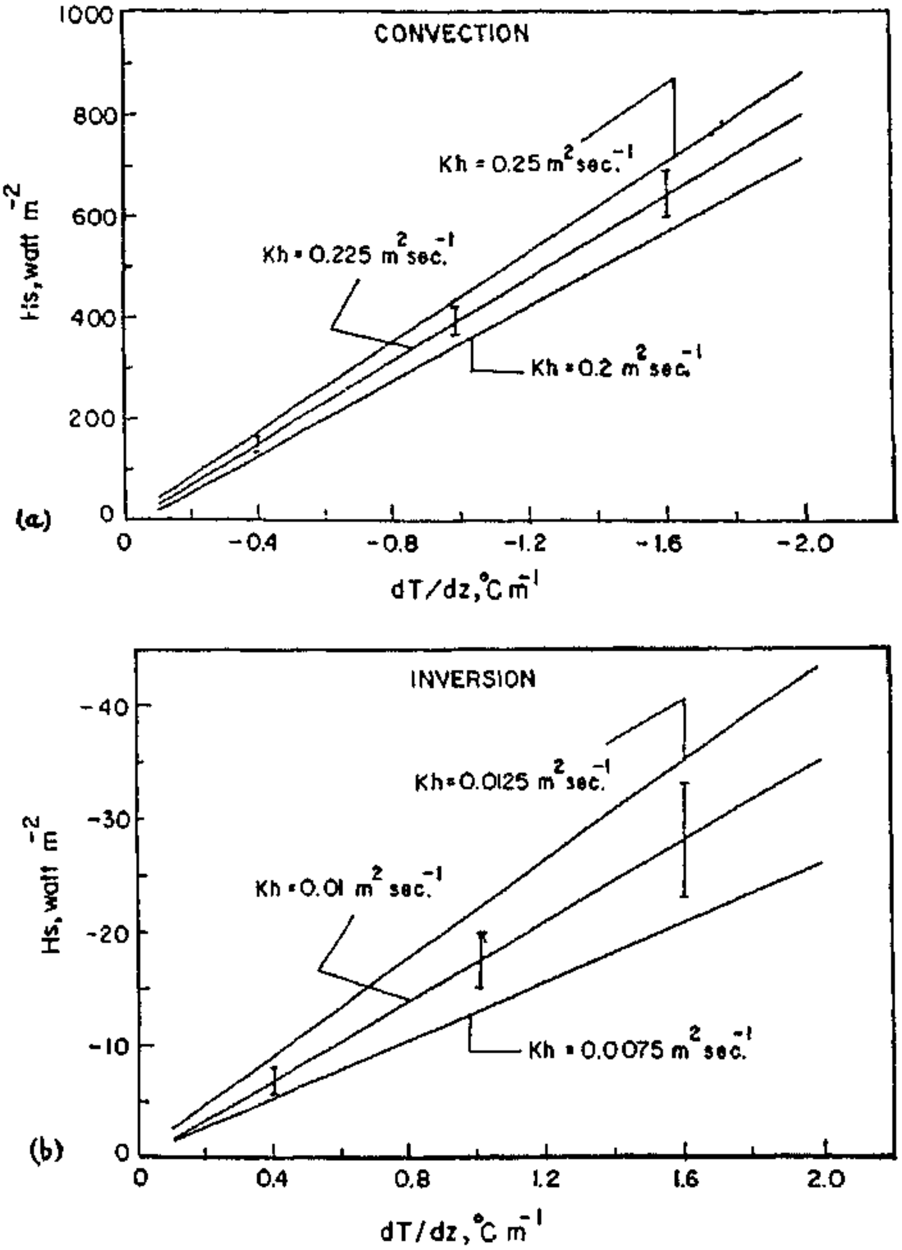


Fig.l: Turbulent heat flux, derived from surface-layer parameters for (a) unstable and (b) stable temperature gradients, for different values of eddy diffusivity. The error bars indicate scatter at 1 —sigma level (after Naithani et al., 1995).

wind speeds, lower atmosphere tends towards weaker stabilities or neutral conditions due to turbulent mixing produced by strong winds.

Figure 2a(i) depicts the diurnal variation of solar radiation received at Maitri from January to May. From the figure it can be seen that the solar radiation value decreases as winter advances. In the month of March the maximum solar insolation reaching the surface is less than half than that received in the month of January. However, in the month of May solar insolation is very low (almost negligible). Surface-layer temperature (Figure 2a (ii)) closely follows the pattern of solar insolation reaching the surface. The magnitude of diurnal variation in temperature is maximum in summer and decreases as winter advances. The boundary layer exhibited a transition from unstable state to stable state depending upon the solar insolation reaching the surface (i.e. sunset and sunrise timings) for all months except May (Figure 2b(i)). In the month of May the boundary layer remain stably stratified throughout the day. Heat flux values also closely follow the temperature, and hence, the solar flux reaching the surface (Figure 2b(ii)). Here positive heat fluxes imply transfer of heat away from the surface (unstable conditions), while negative values imply transfer to the surface (stable conditions). In the positive half of the cycle, the heat flux varies sharply from month to month and decreases very sharply with the advance of winter. The negative values of flux, however, remain almost same for all the months/seasons. This is due to stronger winds during the stable atmospheric conditions. The lower values of fluxes observed for May as compared to January are due to the comparatively stronger surface winds, and, thus, weaker vertical temperature gradients (Figure 2c(i)). Turbulent mixing produced by strong winds decreases the vertical stability of the atmosphere, and, hence, the temperature gradient decreases with winds.

The effect of solar insolation can also be seen in the near- surface wind speeds and directions (Figure 2c(i)-(ii)). Katabatic winds caused by radiative cooling of the near-surface air are a widespread feature of the Antarctic coastal slopes. The cooling of air causes a thermal inversion to develop along the continental slopes, resulting in a favourable pressure gradient for the downslope or katabatic wind component. In summer the daytime heating destroys thermal inversion and, therefore, katabatic wind flow ceases during daytime and is only a nighttime phenomena in summer. The strongest katabatic winds in summer occur near local sunrise and the weakest wind speeds are seen approximately an hour after local noon. The ever-present strong winds from March onwards reflect a continuous 24-hour cooling in the lower atmosphere. During winter months katabatic wind flow depends on the availability of cold air for drainage upstream (Streten, 1968), while the condition for its onset and persistence is satisfied throughout the day. The influence of diurnal cycle of solar heating on

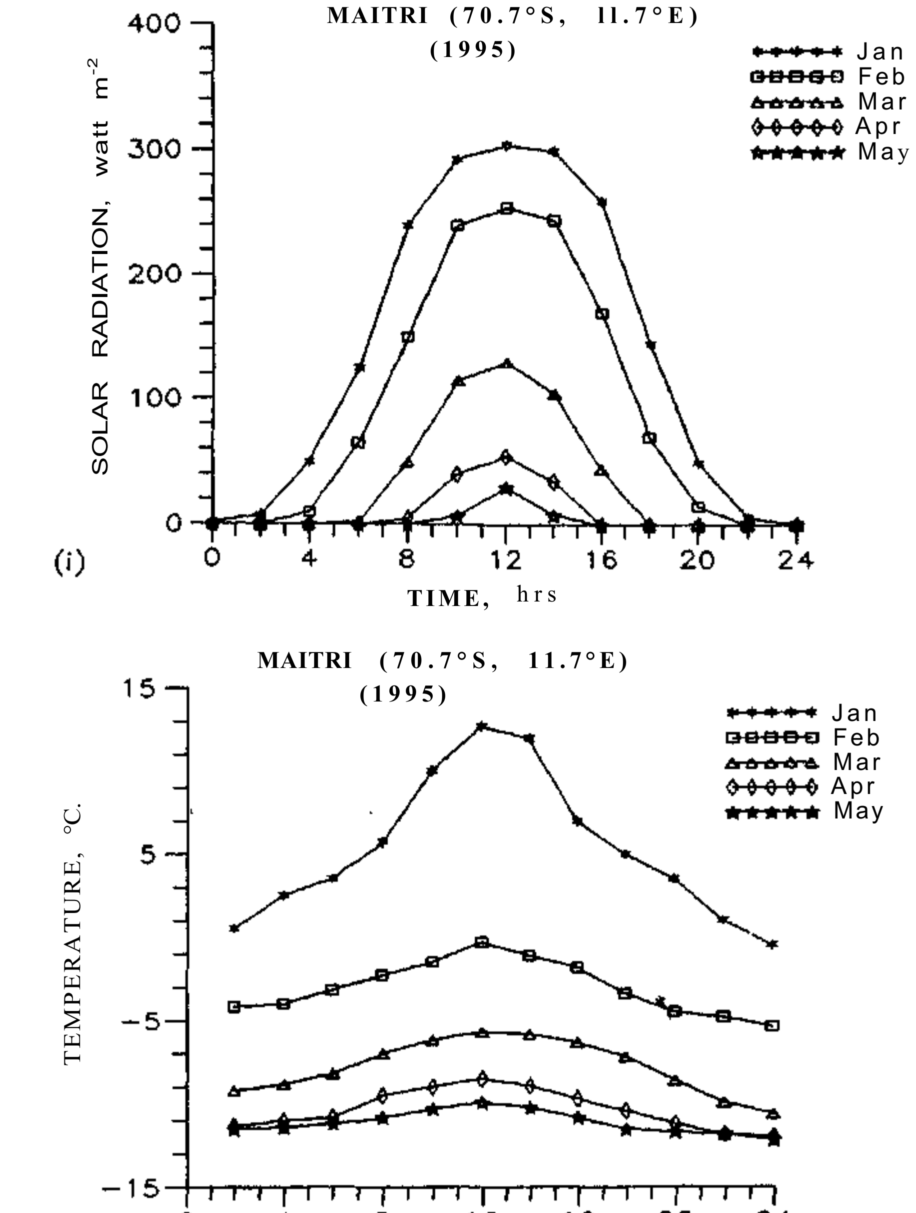
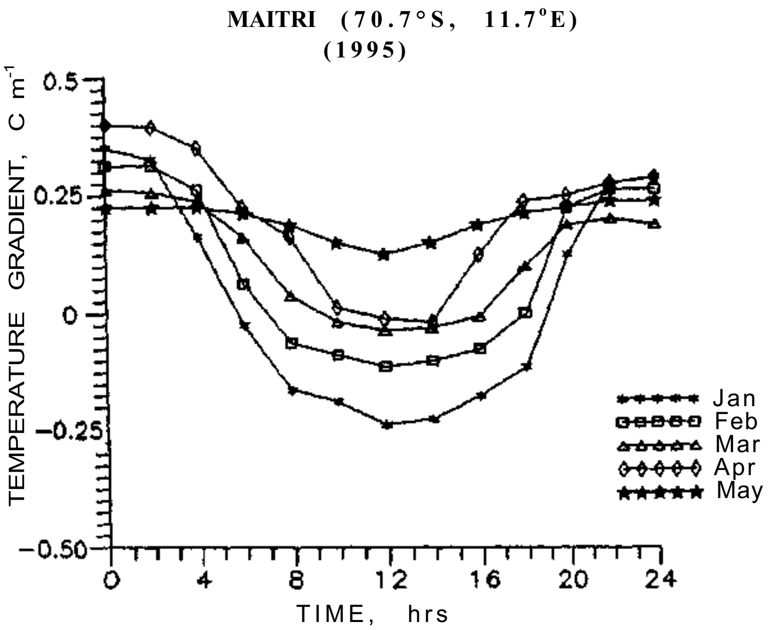
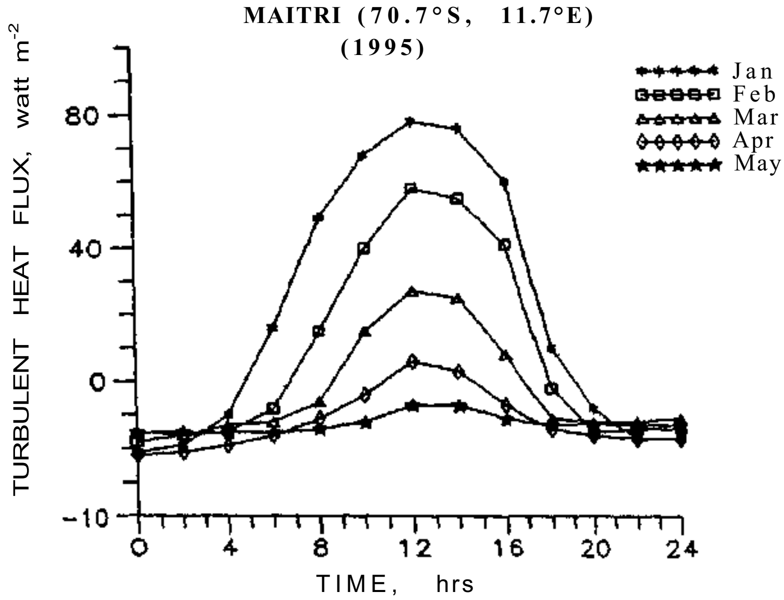


Fig.2a: Diurnal variation of (i) solar radiation and (ii) temperature for different months.

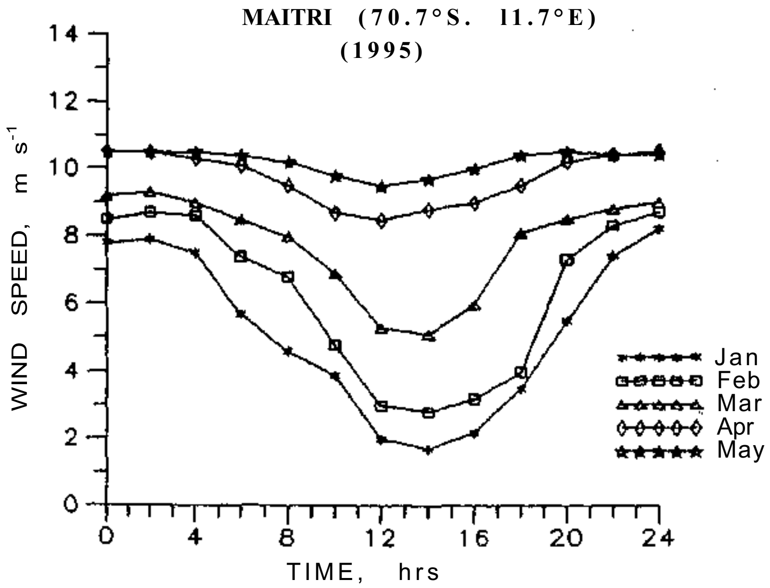


(i)

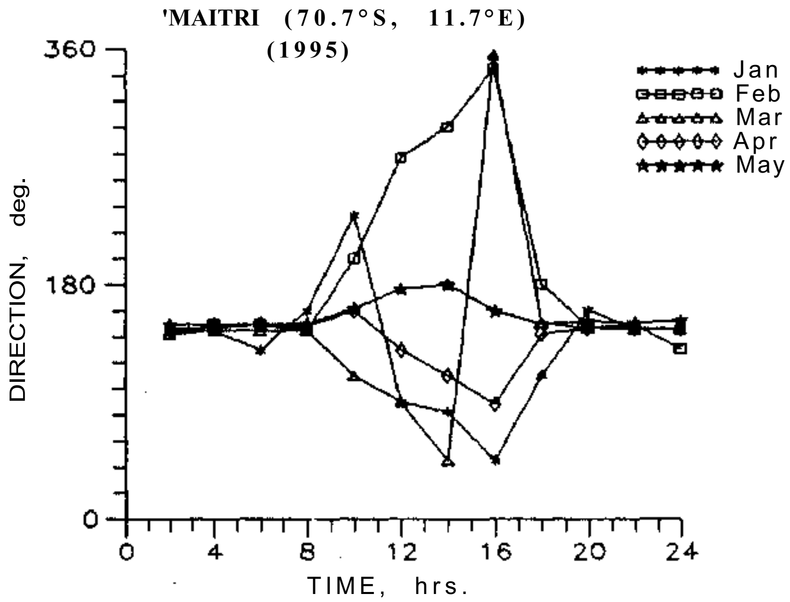


(ii)

Fig.2b: Diurnal variation of (i) temperature gradient and (ii) turbulent heat flux for different months.

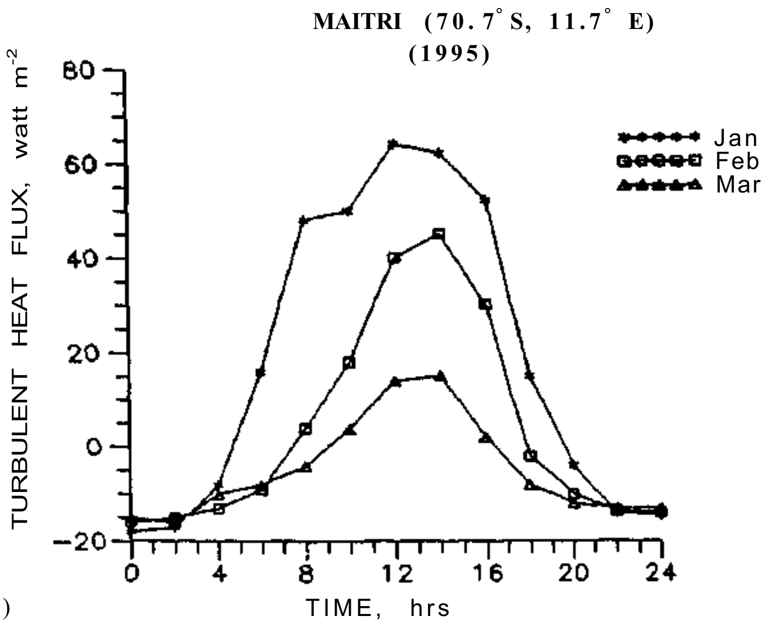


(i)

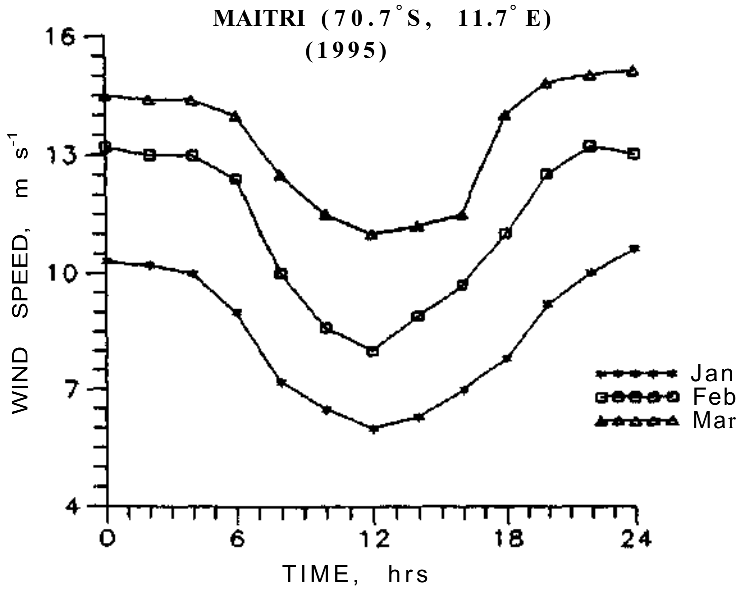


(ii)

Fig. 2c: Diurnal variation of (i) wind speed and (ii) wind direction for different months.



(i)



(ii)

Fig.3: Diurnal variation of (a) turbulent heat flux and (b) wind speed, on days with considerable cyclonic activity.

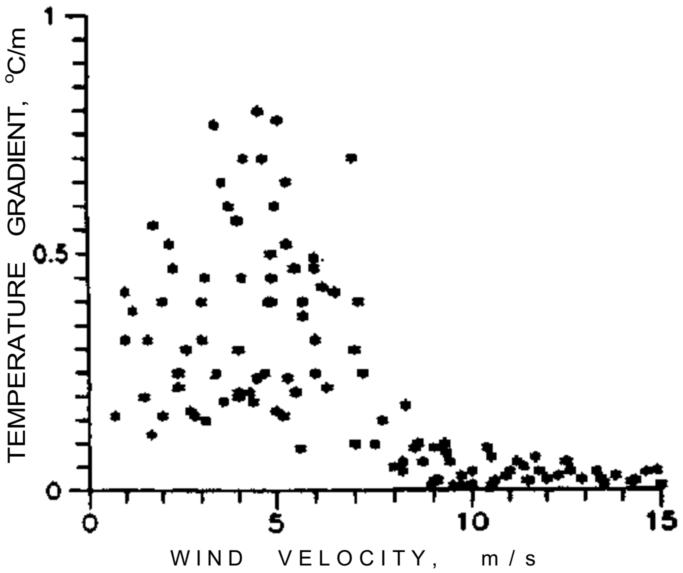


Fig.4: Variation of average temperature gradients between 1.4 and 11.3 m versus wind speed recorded at 11.3 m level.

katabatic winds and temperature has also been reported at Mawson by Shaw (1957) and Streten (1990) and at Adelie Land by Periard and Pettre (1992) and Parish *et al.* (1993). The diurnal modulation of drainage flow direction also reduces by March. Parish *et al.* (1993) have also reported similar results i.e., the diurnal variation in near-surface parameters, for Adelie Land using a 2-dimensional numerical model. They calculated the turbulent parameters for different solar declination angles. Wendler *et al.* (1988) have also estimated the hourly mean turbulent fluxes of sensible heat throughout the day. Their result showed the downward turbulent flux to be maximum around 0200 hrs and the maximum upward fluxes near 1300 hrs. Diurnal variation in summertime boundary layer has also been reported at Adelie Land by Kodama *et al.* (1989).

Figure 3 gives the diurnal variation of turbulent heat flux and wind speed on days with considerable cyclonic activity for different months. For this the average parameters for 3 days have been shown. The heat flux variation appears to be normal as seen during the periods of no cyclonic activity (Figure 2b(ii)), but the winds (Figure 3(ii)) are considerably stronger throughout the day due to the presence of cyclonic circulation.

Figure 4 gives the relationship between wind speed and temperature gradient. As seen in this figure, strong/marked inversions can develop for wind speeds up to a maximum of 7 m/s, for higher winds (> 10 m/s) inversions become weaker. The sharpest gradients have been formed for wind speeds around 4 m/s. These results are similar to those observed at Maudheim (Liljequist, 1957) and Plateau stations (Riordan, 1977). However, it may be emphasised here that we have considered data only for dark/sunless period, to show the effect of winds on temperature gradient, and, hence, on the vertical stability of the atmosphere.

Conclusion

The fluxes of heat and momentum have been estimated using the data collected at Maitri, during the 1995. The boundary layer exhibited a transition from a stable to an unstable state around 0600 LT and back to unstable one around 1800 LT during summer months. The duration of the unstable period decreases as winter advances. Stable conditions are marked by fairly good turbulent mixing. Strong positive vertical temperature gradients occur with wind speeds below 5 m/s and a slight thermal stability occurs even with high wind speeds above 10 m/s, i.e., a shallow surface based inversion layer continues to exist even under high wind conditions.

If one considers the extremely low temperatures and the persistence of stable stratification throughout the year in the surface layer of the Antarctic continent, one might think that the pollutants released during various kinds of activities (burning of garbage and vehicular movements, etc.) would remain trapped within the boundary layer. But, because of the dome shape of Antarctic continent, the prevailing downslope winds or katabatic winds help to move pollutants from the continent towards the coast. Thus the boundary layer experiences minimum pollution potential. Thus, it is not the temperature gradient but the wind which is the main factor controlling dispersion in the lower atmosphere over the Antarctic continent.

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i

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