COMPARISON OF THE AIR LAYER NEAR THE SURFACE AT MIZUHO STATION WITH THAT AT OTHER SITES IN ANTARCTICA

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Abstract: The micrometeorological data obtained on a 30 m tower at Mizuho Station in 1979 are analyzed and compared with the results of analysis of similar data obtained at various sites in Antarctica. Characteristics in the sloped katabatic wind area are obtained. The following statistical characteristics are derived for Mizuho Station. (1) Strong constancy of wind direction. (2) Strong wind speed. (3) Low percentage of the strong stable case in the 0–16 m and 0–30 m air layer. (4) In very stable cases, air temperature gradient between 16 and 30 m increases more than in the 0–16 m layer. (1) and (2) can be explained by the large slope inclination within the stations on the ice sheet. (3) is due to the vertical mixing by the strong wind. (4) seems to be related to the planetary boundary thickness which is said to become shallow in the case of a stable air layer on an inclined surface.

1. Introduction

The energy budget of the atmosphere above the Antarctic plays an important part in the formation of climate. Antarctica is the heat sink in the system most of the year. This is due to the radiative heat loss due to fairly constant terrestrial radiation, and the small amount of absorbed short wave radiation which occurs as a result of the high albedo of the snow surface. The net radiation at the surface is negative, except in a short period in the summer season (YAMANOUCHI *et al.*, 1981). In order to compensate for the loss, heat is supplied to the surface, mainly in the form of sensible heat from the atmosphere. Therefore heat transport near and at the surface is quite important for the heat budget at the snow surface in Antarctica.

In this paper, the characteristics of air layer near the snow surface at Mizuho Station will be compared with observational results obtained at different sites in Antarctica. Mizuho Station is located 250 km inland on a slope of 0.005. Other sites where observations have been taken are in the interior with less inclination, and in fast ice shelf regions where there is no inclination. The main purpose of this study is to clarify the difference in the characteristics of the air layer near the snow surface under different inclinations. Factors other than the inclination are not negligible. These include the general climate of each area, and surface features on the snow surface. However, these other factors do not have a strong effect on the surface boundary layer characteristics because the wind system on the ice sheet is considered to be determined mainly by the inversion strength and the inclination of the surface.

2. Data and Data Sources

The observation system at the 30 m tower at Mizuho Station is described in detail in MAE *et al.* (1981). The sensors were set at 7 levels, that is 0.5, 1, 2, 4, 8, 16 and 30 m. Air temperature, wind speed and wind direction were sampled every minute, and 30-min average values were calculated. These data are used in this paper. When data were missing or showed abnormal values within a 30-min period, this period was omitted from the data ensemble in this paper. In WADA *et al.* (1981) there is a list of data not exactly the same as the present data; that paper gives values at the exact hour. The data used here are 30-min average values. As for comparison, the results obtained at sites shown in the Table 1 will be used. Station name, position, elevation, inclination and the reference are listed. The sites where micrometeorological observations were made are listed in the upper part, and sites with only surface meteorological observations in the lower part of table. The positions of the sites are shown in Fig. 1. All of the micrometeorological observations were made on a tower or a pole, with different heights. The results obtained at each site can show the characteristics of the air layer up to that height. The highest was the 38 m tower at Norway Station. The lowest was the 10 m

Table 1. The site, position, height above sea level, surface condition and reference for stations and sites with micrometeorological observations and with only surface meteorological observations referred to in this paper.

		Site	Position	Height	Surface condition	Reference
Micrometeorological obs.	Interior	South Pole	90°00′S	2800 m	Ice sheet (inclination ≈0.0018)	DARLYMPLE *et al.*(1967)
		Plateau St.	79°15′S, 40°31′E	3625	Ice sheet (inclination<0.001)	LETTAU *et al.* (1977)
	Coastal area	Maudheim	71.1°S, 10.9°W	38	Ice shelf	LILJEQUIST (1957)
		Norway St.	70°30′S, 2°32′W	56	Ice shelf	VINJE (1969)
		Syowa St.	69°00′S, 39°35′E	15	Fast ice	MAKI (1972a, b)
		Little America V	78°18′S, 163°00′W	40	Ice shelf	HOINKES (1967)
	Slope area	Mizuho St.	70°42′S, 44°20′E	2230	Ice shelf (inclination ≈0.005)	
Surface meteorological obs.		Vostok	78.5°S, 106.9°E	3488		
		Pionerskaya	69.7°S, 95.5°E	2740		
		Charcot	69°30′S, 139°02′E	2400		
		Byrd	80.0°S, 120.0°W	1515		

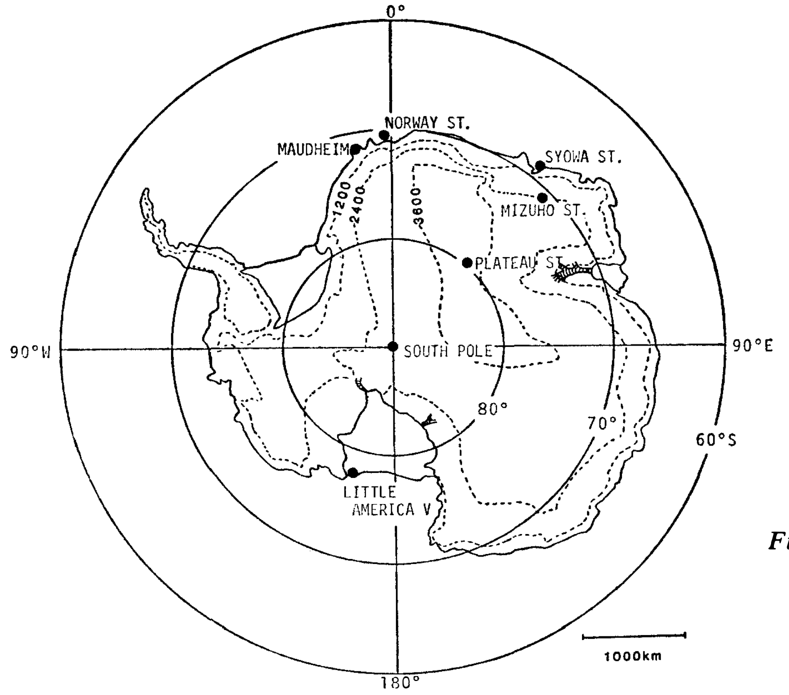

Fig. 1. Locations of sites where micrometeorological observations have been taken.

tower on the fast ice near Syowa Station. The researchers at each site have done analysis according to their own interests. Only at a few points are there the same type of analysis. The data from Mizuho Station were analyzed in the same manner as those of previous researchers for comparison.

3. Results

3.1. Surface wind direction and wind speed

The surface wind system above the ice sheet has been studied extensively. The

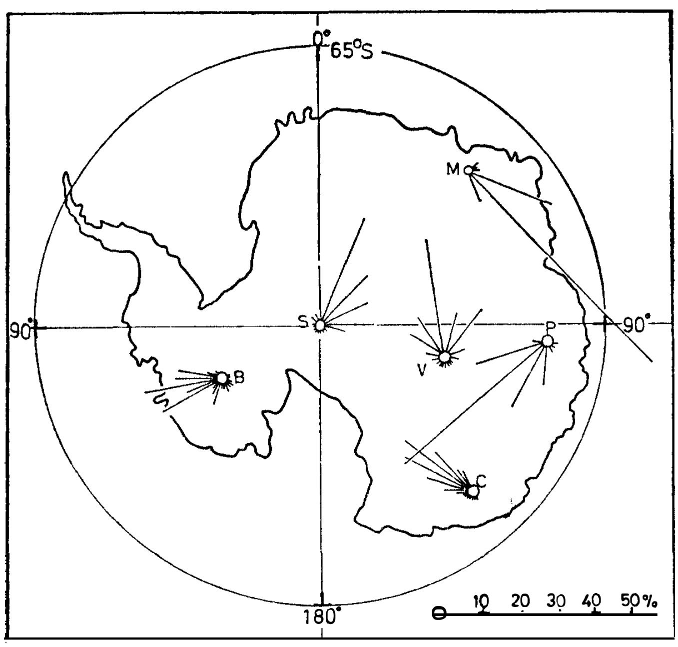

Fig. 2. Frequency distribution of wind direction at sites on the ice sheet for one year. The data shown in the figure are partly taken from WILSON (1968). B : Byrd, C : Charcot, M : Mizuho Station, P : Pionerskaya, S : South Pole, V : Vostok.

wind system in the cold interior (inclination less than 0.002) can be explained by the inversion wind theory (MAHRT and SCHWERDTFEGER, 1970) and the wind in coastal areas where the inclination of the surface is more than 0.01 by the katabatic wind theory (BALL, 1960). On the sea ice and ice shelf, if they are near the coast, they will have an effect on the wind system above the ice sheet, but they are conceived to be usually under the effect of the larger synoptic scale pressure system (MORITA, 1968).

In Fig. 2, the wind rose at the inland station for a year is shown. It must be noted that some have 16 directions and others have 32 directions. From this figure, it can be said that stations such as Charcot, Pionerskaya and Mizuho Station have a strong concentration in the wind direction. These sites are within the region with slope inclination of 0.002 to 0.005. Among them, Mizuho Station has the strongest concentration, 68% in the east direction.

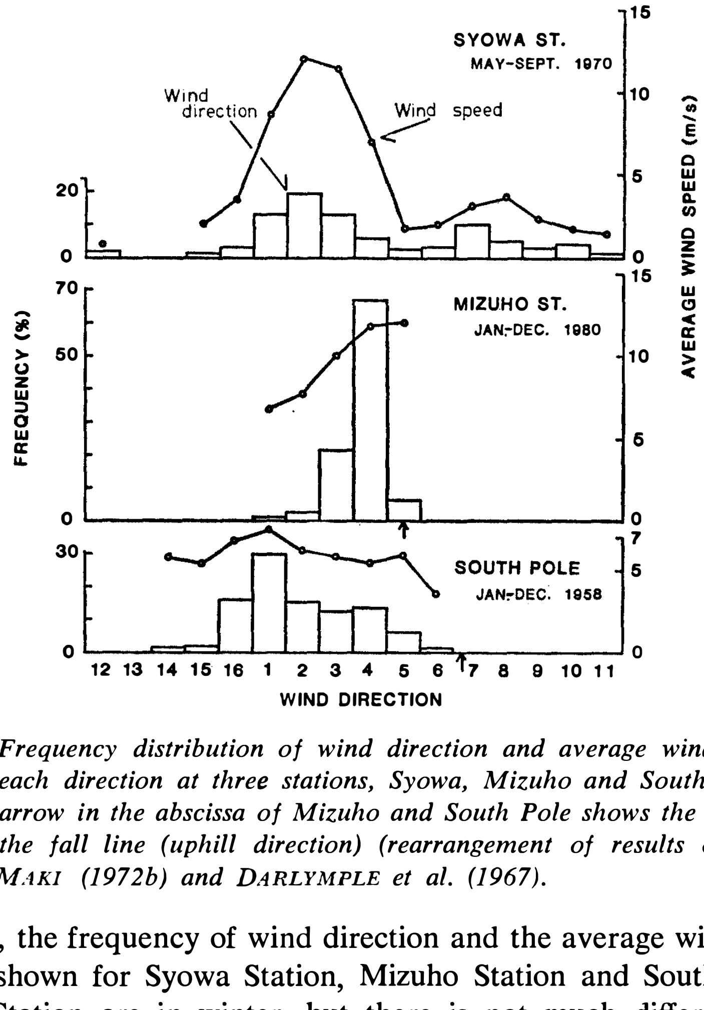

Fig. 3. Frequency distribution of wind direction and average wind speed for each direction at three stations, Syowa, Mizuho and South Pole. The arrow in the abscissa of Mizuho and South Pole shows the direction of the fall line (uphill direction) (rearrangement of results obtained by MAKI (1972b) and DARLYMPLE et al. (1967).

In Fig. 3, the frequency of wind direction and the average wind speed for each direction are shown for Syowa Station, Mizuho Station and South Pole. The data from Syowa Station are in winter, but there is not much difference in the other seasons. At Syowa Station, the direction is scattered over a wide range, but wind speed has one strong peak in the NE direction. The South Pole has a relatively strong concentration in the NNE direction, but wind speed does not show a strong peak. As the SE-SSE direction is the uphill direction at the South Pole, it seems that the NNE wind is a cross-slope wind. In comparison with these two stations, Mizuho Station has a very strong concentration in the east direction as noted before, and the wind speed is stronger as it approaches the direction of the fall line, which is 120°–130° looking uphill. This direction at Mizuho Station is ESE-SE, and the most frequent wind direction E is 30°–40°, counterclockwise from the direction of the fall line.

3.2. Stability of the air layer

The air temperature gradient can show the static stability of the air layer. Two examples for the coastal region and Mizuho Station are compared. No data on the frequency of the static stability for the interior region are available. The frequency distribution of air temperature gradient is shown in Fig. 4. The position

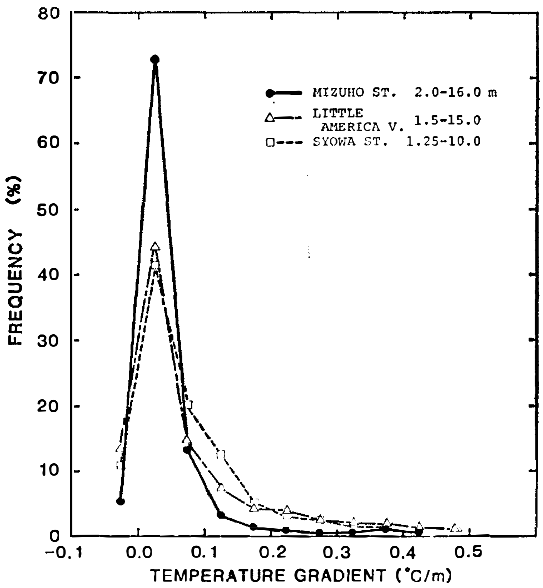

Fig. 4. Frequency of air temperature gradient at three stations, Mizuho, Little America V and Syowa Station (rearrangement of results of HOINKES *(1967) and* MAKI *(1972a)).*

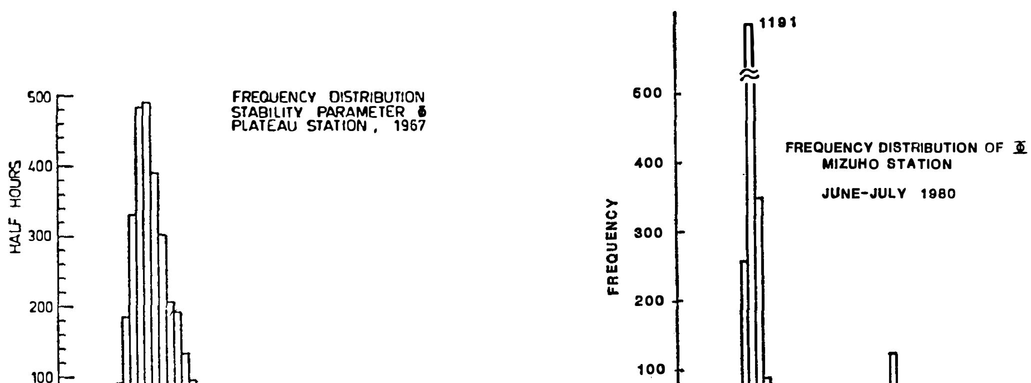

Fig. 5. Frequency of Φ at two stations, Mizuho and Plateau, in winter. At Mizuho Station, Φ >1 is classified into one category (after LETTAU *et al., 1977).*

of the maximum frequency is the same for all three sites at the lowest stability range of 0.0 to 0.5°C·m^{-1}. However, the percentage in this range is especially high at Mizuho Station. The frequency of more stable cases is low compared with the other two sites. It can be said that the static stability of the air layer up to 15 m is generally small for Mizuho Station in comparison with coastal regions.

The bulk stability of the air layer up to 32 m was found for data at Plateau Station. The value,

$$\Phi = \frac{\Delta T}{(\Delta \tilde{u})^2},$$

was taken for the stability parameter. This value is approximately proportional to the Richardson number of the air layer. In Fig. 5, a comparison of the frequency of Φ is given for Plateau Station and Mizuho Station for the winter period. $\tilde{u}$ is given in vector form at Plateau Station, for the air layer below 32 m forms a wind spiral. As for Mizuho Station, a wind spiral was not frequently seen, only when the air was very stable. Therefore, a scalar value was used for Mizuho Station. At Mizuho Station, Φ is concentrated quite strongly in the range between -0.05 and 0.10. As for Plateau Station, the peak is not so significant, and gradually decreases as Φ increases. Therefore, it can be said that at Mizuho Station in comparison with Plateau Station, the bulk stability up to 30 m is very low. If $\tilde{u}$ is given as a vector, Φ will be concentrated more in the lower values, and the contrast will be stronger between these two sites.

3.3. Air temperature profile

The average air temperature profiles for different stabilities are shown in Fig. 6. They are the data in the dark period. At Plateau Station, the temperature profiles are almost linear for all stability ranges. In comparison, Mizuho Station shows a different tendency. Case 1 shows a near-logarithmic profile. As stability increases,

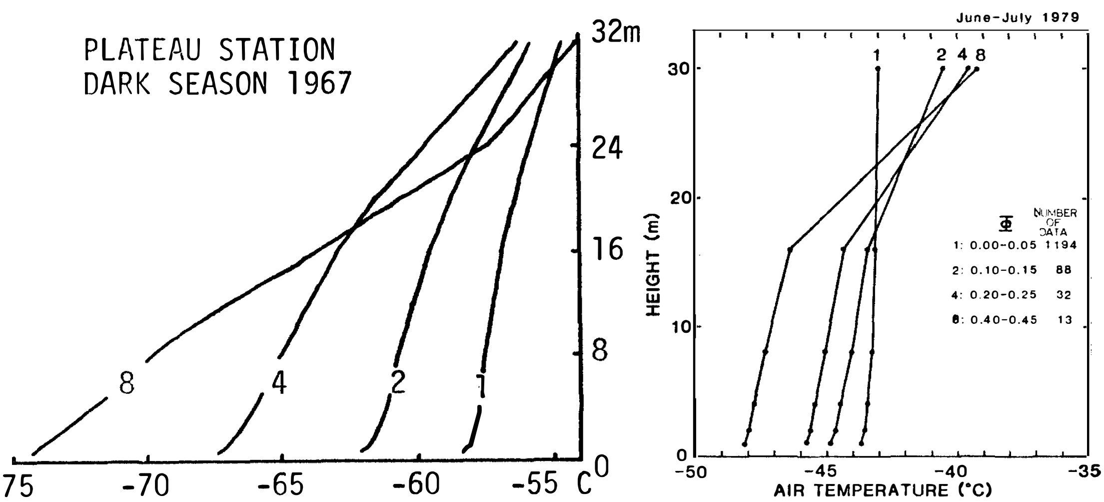

Fig. 6. Vertical temperature profile for different Φ values at Plateau Station and Mizuho Station. Numbers on the profiles show the interval of Φ indicated in the right graph (rearrangement of results obtained by LETTAU *et al., 1977).*

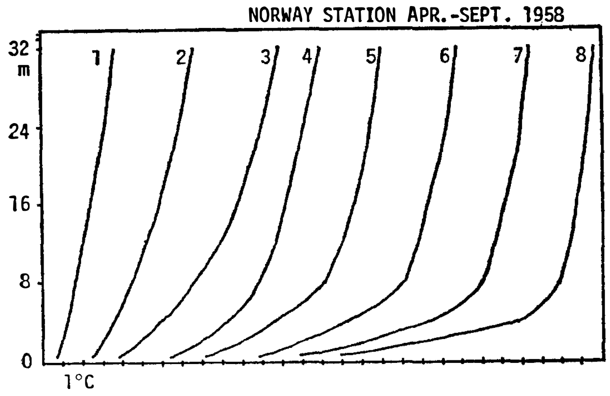

Fig. 7. Vertical temperature profile classified according to different stabilities of between one and four meters for the period of April–September 1958 at Norway Station. The number at the top shows the grade of stability. 1 is 0–0.2°C·m⁻¹, 2: 0.2–0.4, 3: 0.4–0.6, 4: 0.6–0.8, 5: 0.8–1.0, 6: 1.0–1.5, 7: 1.5–2.0 and 8: more than 2.0 (after VINJE, 1969).

the level 0 to 16 m becomes linear. Above that height (16–30 m), the temperature gradient is three or four times larger than the lower layer. Mizuho and Plateau show different tendencies for air temperature profile under similar stability.

At Norway Station, the vertical air temperature profile up to 37 m was classified according to the temperature gradient between 1 and 4 m, and is shown in Fig. 7. The temperature gradient at the lower levels changes while that at the higher levels remain almost unchanged. VINJE (1969) writes that as the temperature gradient of 1 to 4 m increases above 0.6 the temperature gradient at higher levels decreases. This is opposite to the result at Mizuho Station, but is a familiar tendency observed in the nighttime in level areas.

Mizuho Station seems to show a quite unique profile under strong stable condition, temperature gradient being small up to 16 m, but the gradient above 16 m becomes stronger as stability increases.

3.4. Relation between temperature gradient and wind speed

Usually, the air temperature gradient becomes large when wind speed is low, if other thermal components such as net radiation are the same. Figure 8 shows the result for the air layer up to 10 m at Mizuho Station in June. The upper limit of this relation is shown by a solid line. When the wind speed is strong, only a weak temperature gradient can exist. But below 10 $m \cdot s^{-1}$ a strong gradient can occur. Figure 9a shows the result for the case of lower level up to 10 m. At Mizuho Station and Maudheim strong increase in the curve occurs when wind speed is less than 9 $m \cdot s^{-1}$. Furthermore, no temperature gradient more than 0.7 $°C \cdot m^{-1}$ occurs at Mizuho Station. As for Syowa Station, the tendency is different and the increase of temperature gradient occurs at only weaker winds. The difference at Syowa Station probably occurs due to the limited number of samples in very stable situation. Figure 9b shows the result for the air layer up to more than 30 m. In this case increase in temperature gradient occurs at about the same wind speed of less than 12 $m \cdot s^{-1}$. However, at Mizuho Station a stronger temperature gradient can exist at the same wind speed.

Maudheim and Norway Station can be classified as flat surfaces. From the above results, at Mizuho Station, which is situated on an inclined slope, the air layer up to 10 m has the same temperature gradient-wind speed relation as on flat

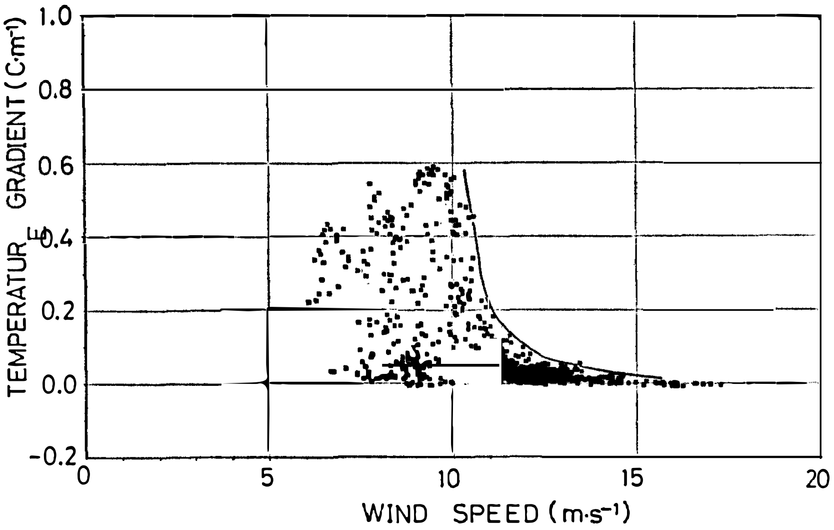

Fig. 8. Relation between wind speed at 8 m and temperature gradient between 2 and 30 m for Mizuho Station in July 1979. The upper limit of the relation is marked by a solid line.

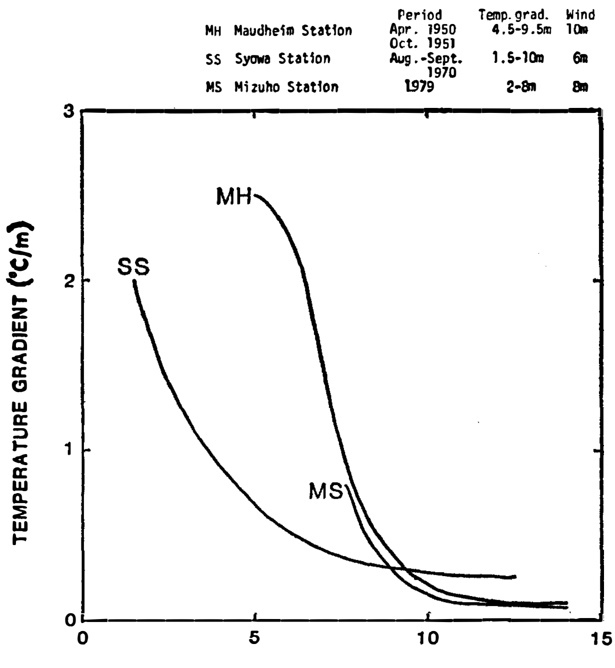

Fig. 9a. The comparison of the upper limit line shown in Fig. 8 for air layer up to 10 m at Mizuho Station, Syowa Station and Maudheim for a specified period (after MAKI, 1972a and LILJEQUIST, 1957).

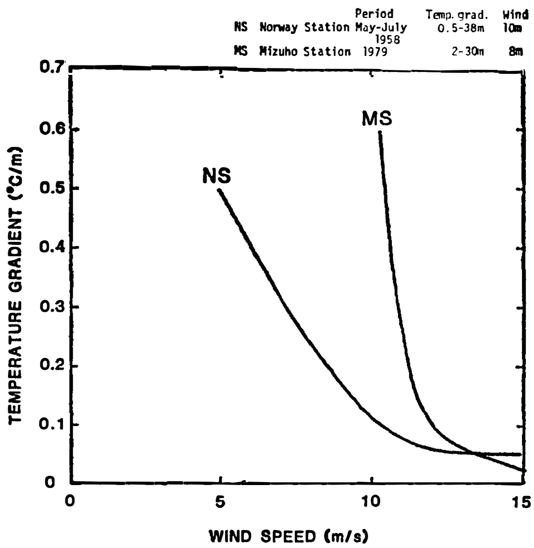

Fig. 9b. Same as Fig. 9a, but for air layer up to more than 30 m at Mizuho Station and Norway Station in the specified period (after VINJE, 1969).

surface, but when the study is extended up to the 30 m level, a stronger temperature gradient than over a flat surface can occur at the same wind speed. This difference between low and high air layers is related to the results shown in Figs. 6 and 7.

At Mizuho Station the temperature gradient at higher level increases more than the lower level when the stability of the air layer increases. The reason for this tendency is probably as follows. Over an inclined surface, the wind speed is partly determined by the temperature gradient, as the katabatic force is related to this. When the air layer is selected to be high enough to include the upper warm air layer above the cooled air layer, the maximum wind speed under the same temperature gradient will be stronger in the case of an inclined site (Mizuho Station) than on a flat site where no katabatic force will act. In the present case, it may be said that 30 m was high enough to include the upper warm air layer, but 10 m was so low that it was within the katabatic wind layer. If the air layer is restricted to only the katabatic wind layer, the air temperature profile is determined primarily by the wind speed as in the case of a flat surface, and as a result the air temperature and wind speed relation was the same at Mizuho Station and Maudheim.

4. Discussion

Some characteristics of the air layer near the surface have been reported in this paper. The main characteristics of the lowest air layer at Mizuho Station are as follows:

(1) Constancy of wind direction,

(2) Strong wind speed,

(3) Low frequency of occurrence of the strong stable case in the 0–16 and 0–30 m air layers,

(4) When stability increases in the 0–30 m air layer, the air temperature gradient in the 0–16 m layer does not increase much, while that in the 16–30 m does.

Among the above characteristics, (1) and (2) are well known. These can be explained from the cause of the katabatic wind. The slope of inclination at Mizuho Station was the largest among the various stations investigated in the present paper, which means that the katabatic force is the strongest of them under same inversion strength. If so, the wind speed will be strong and the concentration of wind direction will also be strong.

The latter, (3) and (4), have not been discussed much before. (3) is primarily due to the strong wind speed at Mizuho Station, which is 11 $m\cdot s^{-1}$ on an annual average. (4) is characteristic of the stable cases which is very rare at Mizuho Station. This is a quite interesting result. In a recent study of the planetary boundary layer (PBL) (GARRATT, 1982), it has been found that on an inclined surface the planetary boundary layer (PBL) becomes shallow, which means that h/L (h is the height of the PBL, and L is the Monin-Obukhov length of the air layer near the surface) becomes small. Furthermore, the temperature gradient at the height h becomes larger than the lower layers. The situation of (4) seems to be related to this. The tendency at Mizuho Station can be explained as follows. When the air layer becomes stable, the height of the PBL decreases and in case 8 in Fig. 6, the top of the PBL has come down to the 16–30 m level. When the air layer becomes more stable the height of PBL might decrease to a lower level. At the top of the

PBL the temperature gradient is usually large, as shown in Fig. 6.

At Plateau Station, the surface boundary layer defined by the constancy of the stress direction is said to be 1–10 m (KUHN *et al.*, 1975). The height determined by this definition is approximately equal to the PBL noted above. The main part of the profile at Plateau is not the surface boundary layer but the region above that. An inversion layer exists above the top of the PBL. In this region a wind spiral is formed.

In order to explain quantitatively the difference shown in the present paper, parameters such as the friction layer height and the height of the PBL should be obtained. For this purpose, original data have to be analyzed.

The present preliminary comparison of the boundary layer shows that the lowest air layer at Mizuho Station has different properties from other sites in Antarctica. The difference seems to arise from the slope. The character of the predominant wind system, that is the katabatic wind system, should be analyzed in more detail before further discussion of the difference of the surface air layer can be given.

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