Preliminary Study on the Structure of the Atmospheric Surface Layer in Mizuho Plateau, East Antarctica

Hiroshi SASAKI*

東南極みずほ高原における接地気層の構造についての予備的研究

佐々木　浩*

要旨．1972年6月から12月までの期間にみずほ基地で行った風と気温の鉛直分布および乱流の観測結果に基づき，東南極のみずほ高原における接地気層の構造について予備的研究を行った．その結果，次のことがわかった．

1) みずほ高原におけるこの期間の接地気層の安定度の特徴は，弱安定状態の出現率が高く，不安定状態の出現率が低いことといえる．

2) 粗度長の平均値は，0.24 cm で，昭和基地と南極点での値より1桁大きな値を示した．これは，みずほ高原でのカタバティック風の風食作用によって形成される高いサストルギの存在によるものと思われる．雪面付近での風速の鉛直分布は，リチャードソン数が約0.1以下のとき，「対数＋直線法則」に従った．

3) 風と気温の変動のパワースペクトル，および顕熱フラックスのコスペクトルの分布は，これまでに多くの研究者によって報告されている結果とほぼ同じであった．運動量のコスペクトル解析から，いくつかの周波数帯でプラス符号をもつ運動量輸送が行われていることが示された．カタバティック風のなかの鉛直風速変動の確率密度分布は，平均値よりも小さい側にかたよっていると推定される．

4) 内部波の波動に伴って現われたと思われる，気温の周期的な変動が冬期間に観測された．

Abstract: A preliminary study on the structure of the atmospheric surface layer in Mizuho Plateau, East Antarctica was made based on the profiles and fluctuations of wind and air temperature observed at Mizuho Station during the period from June to December 1972. The results are summarized as follows:

1) High frequency of slightly stable conditions and low frequency of unstable conditions were a characteristic feature of stability in the atmospheric surface layer in Mizuho Plateau during the period described above.

2) Mean value of roughness length was 0.24 cm and larger by one order than the values at Syowa Station and the South Pole. This may be explained by the presence of high sastrugi produced by erosion of katabatic winds in Mizuho Plateau. The profiles of wind speed near the snow surface followed the "log + linear" law for Richardson numbers less than about 0.1.

3) The distributions of the power spectra of wind and temperature fluctua-

* 日本気象協会北海道本部　Hokkaido District Office, Japan Weather Association, Nishi 23-chome, Kita 1-jô, Chuo-ku, Sapporo 064

tions and those of the cospectra of heat flux were similar to the results reported by many investigators. The cospectral analysis for momentum shows that the momentum with positive sign is transferred within some frequency ranges. It appears that the probability density distributions of the vertical velocity fluctuations in katabatic winds are skew to the region smaller than the mean values

4) Temperature oscillations which seem to be caused by internal wave motions were observed in winter.

1. Introduction

Katabatic winds and low-level inversions are a characteristic feature of the climate of Antarctic coastal regions. As preliminary research for the study on the structure of the atmospheric surface layer in such regions, plofiles and fluctuations of wind and air temperature near the snow surface were measured at Mizuho Station (70°41.9′S, 44°19.9′E, m.s.l. 2230 m; formarly Mizuho Camp, officially redesignated in March 1978) in Mizuho Plateau, East Antarctica, during the period from June to December 1972 by the author who was a member of the 13th Japanese Antarctic Research Expedition.

The snowfield of Mizuho Plateau provided a nearly ideal site for observing the atmospheric turbulence in stable conditions, because it is extensive and nearly horizontally uniform, and the wind speed was larger than 2 m/s even in strong inversion conditions.

The purpose of this paper is to present statistical analyses of stability and the observed temperature oscillations and to examine the form of wind profile and the turbulence characteristics in stable conditions.

2. Measurements and Data Reduction

The measurements were made in the snowfield at Mizuho Station which is located at about 300 km southeast of Syowa Station (Figs. 1 and 2). At Mizuho Station the most frequent wind direction was ESE in each month during the period of the measurements, and the monthly means of wind speed and air temperature were 12.4 m/s and −40.8°C in June and 8.9 m/s and −18.8°C in December 1972 respectively (SASAKI, 1974; YAMADA *et al.*, 1974).

A windmill type anemometer with a vane installed on the top of a 4 m high mast provided continuous records of wind direction and wind speed (5-minute mean). The profile of air temperature was measured by five platinum resistance thermometers mounted on a 10 m high mast, which were set in pipes ventillating naturally. The thermometers were mounted at five levels, 0.5, 1.0, 2.0, 4.0 and 8.0 m above the snow surface. The outputs of the thermometers were continuously recorded on a 6-channel recorder. Temperature data measured at the time when the global solar radiation was more than

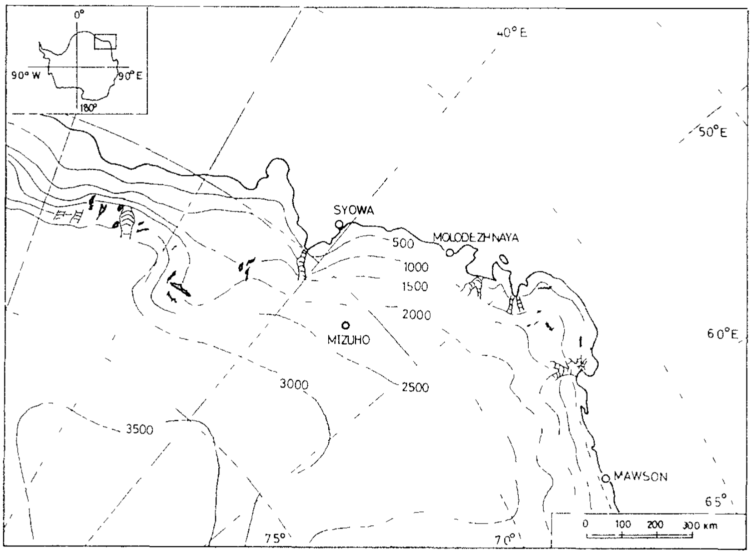

Fig 1. Location map of Mizuho and Syowa Stations

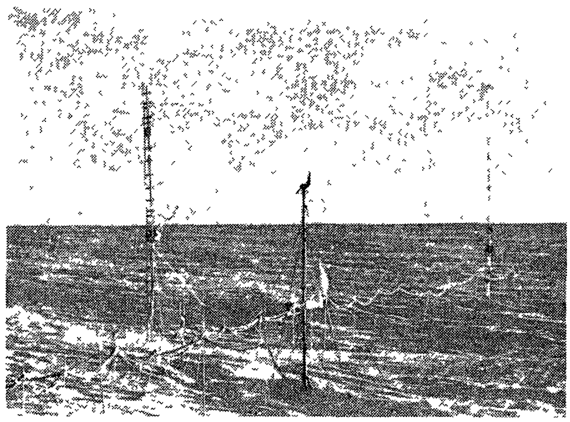

Fig 2 A distant view of the observation site at Mizuho Station.

10 cal cm^{-2}h^{-1} and the temperature change with time in 10 min was more than 0.5°C were not used for analyses of wind profile.

The 10-minute mean profile of wind speed was measured with five small anemometers of the three-cup type manufactured by Makino Instrument Company. The anemometers were mounted on horizontal booms 0.5 m long extending outward from the 10 m high mast at the same levels as the thermometers. The rotations of the anemometers were optically transformed into electric pulses and counted with electromagnetic counters. The reading of the counters was made when temperature inversions occurred.

Wind velocity components and air temperature fluctuations were measured with the sonic anemometer-thermometer manufactured by Kaijo Denki Ltd. The sonic anemometer-thermometer was mounted at a height of 4.5 m of an observation tower taking the form of a ladder, which was located about 20 m apart from the 10 m high mast. The outputs of the sonic anemometer-thermometer were recorded on a magnetic tape recorder. Observations of turbulent fluctuations were made when temperature inversions occurred.

Outputs signals of turbulent fluctuations were filtered with a 6.5 Hz low-pass filter to remove the high-frequency noise. In addition, signals of horizontal wind velocity components fluctuations were filtered with a 0.178 Hz high-pass filter and amplified at appropriate rates. After these steps the analog signals were transformed to digital data cards with the A–D converter for numerical calculations by electronic computer.

3. Results

3.1. Frequency distributions of stability

Temperature differences ΔT between heights of 8 m and 0.5 m were computed from thermometer data based on the readings of every three hours (local time). ΔT is given by $\Delta T = T_8 - T_{0.5}$ where T_8 and $T_{0.5}$ are the temperature at heights of 8 m and 0.5 m respectively. The frequency distributions of class intervals of ΔT by month are given in Table 1. It is evident from Table 1 that each month from July to December has frequency more than 80% for $\Delta T \geqq 0.5$°C, although the frequency in June for this range is only about 60%; this month had the highest average wind speed. Every month has a pronounced peak for the class interval 0.5 to 0.9°C. Lapse conditions occur during the months with sun, November and December. The largest variation of ΔT occurs in December, the first complete month of the antarctic summer. The empirical relationship between ΔT and U_4, wind speed at a height of 4 m measured by the windmill type anemometer, is shown in Fig. 3. The data given in Fig. 3 were taken every three hours on three clear days selected at discretion for a month during the period of the measurements. It can be seen from Fig. 3 that temperature differences larger than 1.5°C can

Table 1. Frequency distributions of temperature differences between heights of 8 m and 0.5 m above the snow surface.

Month	$T_8 - T_{0.5}$ (°C)													No. of data
	−1.0 ~ −0.6	−0.5 ~ −0.1	0.0 ~ 0.4	0.5 ~ 0.9	1.0 ~ 1.4	1.5 ~ 1.9	2.0 ~ 2.4	2.5 ~ 2.9	3.0 ~ 3.4	3.5 ~ 3.9	4.0 ~ 4.4	4.5 ~ 4.9	5.0 ~ 5.4	
June 1972			38.5	52.6	8.9									192
July			13.0	61.9	23.0	1.3	0.4	0.4						239
Aug.			8.9	63.4	22.8	2.8	0.8			0.8			0.4	246
Sept.			17.7	60.6	19.9	0.4	0.9	0.4						231
Oct.			17.8	65.6	15.8	0.8								247
Nov.	0.8	2.5	8.0	70.2	15.5	2.1		0.4	0.4					238
Dec.	0.4	0.4	10.8	48.9	32.9	2.6	1.7			0.4	1.3	0.4		231

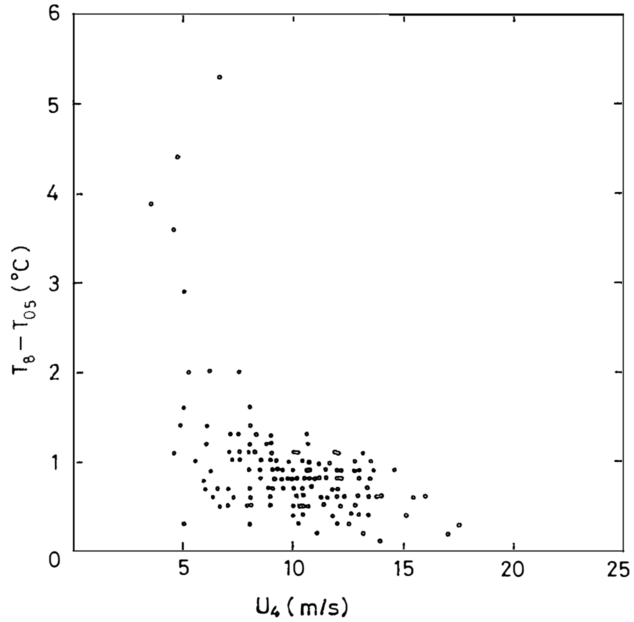

Fig. 3 Temperature differences between heights of 8 m and 0.5 m versus wind speed at a height of 4 m.

occur when U_4 is smaller than 8 m/s.

The stability ratio, SR, at Mizuho Station was computed from ΔT and U_4. Figs. 4a and 4b show comparisons of frequency distributions of class intervals of SR at Mizuho Station in 1972 and the South Pole in 1958 (DARLYMPLE *et al.*, 1966) for two periods: from June to September and from October to December. SR at each site was computed as follows.

$$\text{at Mizuho Station; } SR=(T_8-T_{0.5})/U_4^2 \text{ in } {}^\circ\text{C m}^{-2}\text{s}^2,$$

$$\text{at the South Pole ; } SR=(T_{10}-T_{2.5})/U_{10}^2 \text{ in } {}^\circ\text{C m}^{-2}\text{s}^2.$$

The unit of SR at the South Pole was given in °F/kt^2 in the original paper. The empirical relationship between Richardson number at a height of 4 m and SR at Mizuho Station is shown in Fig. 5. As shown in Fig. 4a, for the period from June to September each site has a pronounced peak of more than 50% for the class interval 0.000 to 0.021. It is evident from Fig. 4a that unstable conditions do not occur at Mizuho Station, but occur at the South Pole during the period from June to September. It can be seen from Fig. 4b that a pronounced peak for the class interval 0.000 to 0.021 dose not appear at the South Pole, but appears at Mizuho Station for the period from October to December. The frequency of unstable conditions at the South Pole in the latter period is much higher than at Mizuho Station. High frequency of slightly stable conditions and low frequency of unstable conditions seem to be a characteristic feature of stability in the atmospheric surface layer in Mizuho Plateau during the period from June to December.

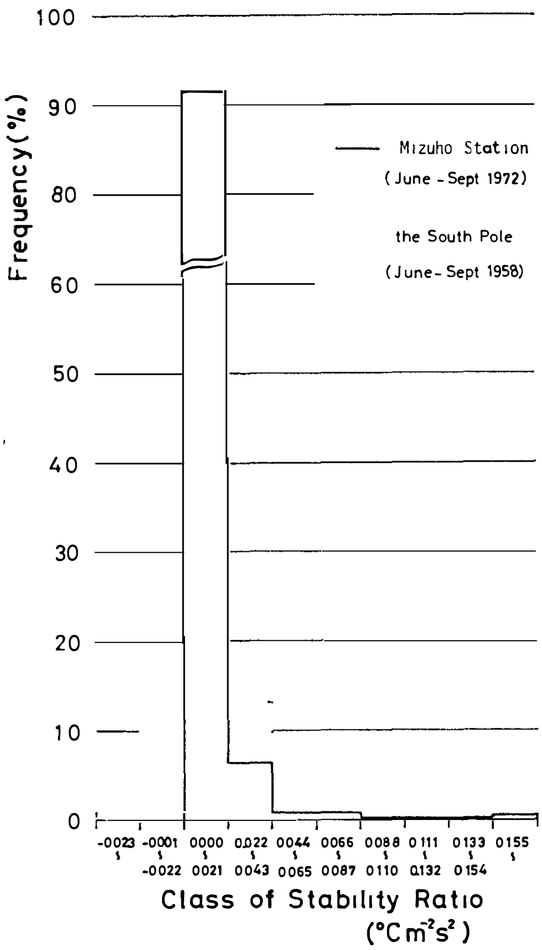

Fıg. 4a. Comparıson of frequency distributıons of class intervals of stabilıty ratıo at Mızuho Station and the South Pole during the perıod from June to September.

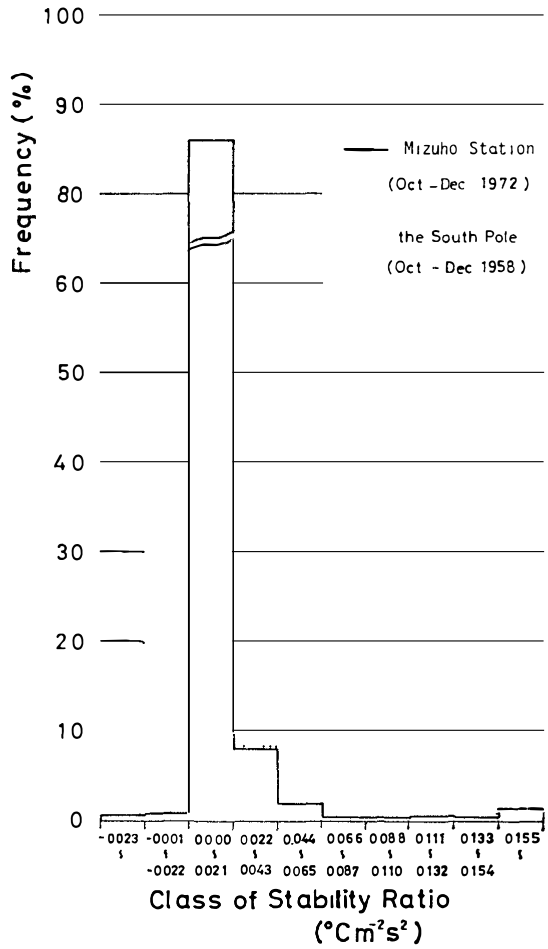

Fıg 4b. Comparıson of frequency dıstrıbutıons of class ıntervals of stabilıty ratıo at Mızuho Statıon and the South Pole durıng the perıod from October to December

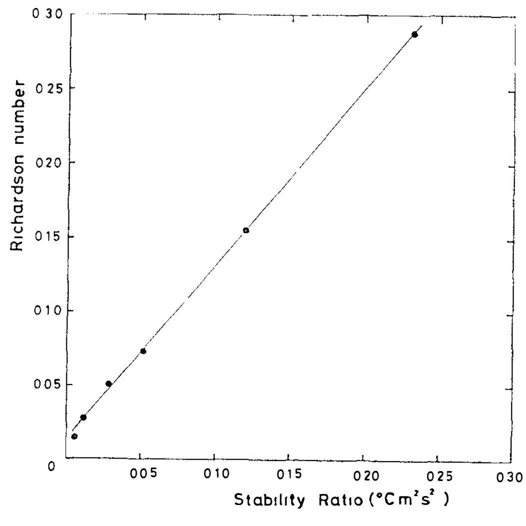

Fıg 5 Rıchardson number versus stabılıty ratıo

3.2. The form of wind profiles

Roughness length z_0 at Mizuho Station was obtained by calculating graphically the twenty wind profiles data in near neutral conditions under which the logarithmic wind law held, although such conditions occurred seldom and only during the period from June to August. Near neutral conditions were defined as $0.00 \leqq Ri_4 \leqq 0.03$, where Ri_4 denotes a gradient Richardson number at a height of 4 m. Mean value of roughness length was 0.24 cm. This value is larger by one order than the values observed at Syowa Station (MAKI, 1972; ADACHI, 1973) and the South Pole (DARLYMPLE *et al.*, 1966) which are about 0.01 cm and 0.014 cm respectively. High sastrugi produced by wind erosion are the characteristic surface texture in Mizuho Plateau where the strong katabatic winds blow constantly. They sometimes exceed 0.5 m in height (NAKAWO, 1975) and are aligned with their major axes paralleled to the wind direction. It can be explained by the surface texture in Mizuho Plateau that the value of z_0 at Mizuho Station was larger than those at the two stations described above.

Fig. 6 shows the mean profiles of wind speed (above) and temperature (below) of class interval of Ri_4. It is evident from Fig. 6 (below) that strong inversions appear at higher level than 4 m above the snow surface.

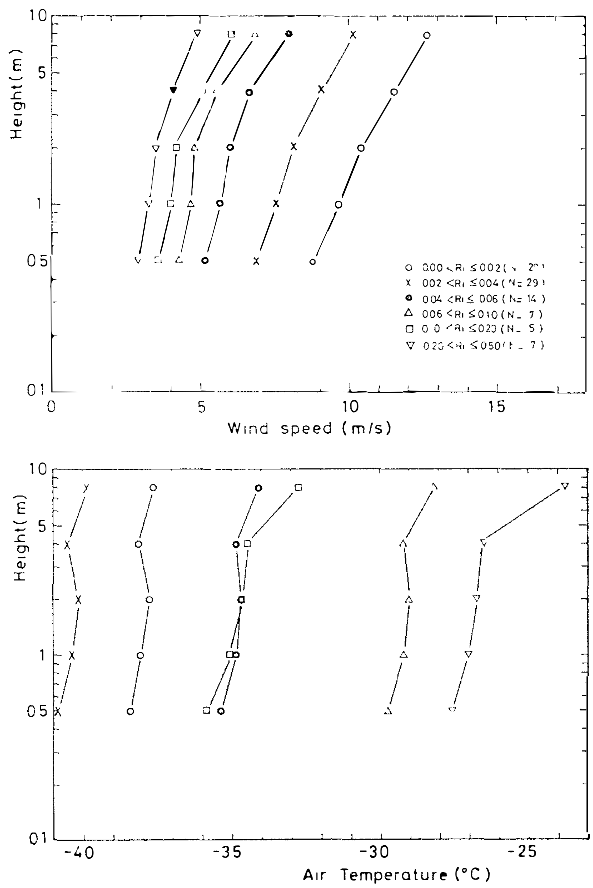

Fig. 6. The mean profiles of wind speed (above) and air temperature (below) of class intervals of Richardson number at a height of 4 m. N denotes the number of data.

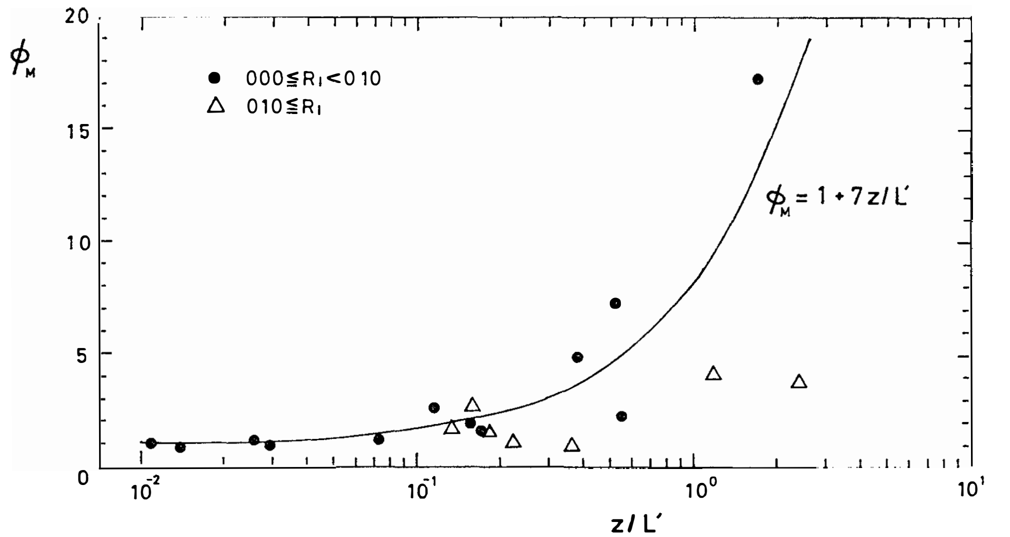

Fig. 7 The relationship between a universal function for wind speed (ϕ_M) and a nondimensional stability index (z/L')

It has been presented by McVEHIL (1964) that the log-linear wind profile fits the observations well for Richardson numbers less than about 0.14. Fig. 7 shows the relationship between ϕ_M and z/L' obtained by the same method as McVEHIL used, where ϕ_M is a universal function for wind speed to be determined and z/L' is a nondimensional stability index;

$$\phi_M\left(\frac{z}{L'}\right)=\frac{kz\partial u}{u_*\partial z}$$

$$L'=\frac{u_*\theta\partial u/\partial z}{kg\partial\theta/\partial z}.$$

k : Von Kármán constant (=0.4),
z : Height,
u : Wind speed,
u_* : Friction velocity,
g : Acceleration of gravity,
θ : Potential temperature.

It can be seen from Fig. 6 that the log+linear low holds for Richardson numbers less than about 0.1 and the relationship between ϕ_M and z/L' appears to follow the empirical formula obtained by McVEHIL (1964).

3.3 Turbulence characteristics

Summary of the observations of the atmospheric turbulence is shown in Tables 2 and 3. It can be seen from Table 3 that the standard deviations of wind velocity components normalized by friction velocity (u_*) for $z/L\geqq5$ have much larger values than

Table 2 The mean profiles of wind speed and air temperature

Run No		1	2	3	4	5
Date		18 Nov	19 Nov	23 Nov	23 Nov.	24 Nov
Start time (local time)		00 36	23 20	20 09	23 11	01 54
Duration for u, v, w (min)		8	8	8	8	8
Duration for w, T (min)		12	12	12	12	12
Weather		Clear (+)	Cloudy	Clear	Clear	Clear
Wind direction		ESE	ESE	ESE	ESE	ESE
Wind speed	0.5 m	8.1	4.8	4.2	6.1	7.2
(m/s)	1.0 m	8.5	5.1	4.6	6.4	7.8
	2.0 m	8.9	5.3	4.7	6.7	8.2
	4.0 m	9.7	6.0	5.4	7.5	9.1
	8.0 m	10.8	7.4	6.4	8.9	10.3
Air temperature	0.5 m	−36.3	−32.6	−24.8	−31.6	−32.5
(°C)	1.0 m	−35.8	−32.1	−24.6	−30.9	−32.1
	2.0 m	−35.7	−31.8	−24.5	−30.7	−31.7
	4.0 m	−36.2	−32.1	−24.9	−30.9	−31.9
	8.0 m	−35.5	−31.2	−24.1	−30.3	−31.3

Table 3 The standard deviations and related parameters of the atmospheric turbulence

Run No	1	2	3	4	5
$u_*=\sqrt{-\overline{uw}}$ (cm/s)	33.0	17.3	16.7	6.1	7.2
$T_*=-\overline{wT}/ku_*$ (°C)	0.26	0.29	0.27	1.07	0.90
z/L (z=4.5 m)	0.070	0.281	0.278	8.43	5.06
σ_u/u_*	2.00	2.12	2.10	6.10	8.40
σ_v/u_*	1.72	1.73	1.88	14.5	7.01
σ_w/u_*	1.50	1.46	1.57	5.75	6.13
σ_T/T_*	0.77	0.79	0.93	0.21	0.22
σ_v/σ_u	0.86	0.82	0.90	2.38	0.83
σ_w/σ_u	0.75	0.69	0.75	0.94	0.73

those reported by other authors, where L is the Obukhov length. It seems that these large values depend mainly on small friction velocity for $z/L \geqq 5$. The standard deviations of temperature normalized by scaling temperature (T_*) for this stability range have small values equal to about 0.2 which are of the same order as presented by KONDO *et al.* (1978). But the data are not enough in number and more observations concerning these points are needed.

The normalized power spectra of wind velocity components and temperature are shown in Figs 8 and 9. It appears that all of these spectra follow the so called −5/3 low

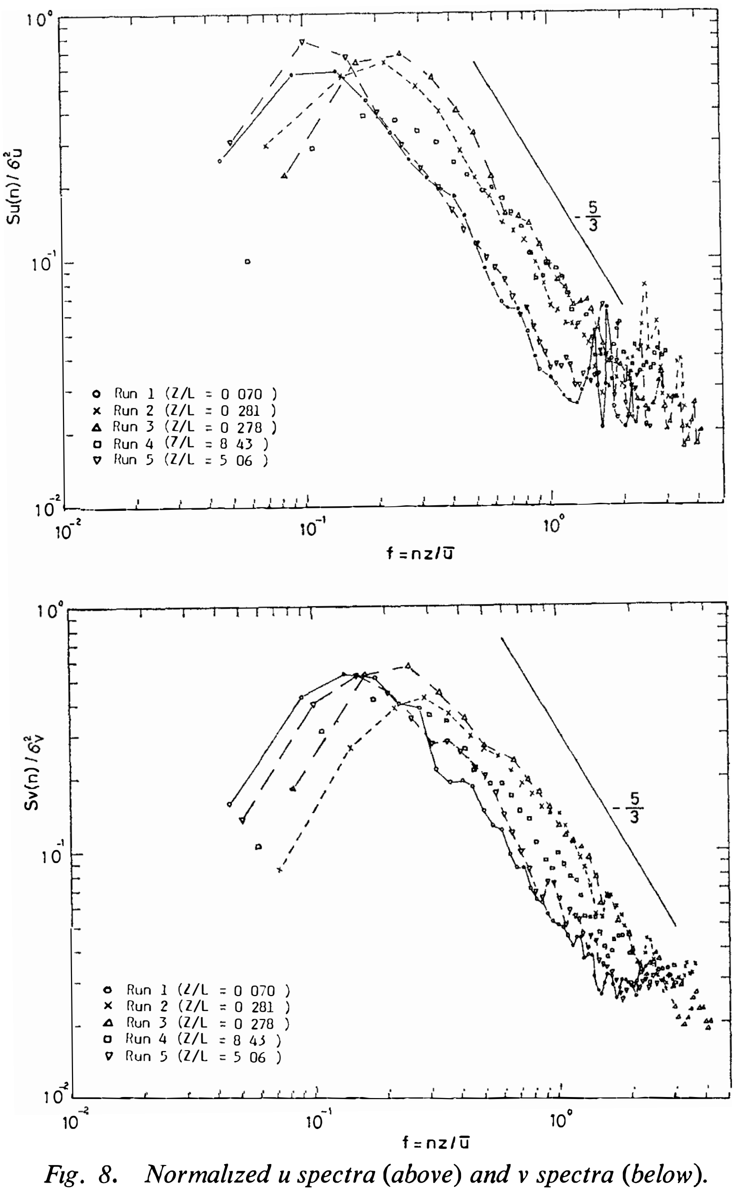

Fig. 8. Normalized u spectra (above) and v spectra (below).

in high frequency region. The cospectra of momentum flux and heat flux are shown in Figs. 10 and 11 respectively. It can be seen from Fig. 10 that the momentum with positive sign is transferred within some frequency ranges. This suggests that the momentum flux near the snow surface in the katabatic winds region may be smaller than the ordinary one. The distributions of heat flux cospectra shown in Fig. 11 are similar to those reported by many investigators.

It seems that the study on the vertical velocity skewness $\overline{W'^3}/\sigma_w{}^3$ in stable conditions has not been made fully (CHIBA, 1978). The skewness is the lowest order odd moment nondimensionalized (LUMLEY and PANOFSKY, 1964). It is zero when the density is symmetric and not zero for the skewed density function. It can be seen from Fig.

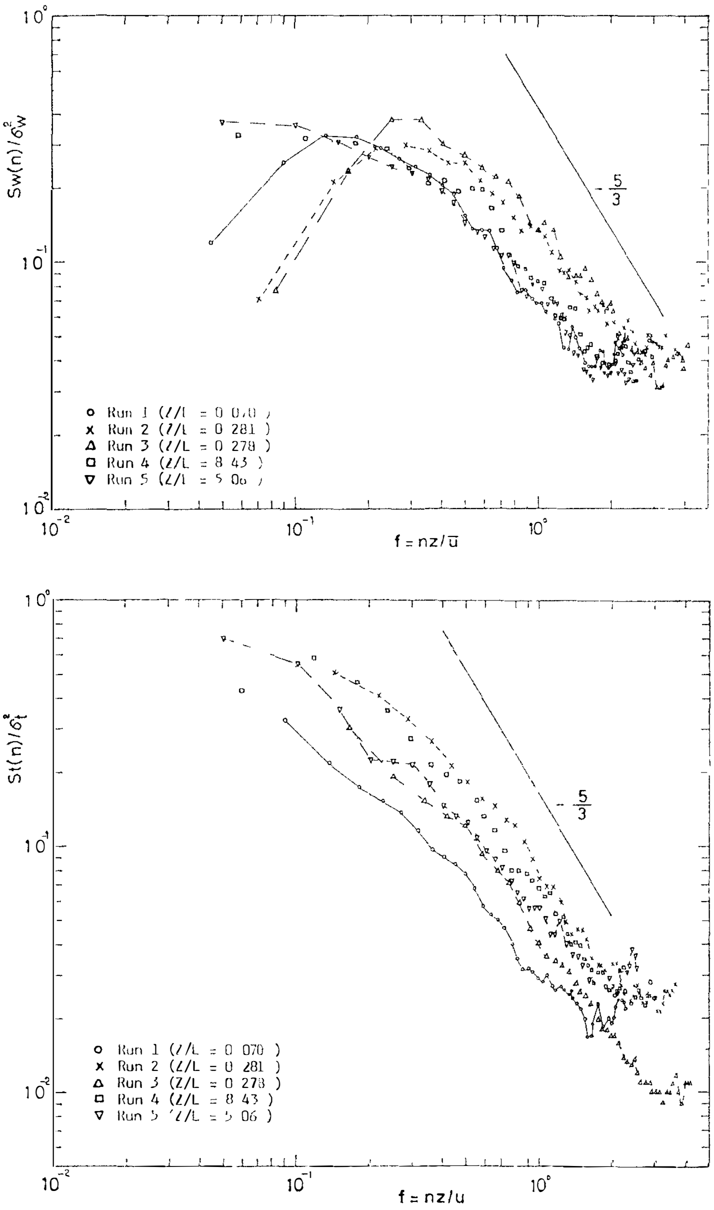

Fig 9. Normalized w spectra (above) and temperature spectra (below)

12 that the vertical velocity skewness obtained from the observations at Mizuho Station is about -0.1 and independent of stability (z/L). It appears that the probability density distributions of the vertical velocity fluctuations in katabatic winds are skew to the region smaller than the mean values.

3.4. Observed temperature oscillations

Fig. 13 shows the example of temperature oscillations observed by the five thermometers installed on a 10 m high mast in the winter of 1972. Surface meteorological conditions in these occurrences were as follows: the amount of cloud was 0/10–2/10, air

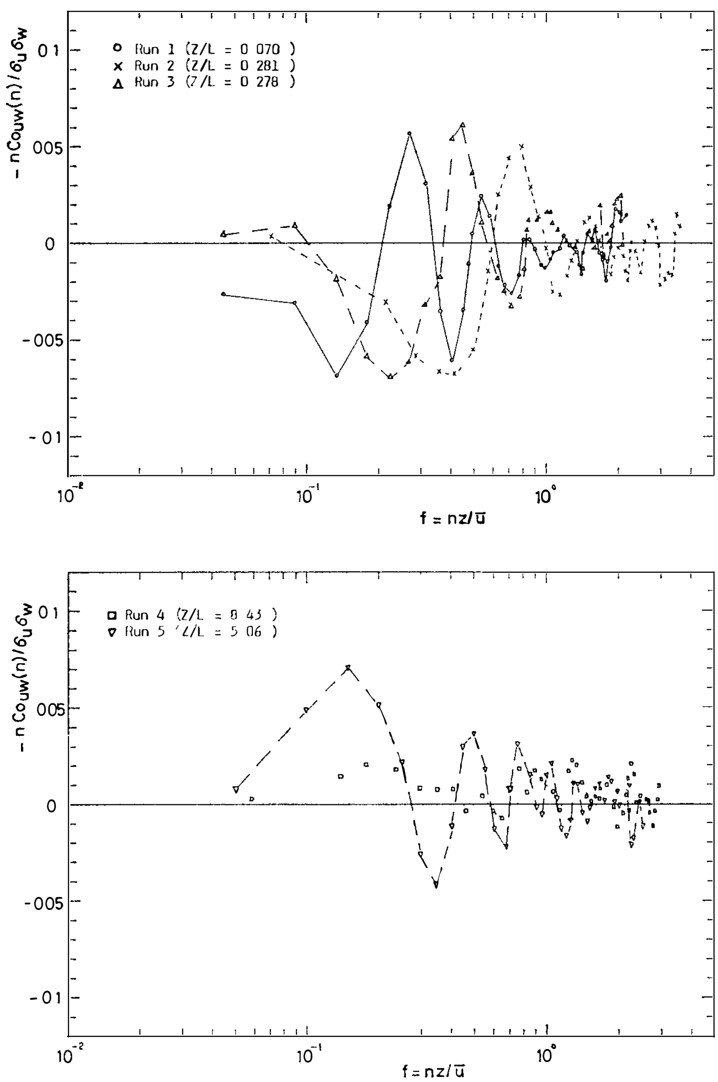

Fig 10. Normalized cospectra between u and w.

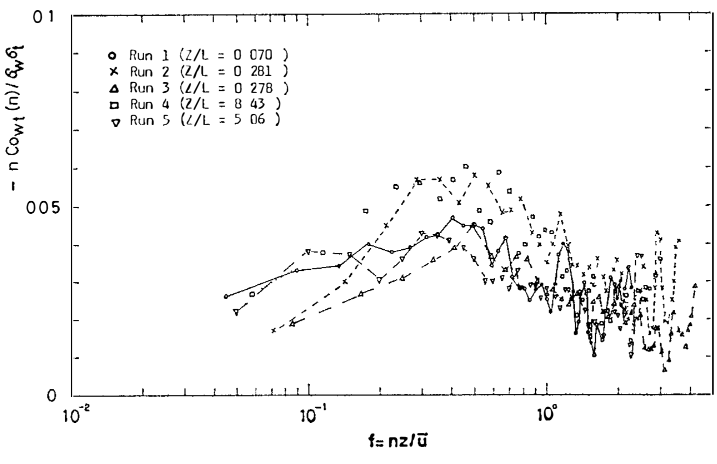

Fig 11. Normalized cospectra between w and temperature.

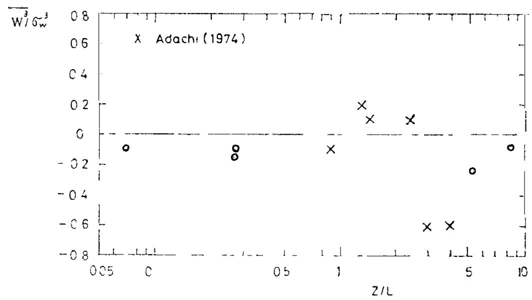

Fig 12. The vertical velocity skewness versus stability

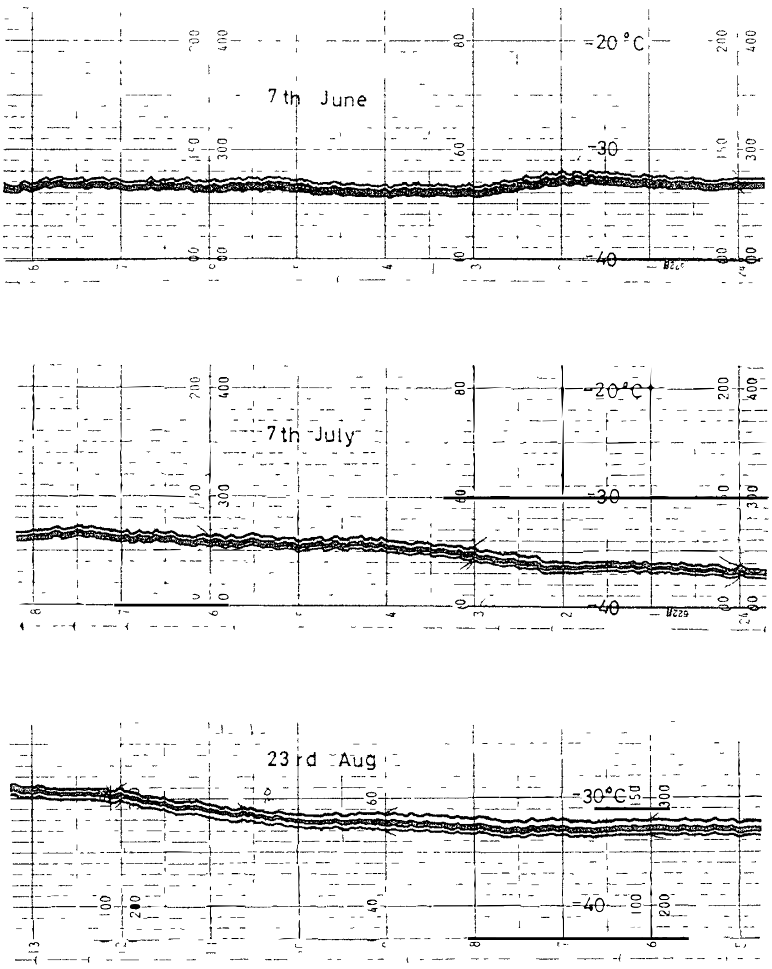

Fig 13 The temperature oscillations observed at Mizuho Station, 1972

temperature was higher by 5–7°C than monthly mean values, wind speed was 10–12 m/s and wind directions were E–ESE (YAMADA *et al*, 1974) Fig 14 shows the temperature profiles in these occurrences obtained from the radio-sonde data at Syowa Station It can be seen from Fig 14 that an inversion layer or a stable layer appeared at the altitude which was about as high as Mizuho Station (2230 m)

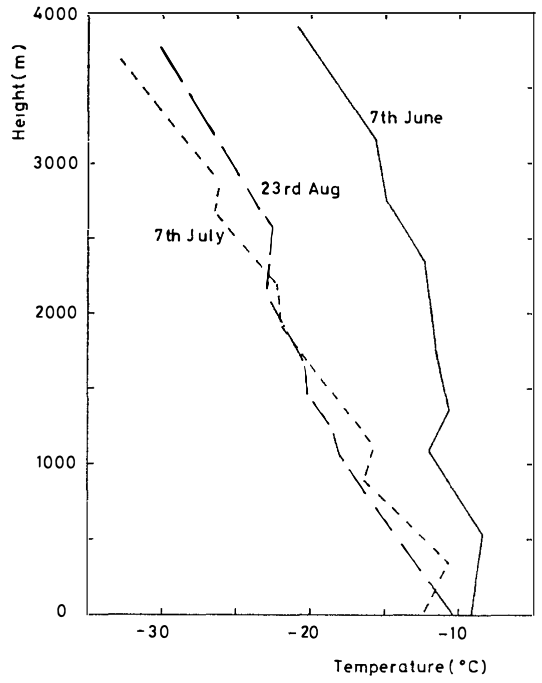

Fig. 14. Temperature profiles observed at Syowa Station on the days when the temperature oscillations were observed at Mizuho Station.

It can be seen from Fig. 13 that the period of oscillations is about 5–15 min and their frequency is comparable to the frequency of Brunt-Väisalä for atmospheric internal wave motions. STEWART (1969) suggested that atmospheric wave motions will frequently be mixed with turbulence in stable stratifications. More precise observations for internal wave motions may be needed for the study on the atmospheric surface layer in Antarctica and there may be many chances of observation for this phenomenon in Antarctica.

Acknowledgments

The author would like to express his hearty thanks to Prof. C. MAGONO, Hokkaido University for recommending him to participate in the 13th Japanese Antarctic Research Expedition. And the author expresses his sincere gratitude to Dr. S. KAWAGUCHI, the leader of wintering party of the 13th Japanese Antarctic Research Expedition and to the members of the expedition for their kind support in the field work at Mizuho Station.

References

ADACHI, T. (1973). Nankyoku Syowa kiti ni okeru ranryû kansoku (I) (Observation of atomspheric turbulence at Syowa Station in Antarctica (I)). Nankyoku Shiryô (Antarct. Rec.), **47**, 62–76.

CHIBA, O. (1978): Stability dependence of the vertical wind velocity skewness in the atmospheric surface layer. J. Meteorol. Soc. Jpn, **56**, 140–142.

DARLYMPLE, P C, LETTAU, H H and WOLLASTON, S H (1966) South Pole micrometeorology program. data analysis Studies in Antarctic Meteorology, ed by M. J RUBIN, Washington, Am Geophys Union, 13–53. (Antarct Res Ser., **9**)

KONDO, J, KANECHICA, O and YASUDA. N (1978): Heat and momentum transfer under strong stability in the atmospheric surface layer J Atmos Sci, **28**, 1012–1021

LUMLEY, J L and PANOFSKY, H A (1964) The Structure of Atmospheric Turbulence New York, Interscience, 239p

MAKI, T (1972) Nankyoku no kaihyô-jô deno antei jôtai-ka ni okeru secchi kisô no kansoku (The observation of the atmospheric surface layer in stable stratification on the sea ice in Antarctica) Tenki, **19**, 415–421

McVEHIL, G E (1964) Wind and temperature profile near the ground in stable stratification Q J R Meteorol Soc, **90**, 136–146

NAKAWO, M (1975) Variation of surface micro-relief of snow cover at Mizuho Camp in 1971–1972 JARE Data Rep, **27** (Glaciol), 84–105

SASAKI, H (1974). Higashi-Nankyoku Mizuho Kansoku kyoten ni okeru chijô kishô kansoku (Surface meteorological observations at Mizuho Camp, East Antarctica) Nankyoku Shiryô (Antarct Rec), **50**, 21–28

STEWART, R W. (1969). Turbulence and waves in stratified atmosphere Radio Sci, **4**, 1269–1278

YAMADA, T, SASAKI, H and KAWAGUCHI, S (1974). Meteorological data at Mizuho Camp, Antarctica in 1971–1973 JARE Data Rep, **25**, 85p

(*Received March 13, 1979*)