THE ATMOSPHERIC CONDITIONS FOR EXTREMELY LOW AIR TEMPERATURES AT MIZUHO STATION, ANTARCTICA

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Abstract: At Mizuho Station (70°42′S, 44°20′E, 2230 m), there were 17 days with extremely low air temperature of below −50°C in the winter of 1980. The atmospheric conditions were investigated to clarify the conditions requisite for the occurrence of these cases. The aerological data at Syowa Station (69°00′S, 39°35′E) were used for this analysis. For the occurrence of extremely low air temperature at Mizuho Station, the following conditions are required: The wind direction at the level of 600 mb which can be considered to be the geostrophic flow above the inversion layer, should be from south to west (S–W) at Syowa Station. The wind direction at Mizuho Station is from SE–SW, meaning the synoptic scale pressure gradient from SW–NW to NE–SE which is in the opposite direction of the fall line there. The moisture content of the air mass should be low so that there is no cloud formation. Also the air temperature has to be at least lower than the monthly mean. If these conditions are satisfied, quite strong temperature inversion will occur near the surface, resulting in extremely low surface air temperature. Wind speed at the surface level is only a little lower than the average.

1. Introduction

Antarctica is said to be the coldest continent on earth. For example, the recorded lowest surface air temperature on earth was −88.3°C recorded in Antarctica at Vostok Station (78°28′S, 106°48′E, 3488 m) on August 24, 1960. The lowest temperature experienced by the Japanese Antarctic Research Expedition was −60°C in 1981 during the traverse at the elevation of 3076 m in the Enderby Land (SATOW *et al.*, 1983). At Mizuho Station (70°42′S, 44°20′E, 2230 m), there are at least several days in a year when the air temperature drops below −50°C. Recorded lowest air temperature up to now at this station is −58.1°C (June 6, 1981).

In this paper, the air temperature data at Mizuho Station will be summarized, and the characteristics of the atmospheric conditions when extremely low air temperature occurred at Mizuho Station will be discussed.

2. Data

The data used in the present analysis are shown in Fig. 1. They are wind speed, wind direction and air temperature at the 600 mb level at Mizuho and Syowa Stations, and surface meteological data at Mizuho Station. SCHWERDTFEGER (1970) wrote

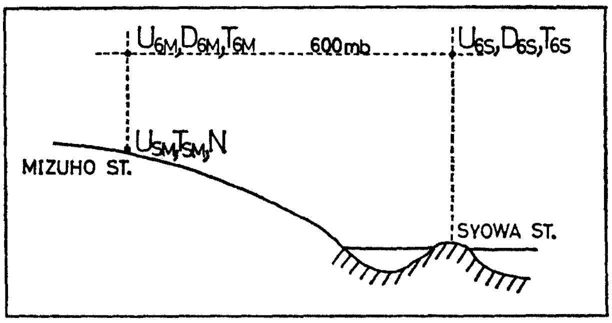

Fig. 1. The meteorological data used in this paper.

that the surface level air temperature depends strongly on the height of observation due to strong surface inversion in the interior of the ice sheet. As for Mizuho Station, there exists a strong temperature gradient in the lower air layer, but it does not come down to the height of screen level (OHATA *et al.*, 1982), so the screen level air temperature at Mizuho Station T_{SM} can be said to be quite representative.

As the aerological data available at Mizuho Station are for only limited days, the aerological data at Syowa Station (69°00′S, 39°35′E) will be mainly used. Before this can be done, the correlation between these data must be checked. Comparison

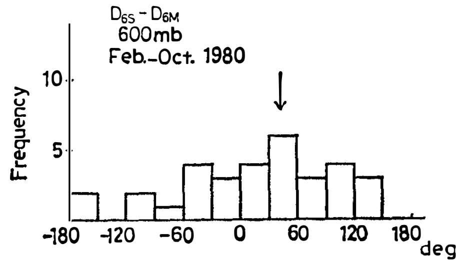

Fig. 2. Frequency distribution of $D_{6S}-D_{6M}$.

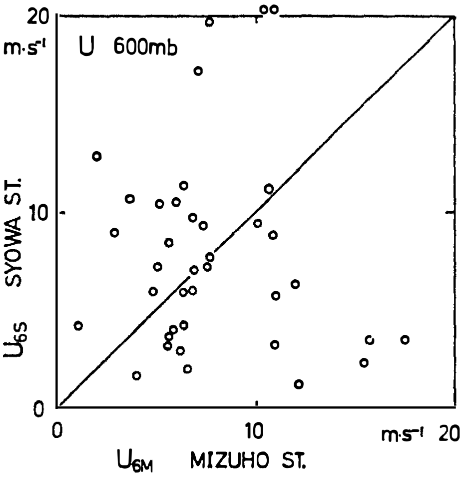

Fig. 3. Relation between U_{6S} and U_{6M}.

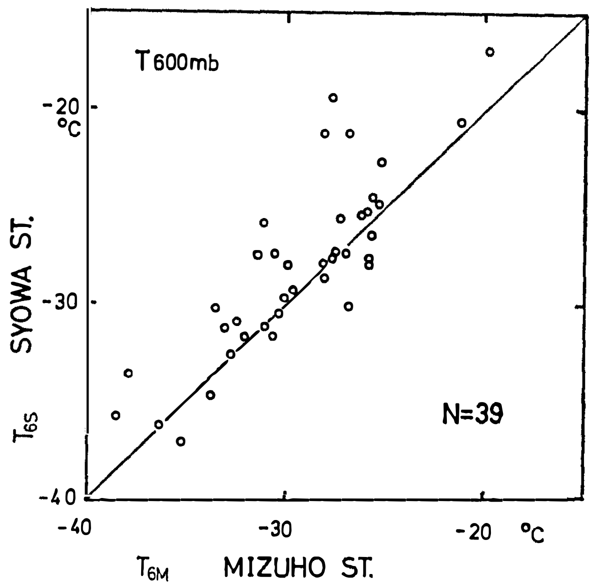

Fig. 4. Relation between T_{6S} and T_{6M}.

will be made at the 600 mb level which can be considered to be higher than the top of the inversion.

In Figs. 2–4, the comparisons of wind direction (D_{6M}, D_{6S}), wind speed (U_{6M}, U_{6S}) and air temperature (T_{6M}, T_{6S}) are made for days when aerological data are available at Mizuho Station during the period from February to October 1980. The suffix 6M and 6S stand for 600 mb level at Mizuho Station and Syowa Station respectively. In Fig. 2, $D_{6S}-D_{6M}$ is shown. There is a broad peak centered in the range of 30–60°, which means that on the average, the wind direction at Syowa Station is displaced approximately 45° clockwise.

In Fig. 3, the relation between U_{6M} and U_{6S} is shown. It can be said that the relation is quite variable. Figure 4 shows that the air temperature has the best correlation among these three. The average difference $T_{6S}-T_{6M}$ is 1.2°C, and Syowa Station is higher. In Fig. 5, average value of $T_{6S}-T_{6M}$ is obtained according to the wind direction at Syowa Station. It can be said from this figure that there is no systematic tendency of $T_{6S}-T_{6M}$ in relation with the wind direction.

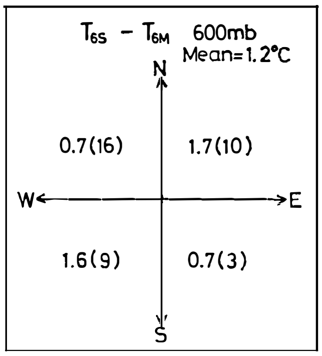

Fig. 5. Mean values of $T_{6S}-T_{6M}$ according to the wind direction U_{6S}. Wind direction is divided into 4 sectors. The number in the parentheses are the sample number.

3. Low Air Temperatures in 1980

The air temperature data for 1980 listed in OHATA *et al.* (1981) show the well known coreless trend in the annual pattern. Low air temperature below −50°C occurs from April to the beginning of October. Here, we will define the days when the daily minimum air temperature was below −50°C as the extremely low air temperature (denoted as ELAT hereafter) days. The number of such days in 1980 was 17, as shown in Table 1.

In order to find the conditions needed for the occurrence of the situation, other related meteorological elements, that is, the cloud amount N and the surface level (8 m) wind speed U_{SM} which is related to radiation balance and diffusion coefficient respectively, will be examined. In Table 2, the daily average values of N and U_{SM} for the ELAT days and the whole period from April 21 to October 10 are compared. N was 0.8 and 3.6 and showed a significant difference. U_{SM} was 11.6 and 12.3 $m \cdot s^{-1}$, and showed no significant difference. We will consider N as a parameter which is related straightly to the net radiation budget. This may be the most important factor for occurrence of low air temperature. Here we will compare the wind speed for the ELAT days and the days with $N \leq 1$ for the whole period. It is 11.6 and 12.7

Table 1. The ELAT days at Mizuho Station. Along with U_{SM} and daily minimum of T_{SM}, D_{6S}, U_{6S} and T_{6S} are shown. The value next to T_{6S} in the parentheses is the monthly mean value of T_{6S}.

	Mizuho Station		Syowa Station		
	U_{SM} (m·s^{-1})	T_{SM} (°C)	D_{6S} (deg)	U_{6S} (m·s^{-1})	T_{6S} (°C)
Apr. 30	11.5	−52.8	254	17.9	−33.0 (−28.0)
May 1	10.6	−51.5	249	22.3	−35.2 (−28.6)
6	13.2	−51.7	201	19.3	−30.0
7	14.6	−50.9	228	17.3	−32.6
8	14.2	−50.8	227	9.7	−30.2
9	15.4	−51.2	252	18.4	−29.5
June 5	8.2	−50.5	271	9.5	−35.4 (−32.1)
6	8.0	−50.8	205	9.3	−35.2
16	10.5	−52.1	187	15.5	−33.2
July 12	10.5	−52.4	266	9.2	−31.9 (−28.8)
Aug. 14	10.7	−55.1	254	13.0	−32.3 (−32.4)
15	13.7	−55.2	246	7.6	−28.2
16	13.9	−52.4	224	20.3	−22.8
Sep. 29	8.8	−53.6	240	4.3	−36.0 (−30.3)
30	11.3	−54.9	243	6.7	−35.7
Oct. 1	12.3	−53.6	253	8.9	−35.8 (−31.8)
2	10.6	−53.4	298	13.1	−35.5
Mean	11.6		241	13.1	−32.5 (−30.4)

Table 2. Cloud amount N and wind speed U_{SM} for the ELAT days and the whole winter period (April 21–October 10).

	ELAT days (17 days)	April–October
Cloud amount (N) (10 grades)	0.8	3.6
Wind speed (U_{SM}) (m·s^{-1})	11.6	12.3

respectively. These show a larger difference than the above values but still the difference is not so significant. Here only the cloud amount can be considered as the requisite condition.

The condition of meteorological elements at the surface level is strongly related to the condition of the upper air. The aerological data were taken by a low level radiosonde at Mizuho Station in 1980. However, the data were limited and only one or two observations were made on the ELAT days. Therefore, the aerological data taken at Syowa Station will be used to make up for this. In Table 1, the ELAT days are listed with the corresponding aerological data of the 600 mb level at Syowa Station. The data show that the wind direction at the 600 mb level is distributed in a small range of 187–298°, less than 1/3 of the whole azimuth. D_{6S} in the whole period from April to August shows concentration in the range of 0–60° and 210–360°. The percentage of wind direction between 180 and 300° is only 40% of the whole cases. As it will be seen in the next section that the wind direction at 600 mb at Syowa Station is strongly correlated to that at Mizuho Station, it can be concluded that wind direction from the south to west (S–W) sector is also a requisite condition for ELAT. As the wind at the 600 mb level can be considered to be the geostrophic flow, the above condition means the existence of pressure gradient in the W–NW to E–SE direction.

The value $\Delta T = T_{6S} - T_{SM}$, which can be considered to be the approximate strength of the inversion, shows mean value of 20.0°C on the ELAT days.

The average difference of air temperature at the 600 mb level at Syowa Station (T_{6S}) on the ELAT days from monthly average values is 1.9°C. This is not a large value.

4. The Effect of South to West Winds

It was seen in Section 3 that south to west (S–W) upper wind at Syowa Station is a requisite condition for occurrence of ELAT. In this section, it will be discussed how this factor affects the air temperature structure above Mizuho Station.

Air temperature at the surface level can be considered as the modification of the general air temperature pattern (adiabatic lapse rate) by the temperature inversion near the surface. And so, the surface temperature can be expressed as $T_6 - \Delta T$, using the 600 mb level air temperature (T_6) and the strength of temperature inversion (ΔT). It will be of interest, to know the features of T_6 and ΔT in the case of S–W winds. In other words, what is the relative importance of advection of a cold air mass and the strong temperature inversion.

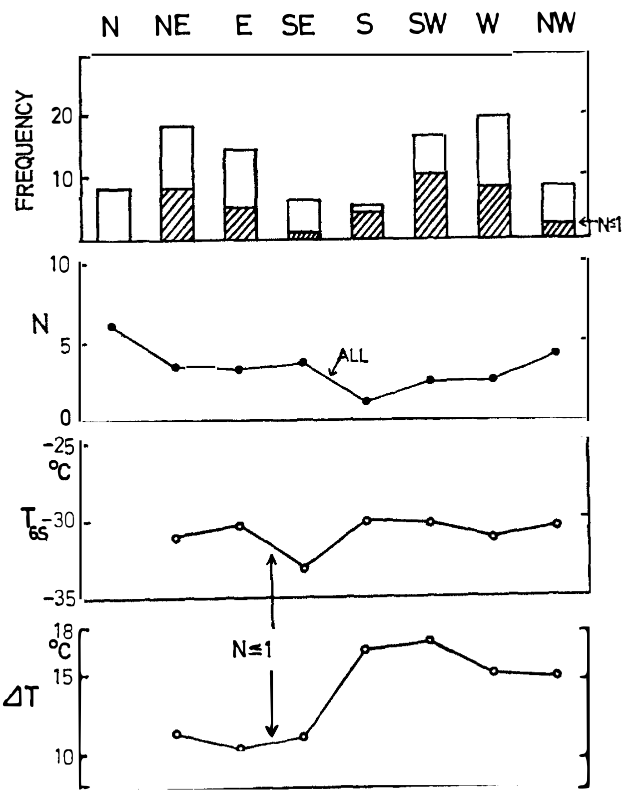

Fig. 6. Dependency of mean values of N, T_{6S} and ΔT on the wind direction D_{6S}. Frequency is subdivided into $N>1$ and $N \leq 1$. N is obtained for all days. T_{6S} and ΔT are obtained for the cases of $N \leq 1$.

In Fig. 6, the average values of N, T_{6S}, and ΔT are obtained according to D_{6S}. The period of analysis is from May 1 to August 15. ΔT is obtained as $T_{6S}-T_{SM}$. Daily average values are taken for N and T_{SM}, and data at 15 LT for T_{6S}. At the top of Fig. 6, the frequency of wind direction D_{6S} is shown for all cases and cases when $N \leq 1$. Frequency shows local maximum in the direction of NE and W. From the second one, it can be said that N is slightly lower in the case of S–W. This is probable, because the air mass from the southern sector should contain less moisture than the air mass from the north which is from the sea side. T_{6S} and ΔT are obtained for only the days with $N \leq 1$. T_{6S} does not show any clear tendency upon D_{6S}. It only shows a little low value in the direction of SE. This may be due to the small sample number in this direction. No significant tendency can be seen in the direction of S–W, which is the requisite condition for ELAT. In comparison ΔT shows rather a systematic tendency, a large value in the direction of S–W. From this it can be said that when D_{6S} is S–W, T_{6S} shows no particular tendency, but ΔT does. In the case of S–W wind such special feature can be seen. This feature seems to be the key to the occurrence of the ELAT days. So the occurrence of ELAT can be said to be related to the increase in ΔT, not to the low T_6.

5. ΔT and Synoptic Scale Pressure Gradient

There arises a question why ΔT is large in the case of S–W wind. It was shown in Section 2 that the wind direction at Mizuho Station was 45° counterclockwise on the average compared with that of Syowa Station. This means SE to SW wind at Mizuho Station in these cases. The synoptic scale pressure gradient will be in the direction of SW–NW to NE–SE which is opposite to the direction of the fall line at Mizuho Station. Under the same temperature inversion condition, wind speed would

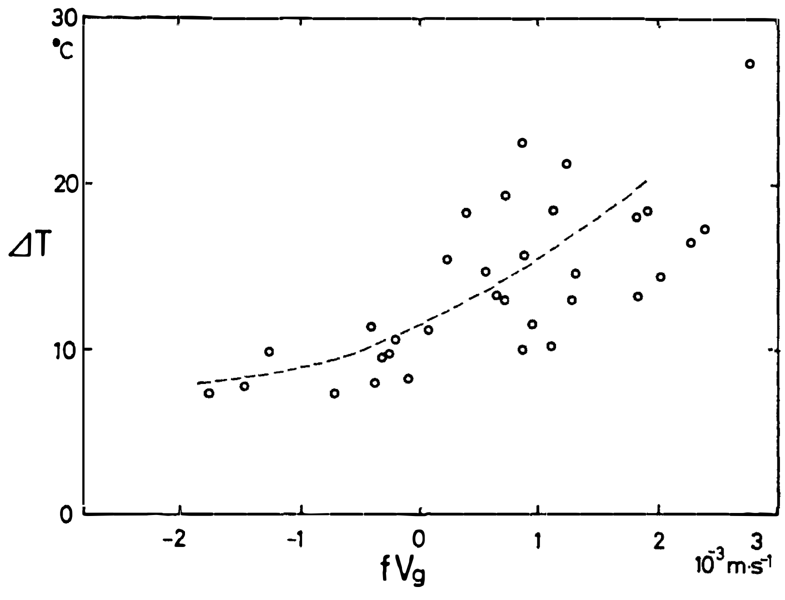

Fig. 7. Relation between ΔT and the synoptic scale pressure gradient fV_g in the direction of the fall line at Mizuho Station. The value of U_{6S} was used for V_g.

be weaker in this case. Subsidence flow will be weak if the wind is weak. Inversion will probably strengthen in the above case until the wind speed increases and the vertical heat transport is maintained by the subsidence flow to compensate for the radiative heat loss at the surface. It was shown in Section 3 that the wind speed in the case of ELAT was only a little lower than the average. This can be explained by the above context.

In Fig. 6, ΔT was related only to wind direction. However, as the essential factor which affects the boundary layer is the synoptic scale pressure gradient, the relation between ΔT and the pressure gradient force in the direction of the fall line at Mizuho Station was taken. It is shown in Fig. 7. Pressure gradient fV_g was calculated from the wind vector at the 600 mb level, postulating the geostrophic wind approximation. Only the days with $N \leq 1$ were taken. There is a clear relation between these two. It can be said that when the pressure gradient against the slope is stronger, ΔT is larger.

6. Conclusion

Low air temperature below $-50°C$ occurred 17 times during the winter at Mizuho Station in 1980. This was accompanied by a low cloud amount. In these cases the 600-mb aerological data at Syowa Station showed a somewhat low (1.9°C lower on the average than the monthly mean) air temperature. Also the wind direction was concentrated in the direction of S–W.

In order to see the effect of S–W wind, that is the pressure gradient from W–N, the analysis of aerological data at Syowa Station and surface meteorological data at Mizuho Station was made, including only the clear weather days. This showed that under the S–W wind, advection of cold air was not seen, but a strong temperature inversion existed. In general the S–W wind at Syowa Station means a synoptic scale pressure gradient of SW–NW to NE–SE at Mizuho Station. This pressure gradient is opposite to the direction of the fall line of the slope at Mizuho Station, and this resulted in the strong temperature inversion. Therefore, for the occurrence of extremely low air temperature below $-50°C$ at Mizuho Station, the following condition would be needed. The wind at 600 mb should be S–W at Syowa without much moisture for cloud formation. Similar situation will be seen at Mizhuo Station also. As a result, quite strong temperature inversion will occur resulting in extremely low air temperature. The temperature of the synoptic scale air mass does not have to be so low. The wind speed at the surface level will be only a little lower than the average. In this analysis, data were not sufficient, to see the relation between ΔT and $T_{6M}-T_{6S}$, and $D_{6S}-D_{6M}$. More data collection above the continent is needed to have better understanding on the type of air mass in this region.

The most important factor will be the formation of the strong temperature inversion. In order to examine this phenomenon in more detail, the heat balance of air mass near the surface must be scrutinized in relation to subsidence flow and turbulent heat transfer. Also the radiative flux under the temperature inversion condition should be investigated.

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