THE CLIMATE OF THE INTERIOR OF MIZUHO PLATEAU

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Abstract: The scheme and results of the mobile meteorological observation on Mizuho Plateau, East Antarctica are reported. The surface wind and temperature at 4 temporary stations on the traverse route were compared with those of Mizuho Station during the same period. Each station is classified under the category of cold katabatic or cold interior climate though the transitional status is revealed for the latter. Evident decrease of surface wind towards inland is due to the decrease in the surface inclination. The increase in the temperature lapse rate towards inland resulting from the lowering of minimum temperatures is caused by the weakness of the surface wind when the minimum temperature is present as well as by the light breeze of the inland. It is also caused by the decrease of the effect of synoptic disturbance. The surface prevailing wind at V142 (upper end of the plateau) is supposed to be originated from further interior. The small inversion and the locally produced northerly wind was present when the general wind was blocked at V142. The cooling of the atmosphere over V142 is commenced either from the surface or from the height of lower troposhere. The development of the surface inversion is restrained by the successive warm advection from the upper atmosphere. Though the upper air circulation over V142 is not alike over the coast, the warming occurs simultaneously on an occasion of remarkable warm advection.

1. Introduction

The Japanese Antarctic Research Expedition (JARE) has been making meteorological observation at Mizuho Station (70°42′S, 44°20′E, 2230 m a.s.l.), East Antarctica since 1976. Many papers on the surface climatology of Mizuho Plateau were published and the cold katabatic climate was commonly emphasized. However, few works were done on the cold interior climate of this plateau.

As part of the POLEX-South program, meteorological investigation in the cold interior by mobile observation was made by JARE-22 in 1981. The traverse was made from Mizuho Station to inland along the flow line of the prevailing katabatic

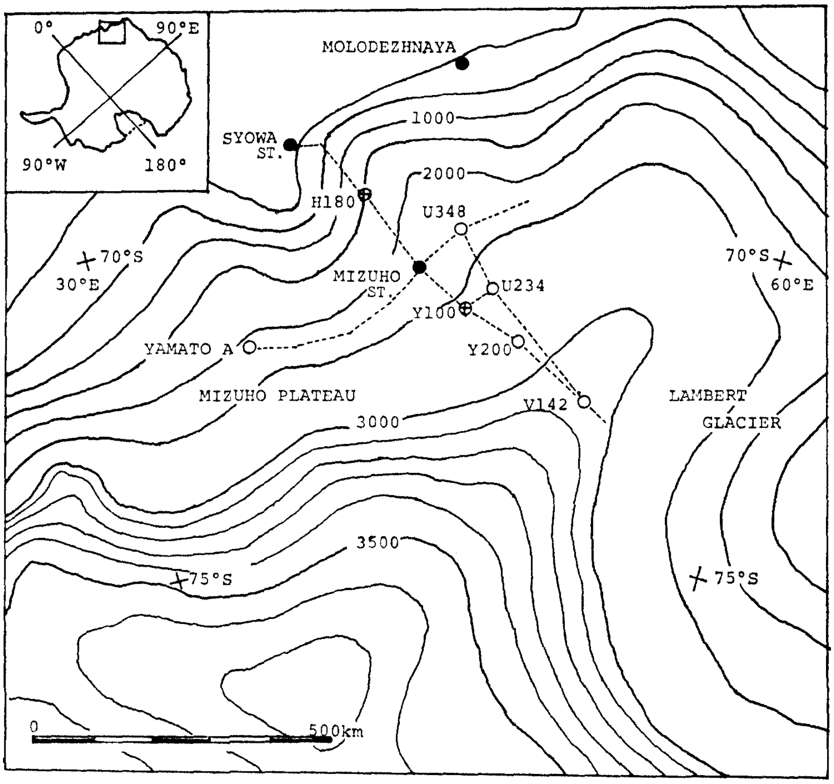

Fig. 1. Mizuho Plateau and stations: Black circle=permanent station; open circle=mobile station; cross circle=automatic weather station; broken line=traverse route. Contour intervals are 500 m and 100 m below and above 3000 m respectively.

Table 1. Temporal meteorological stations of JARE-22.

Station	Altitude (m)	Surface inclination (m/km)	Surface flow-line (°)	Meteorological observations		
				Duration	Sonde	Pi-bal
Y100	2584	3.0	325	Sep. 29–Oct. 4	4	12
Y200	2840	2.8	315	Oct. 7–8	3	12
V142	3076	1.0	40	Jan. 30–Feb. 9	—	36
				Oct. 14–27	32	60
U234	2644	2.6	305	Nov. 6–12	5	20
U348	2403	3.3	315	Nov. 15–18	—	20
Yamato A	2217	7.8	325	Dec. 13–28	18	40
Mizuho Station	2230	3.9	310			

wind. The traverse route and the stations are shown in Fig. 1 and remarks of each station are listed in Table 1. A pre-survey and surface meteorological observation were made at V142 (Table 1) during 11 days in February. The main observation including upper air sounding was made from October 13 to 28 at the same place by use of mobile meteorological station. Several days temporary observations were made on the way to and from V142. Observation was also made in Meteorite Ice Filed from December 13 to January 4 of the next year. The observational scheme widely ranged from surface boundary layer to upper troposphere as is mentioned in the following section. The surface wind and temperature data compared with those of

Mizuho Station and the upper data with those of Syowa Station are discussed in this paper. The climate of the interior of Mizuho Plateau is outlined through this work.

2. Mobile Observation and Data Acquisition System

It is a hard work to install the meteorological instruments in the cold and gusty environment of Antarctica. The mobile meteorological station including a 12-m tower was designed for prompt and easy establishment or removal of a temporary station. The tower was shortened by half and laid on a sledge. It is erected and stretched up to 12 m by hand winch at an observation site and supported by wire stays before the mouting of sensors. Within half an hour the tower is established if four men are available for the work. Sensors for near-surface observation are mounted on a 4-m pole erected on undisturbed surface. Teflon-coated cables were used from the sensors to the junction box beside the mobile station.

The mobile station is made of heat-shielded square housing of 4×2×2 m in size with four sledge runners at the base. Each runner is independently suspended to avoid large shock when the runner crossed over sastrugi. The room instruments, *i.e.* amplifiers and recorders, are fixed on metal plates and mounted on shelves on the wall of the station. Bumping absorbing rubber is used for the bolt connection of the instrument-bearing plates and shelves. The electric power is supplied by a 3-kVA generator laid on the floor of the station and the room air is warmed by radiated heat from diesel engine. As a result the room temperature was kept +10°～+20°C when outside atmosphere was below −60°C.

Boundary layer observation and upper-air sounding are two main schemes of the mobile observation. The fully-equipped measurement was made at V142 and in Meteorite Ice Field. The observation scheme is illustrated in Fig. 2. Boundary layer measurement was mainly made through the turbulent measurement by

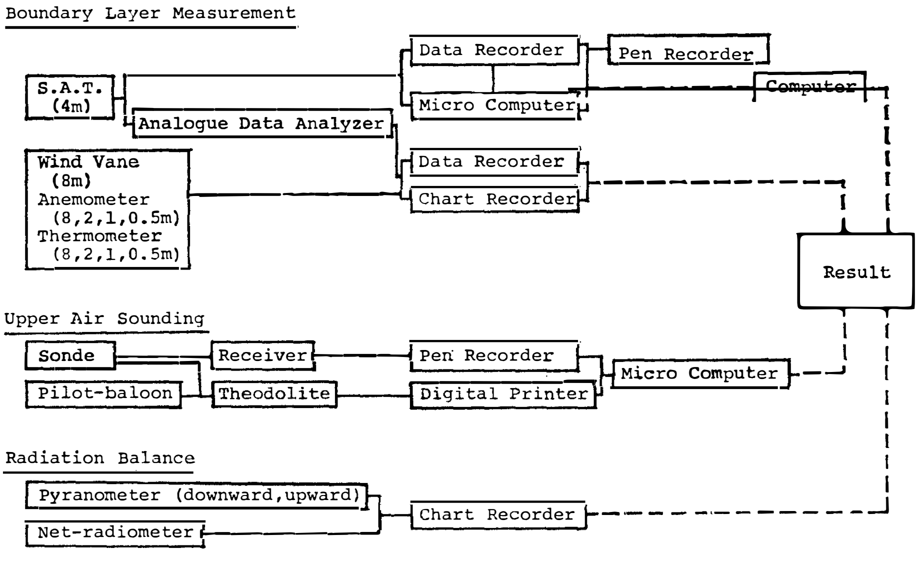

Fig. 2. Flow chart of the mobile meteorological observation. Broken line shows laboratory work.

ultra-sonic anemothermometer (SAT, Kaijo DAT-300). Signals from SAT are sampled by digital data recorder (TEAC DR-200) or microcomputer (TEAC PS-80) with sampling frequency of 1–10 Hz. The data of cassette tape were D/A monitored by microcomputer to check the recording level after the recording was completed. The mean and variance of three components of wind velocity and covariances ($\overline{W'U'}$, $\overline{W'T'}$) from SAT signals are obtained through low-pass filter and analogue multiplier. SAT was mounted on top of a 4-m pole where it is highest to check the leveling and lowest to avoid drifting snow. Wind and temperature profile was measured at 5 heights (8, 4, 2, 1 and 0.5 m) and wind direction was measured at 8 m. The instruments employed are the same as those installed at the 30-m tower of Mizhuo Station (Mae *et al.*, 1981). Signals were sampled by data recorder with 0.1 Hz and traced by chart recorder. At another station, boundary layer measurement by SAT alone and upper air sounding were made as shown in Table 1.

Upper air temperature from surface up to 3000 m was measured by radiosounding. The radiosonde used is the same (Meisei JWA-75TWS) as that used by JARE-21 (Kobayashi *et al.*, 1982) except the modification of pressure range available for higher altitude. 32 soundings at V142, 28 in Meteorite Ice Field and 16 at another station were successful. The position of sonde was measured by theodolite (Tamaya digital-theodolite) and every 10-seconds' azimuth and altitude were printed out. More than 100 ascents of pilot baloon were also followed by the same way at V142. Some of the baloons could be followed at altitudes above 10 km from the surface.

3. Surface Climatology of Cold Interior and Cold Katabatic Region

3.1. *Climate of V142*

The annual mean temperature estimated from firn temperature of 10 m depth at V142 is −48°C. The mean annual temperature at Mizuho Station during the last 5 years is −32.0°C. The estimated temperature lapse rate between these two stations is 1.9°C/100 m. The firn temperature is 1–2°C lower than the air temperature when inversion is present (Dalrymple, 1966). However, this lapse rate is very close to the value of Antarctic interior above 3000 m (Satow, 1978) allowing the effect of inversion. Hourly values of temperature, wind speed and direction of the two stations from October 14 to 27, 1981 are shown in Fig. 3. Large southward deviation of wind direction at V142 is due to the directional difference in surface inclination (Table 1). Wind direction at V142 is persistent and wind speed has regular daily variation except from the 21st to the 23rd. This is the representative pattern of the Antarctic katabatic wind. However, the direction of the wind is opposite to the surface flow line. The prevailing wind at V142 is from 140°–180°, but surrounding surface topography is below horizon in 10°–240°; namely, it is an upslope wind. V142 seems to be located at the center of a large ridge between Mizuho Plateau and the Lambert Glacier drainage as shown in the contour map of Fig. 1, which was reproduced from the radio echo sounding map (Levanon *et al.*, 1977). However, the barometric altimetry along V route (Satow *et al.*, 1983) confirmed that the station is located on the slope down to the Lambert Glacier towards a SE direction. According to the definition, the prevailing wind at V142 cannot be classified as 'katabatic wind'. It is

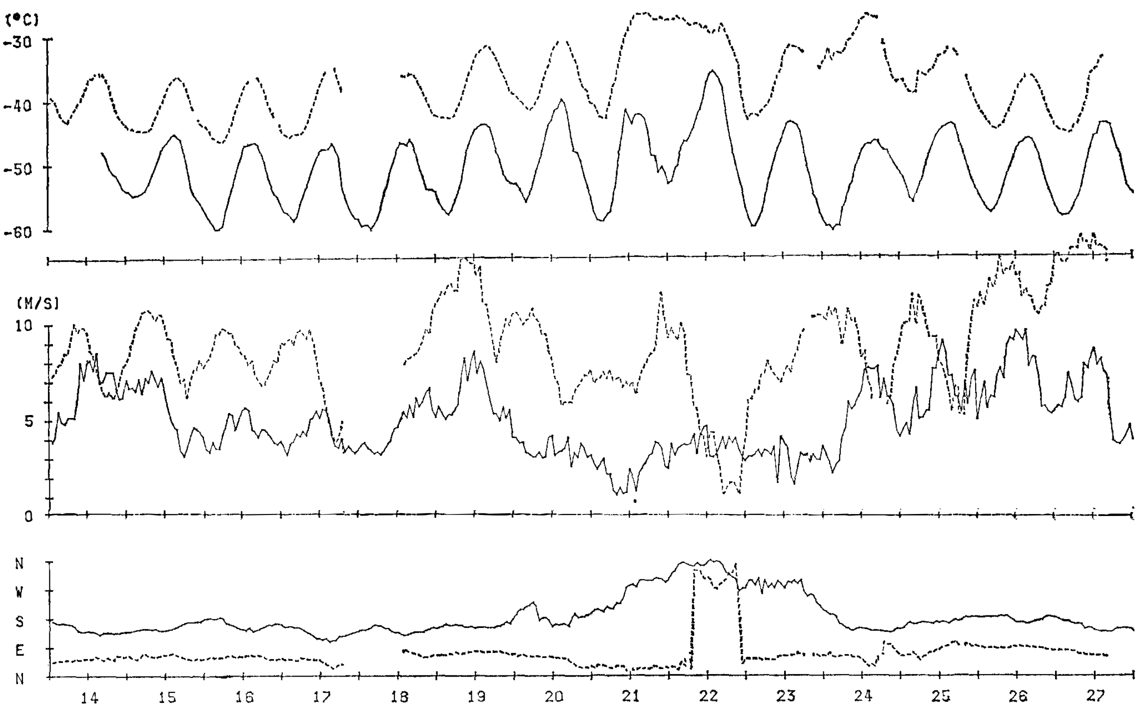

Fig. 3. Temperature (above), wind speed (middle) and wind direction (below) at V142 (solid line) and Mizuho Station (broken line) from October 14 to 27.

adequate to be called 'fall wind' which means the outflow of cold air of further interior with higher elevation. The climate of V142 can be classified as cold interior according to the criteria of DALRYMPLE (1966) considering the relatively small wind speed and estimated annual mean temperature. The increase in daily range of temperature at V142 is due to the remarkable lowering of minimum temperatures compared with Mizuho Station. Several acquainted reasons are considered for the lowered minima at V142. One of the reasons is that the wind speed decreases when the temperature minimum is present. This is accounted for by the fact that the phase lag between the minimum temperature and the maximum wind speed is different between the two stations except on the days of 21 and 22. Maximum wind speed at V142 is delayed for several hours than at Mizuho. This is reasonable if the difference in the time lag is caused by that of averaged terrain inclination (Table 1) as pointed out by SAKAMOTO and ISHIDA (1973). The most striking feature in the time change of the meteorological element in Fig. 3 is the pattern from the 21st to 22nd. The wind changed to northerly at both stations under the effect of synoptic disturbance. Mizuho was cloudy with snowfall during the period, but V142 was only overcast by cirrostratus. The radiation cooling does not seem to have taken place due to the dense cloud, thence daily temperature change disappeared at Mizuho whereas it was present at V142. As the result, the locally produced katabatic wind speed at V142 exceeded the wind speed at Mizuho where katabatic wind did not occur. This is one of the remarkable examples showing the effect of synoptic disturbance on Antarctic interior. This may also be one of the reasons for the difference in the lapse rate of mean temperature between Mizuho and V142.

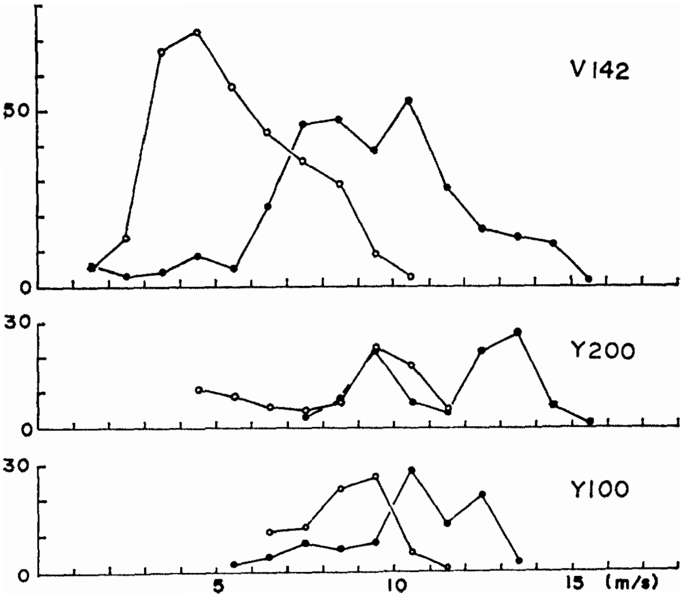

Fig. 4. Frequency distribution (numbers) of hourly wind speed at each mobile station (open circle) and Mizuho Station (black circle) during the same period.

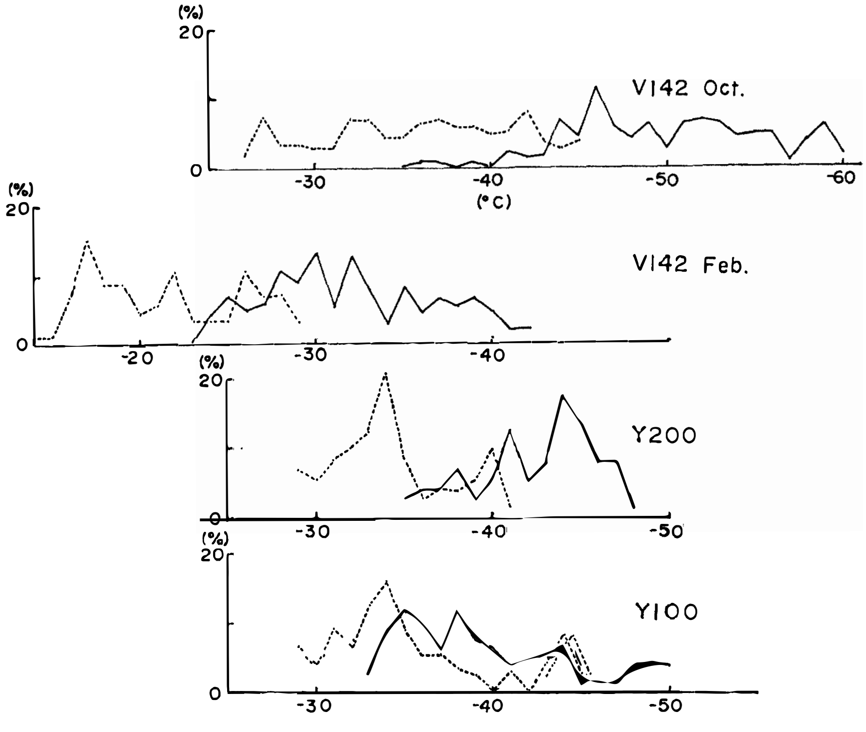

Fig. 5. Frequency distribution (percentage) of temperature at each mobile station (solid line) and Mizuho Station (broken line) during the same period.

The climatic difference between the two stations is revealed more evidently by the frequency distribution of wind and temperature during the same period of observation. Frequency distributions of wind speed at V142 and Mizuho are compared in Fig. 4. The decrease of wind speed at V142 is evident. The maximum frequency at Mizuho is in the class of 10–11 m/s though at V142 it rarely exceeds 10 m/s.

The distribution pattern is also different between the two stations. Mizuho has normal distribution without distinct mode, whereas the distribution at V142 is of the gamma type with a mode in the class of 4–5 m/s. Since the distribution pattern of Mizuho in Fig. 4 resembled the annual mean pattern shown by ISHIKAWA and KOBAYASHI (1982), the mean wind speed at V142 during the observation can be regarded as an annual mean. The assumed mean annual wind speed of 5–6 m/s at V142 is also suitable for the criterion of cold interior climate (DALRYMPLE, 1966). Percentage frequency distribution of temperature is shown in Fig. 5. The temperature at V142 in October are distributed 1.4 times larger in range than at Mizuho. The ratio in February is 1.3. The temperature lapse rate between the two stations estimated from the differences in the extreme of the maximum (left end of the distribution) is 1.1°C/100 m in both October and February. The excess from the dry adiabatic lapse rate suggests that the air temperature at V142 is under non-adiabatic effect all the time. The difference in minimum temperature estimated in the same way is 15°C (1.8°C/100 m) in February and 16°C (1.9°C/100 m) in October. These large values show that the non-adiabatic effect on the formation of minimum temperatures. The main reason for the increasing lapse rate towards inland may be the promotion of radiation cooling due to the station altitude, the low frequency of cloud ceiling and the development of nocturnal inversion caused by light breeze.

3.2. Climate of Mizuho Plateau revealed by mobile observation

To know the transitional climate from the cold katabatic region to the cold interior the frequency distributions of temperature and wind at the temporary stations along the traverse route on the way to V142 are also shown in Figs. 4 and 5. The frequency distributions at Mizuho Station during the same periods are also shown for comparison. The distribution pattern of the temperature at Y100 is quite similar to that of Mizuho Station, while it is symmetrical at Y200. The temperature range shifts to lower values compared with Mizuho Station, but the remarkable elongation of the curve to the lower temperature range as seen at V142 is not found at these two stations. Although the gamma type distribution pattern of wind speed found at V142 is not seen also at these stations, the decrease in the wind speed towards inland is evident. Since the firn temperature of 10 m depth obtained at Y′210 (2880 m), 33 km south of Y200, by JARE-15 was −41.7°C (SATOW, 1977), the mean annual temperature at Y200 can be regarded as below −40°C. The mean annual wind speed at Y200 can be deduced as 7 m/s from the wind speed ratio of Y200 to that of Mizuho during the mobile observation and the mean annual value of 10.5 m/s at Mizuho, if the mean value of 11.1 m/s during the observation at Mizuho is assumed to be the annual mean. If this assumption is valid the climate of Y200 can be classified as cold interior. However, the distribution patterns of the temperature and wind can be assigned neither to the group of Mizuho not to that of V142. Since the definite boundary between the cold katabatic region and the cold interior is actually difficult to fix, the climate of Y200 can be regarded as the transitional status between these two types.

The frequency distribution of wind speed in Meteorite Ice Field, 350 km west of Mizuho Station, from December 13 to 28 is shown in Fig. 6. The distribution pattern at both stations, is very similar, though there is a shift of 4–5 m/s in the

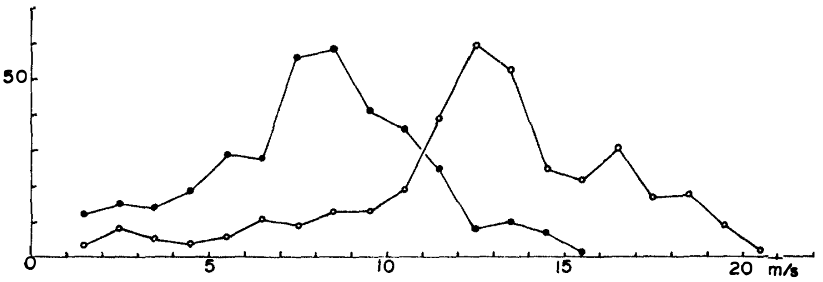

Fig. 6. Frequency distribution of hourly wind speed at Yamato (open circle) and Mizuho Station (black circle) during the same period.

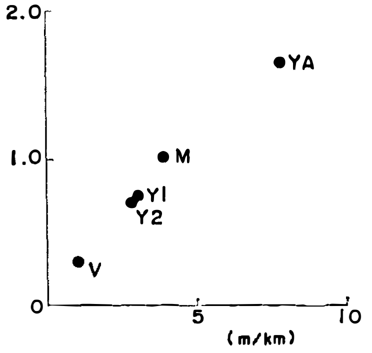

Fig. 7. Ratio of mean wind speed at the mobile station to that of Mizuho Station (ordinate) and mean surface inclination (abscissa). Symbols are; M= Mizuho Station, YA=Yamato A, Y1=Y100, Y2=Y200, V=V142.

distribution range. The increase of wind speed in Meteorite Ice Field compared with Mizuho is considered to be caused by the increase in the terrain inclination as can be seen in Table 1. The ratio of mean wind speed observed at each temporary station to that of Mizuho Station during the same period versus mean terrain inclination is plotted in Fig. 7. The inclination (m/km) was estimated from the distance of 200 m height difference along the maximum flow line around each station in Fig. 1. The increase in the wind speed with surface inclination is clearly shown. It can be said that the strength of the mean surface wind on the ice slope is controlled by the surrounding surface inclination.

4. Wind and Temperature Aloft of Cold Interior

32 upper air soundings at V142 showed the existence of persistent surface inversion as expected from the temperature lapse rate between Mizuho and V142. The maximum inversion of 24.5°C from the surface up to 200 m was observed at V142 at 03 LT on October 21. Mean values of inversion intensity and depth in October and December at several stations of East Antarctica (DALRYMPLE, 1966; KOBAYASHI *et al.*, 1982) are shown in Table 2. The soundings at V142 were made from 13th to 28th and three ascents at Mizuho were made in the daytime of October 1st, 7th and 16th. A remarkable difference in the daytime inversion intensities is not found at the stations of Mizuho Plateau in both October and December while the depth differs much. A precise evaluation of the inversion depth cannot be made in the layers of small temperature gradient and large errors are not avoidable (SCHWERDTFEGER, 1970).

Table 2. Intensity and depth of surface inversion in East Antarctica.

Station	Elevation (m)	Year	October			December		
			Number (Time)	Intensity (°C)	Depth (m)	Number (Time)	Intensity (°C)	Depth (m)
Mizuho Station	2230	1980	3 (13, 14, 17 h)	8.2	142	3 (23 h)	3.0	160
Y100	2584	1981	4 (15 h)	6.8	268			
Y200	2840	1981	3 (15 h)	7.8	943			
V142	3076	1981	9 (03 h)	17.7	295			
			16 (15 h)	6.7	283			
			32 (Total)	11.0	300			
Yamato A	2217	1981				8 (03 h)	2.4	122
Pionerskaya	2741	1958		8.7	950		2.4	620
Vostok I	3252	1957		8.0	816			
Vostok	3488	1958, 60, 61		17.0	857		2.5	470
Sovietskaya	3622	1958		20.6	1018		2.7	494

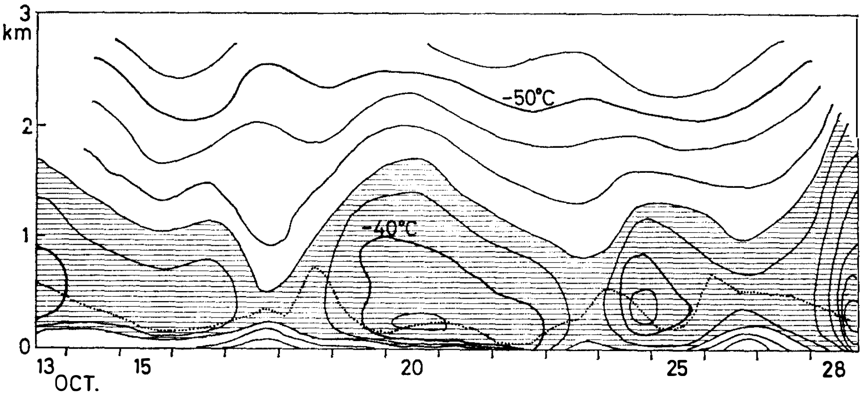

Fig. 8. Time-height cross section map the temperature over V142. Dotted line shows inversion height. Shaded area represents temperatures above —44°C.

However, the inversion depth of V142 is not only small compared with another interior station, but smaller than that of Y200.

The height-time cross section map of temperature at V142 from October 13 to 28 is shown in Fig. 8. The lower troposphere over V142 is characterized by successive warming and cooling which is distinct by the variation of the area encircled by —44°C isotherm. The warming process has three types; the whole layer (19th–20th, 28th), the lower half (24th) and the upper half (17th). The cooling of the atmosphere is produced not only from the surface but also from the middle layer 1000–1500 m above the surface simultaneously (17th, 23rd, 26th). The inversion becomes deeper by this cooling with the time lag of 0.5–1 day, though it was not seen on the 28th due to remarkable warm advection which replaced the air mass of the whole layer. The small inversion with the intensity of 4.5°C and depth of 43 m was formed on 22nd. The accompanying surface wind was northerly (Fig. 2) which is the opposite direction of the prevailing wind, namely the downslope direction. This is evidently the locally formed katabatic wind. Height-time cross section map of wind is shown in

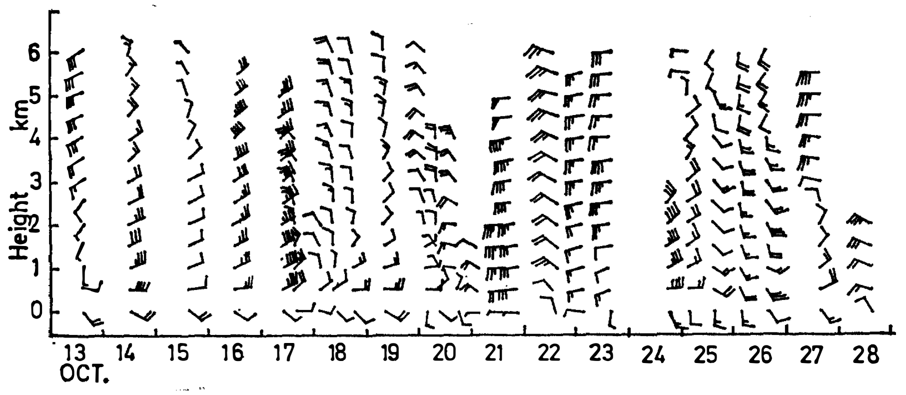

Fig. 9. Wind aloft over V142 in knots mainly based on 15 LT observation.

Fig. 9 to see the upper advection. A remarkable warm advection from 17th to 20th seems to be commenced at the height above 2 km in Fig. 8. The geostrophic wind above 2 km veers counterclockwise with height on 17th in Fig. 9. This implies the warm advection above this height judging from the thermal wind relationship of the southern hemisphere. This warm advection can be traced back up to the height of 6 km from the surface on 14th. The warming on 19th–20th and 24th is also explained by the warm advection above 1 km from the surface. The clockwise veer of wind with height from 1000 m–1500 m on 23rd and 26th shows the cold advection. However, the cooling on 17th cannot be explained by the cold advection.

Wind and temperature at 500 mb surface above V142 and Syowa Station were compared in Fig. 10 to estimate the extent of warm/cold advection. The temperatures at the two stations are not closely correlated, although lower values of V142 than Syowa Station due to poleward meridional temperature gradient (SCHWERDTFEGER, 1970) are roughly kept except on 13th, 19th and 24th. In the above exceptional date the cooling over Syowa is explained by the passage of a depression, which can be deduced from the remarkable change in the wind direction. The accompanying out-

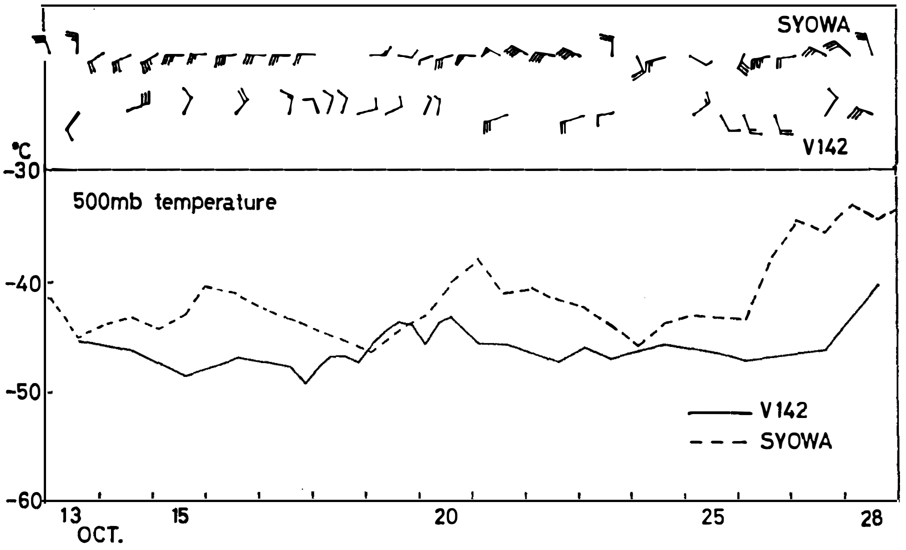

Fig. 10. Wind (above) and temperature (below) at 500 mb surface over Syowa Station and V142.

flow of the cold air from the interior is not always present over V142. It would be adequate to say that the air flows over these two stations are under different circulations. However, the extent of warm advection of 28th can be said large enough to involve both stations. The maximum temperature at the screen level increased from −42°C (27th) to −27°C (28th) at V142. This is considered to be one of the major intrusions of warm air to the Antarctic interior which works as a poleward heat transporter to compensate radiative heat loss (SINCLAIR, 1981). The weakness and directional inconstancy of the 500 mb wind over V142 compared with Syowa suggest that V142 is located close to the inner core of polar vortex.

5. Summary of the Climate of Mizuho Plateau

The purpose of the mobile observation of the POLEX-South program was to make the meteorological observation along the flow line of katabatic wind on Mizuho Plateau. At V142, the upper end of the plateau, stationary accumulation of the cold air and its descent towards coast had been expected. The decrease in the surface wind speed and temperature was evident along Y route. The climate of V142 and Y200 is classified as the cold interior, though the transitional status from the cold katabatic climate has been shown for the latter. However, the prevailing wind at V142 was the fall wind from further interior with higher elevation. The driving force of this wind is strong and the depth is large enough to overcome the upslope inclination. This is proved by the formation of local katabatic wind along the flow line of surrounding topography when the fall wind was blocked by synoptic scale wind. The extent of the katabatic wind on Mizuho Plateau is much larger than previously imagined from the topography of East Antarctica.

Radiation and wind are of particular concern to account for the increase in the temperature lapse rate towards inland. The increased negative value of effective radiation towards inland as can be seen in the observational results along the slope stations of East Antarctica (RUSIN, 1964) is due to the decrease in atmospheric radiation in spite of the decrease in the terrestrial radiation by the lowered surface temperature. The effects of the altitude and the continentality are considered for the decrease in the atmospheric radiation. The former is explained by the decrease in the atmospheric constituents above the station altitude and the latter by the decrease of dense cloud cover. The effect of the cloud cover was revealed as specific difference in the effect of synoptic disturbance than the semistationary results in our study. The mean cloud coverage during the observation in October was 4.3 at V142 and 5.1 at Mizuho, while in February it was 4.1 at V142 and 2.2/10 at Mizuho. The cooling is produced by radiation effect, but its development depends on the wind speed. Light breeze in the interior is evidently favorable for the formation of the low temperature. However, a larger time lag between the minimum temperature and the maximum wind speed in the interior compared with the strong katabatic wind area would be further favorable. Though the promotion of the low temperature was emphasized by the non-stationary nature of the katabatic wind, the mean wind speed at each station can be shown as the stationary problem. The normal speed of the steady and uniform katabatic wind can be assumed to be proportional to the terrain inclination and the intensity of the surface inversion (Ball, 1956). Since the inversion intensity does not change so large at each temporal station over Mizuho Plateau (Table 2), the mean wind speed is determined by the terrain inclination for the first approximation. The linear relationship of wind speed versus terrain inclination in Fig. 7 shows the validity of the above hypothesis.

The inversion depth over V142 does not develop because it is restrained by the successive warming from the upper atmosphere. The warm air advection occurs at a height of 1 km above the surface and another at a height of tropopause. The latter is propagated to the lowest layer 3–4 days later. The cooling of the lower atmosphere occurs not only from the surface but at heights of 1000–1500 m. The circulation pattern on the 500 mb surface is not alike over the coast (Syowa) and the interior (V142). The circulation above the coast seems to be affected by the westerly wave more definitely than the interior where the circulation seems to be under the control of the polar vortex. However, remarkable warm air intrusion has much larger extent and depth to involve from the coast to the interior. It is very interesting to know whether the warm/cold advections are cancelled during the mean status and the radiative heat loss is compensated by adiabatic heating of subsided air mass (White and Bryson, 1967). The different circulation patterns found over the interior and the coast should be carefully taken into account for the evaluation of the mean status.

The mobile observation is highly recommended for the climatological research on the Antarctic plateau and is probably the sole means to cover the vast area of the Antarctic Continent. However, the existence of a permanent station on the plateau is essential. The data of temporal observation would not have much advantage until they are referred to those of the permanent station.

Acknowledgments

The authors are grateful to Dr. C. Nakajima for his encouragement and advice throughout the work, and to Dr. S. Kawaguchi for the valuable comments on the manuscript. Thanks are also extended to Mr. S. Takeuchi of the National Institute of Polar Research for the design of the mobile station. Thanks are lastly due to the members of traverse parties for their sincere cooperation in the investigation and traverse, and to all the members of JARE-22 who supported the inland traverse.

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(Received May 2, 1983; Revised manuscript received June 23, 1983)