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Scientific paper

Meteorological characteristics of Antarctic inland station, Dome Fuji

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***Abstract*:** Surface meteorological observations were carried out during 1995 and 1997, and extended atmospheric science observations were carried out in 1997 as a sub program of "Atmospheric Circulation and Material Cycle in the Antarctic (1997–2001)" at Dome Fuji Station (77°19′S, 39°42′E) where deep ice core drilling was done. The annual mean surface air temperature was –54.4°C with the lowest record of –79.7°C. The mean wind speed was 5.8 m/s with no clear prevailing wind direction. From aerological soundings, temperature profiles are described; they are characterized by a strong surface inversion such as 25°C, on a normal winter day. Abrupt warming occurred several times a year; the largest showed 40 degree temperature increase within two days between 17 and 19 July 1997. The event was associated with the intrusion of an anticyclone, "a blocking high", and many drastic phenomena such as large accumulation of snow followed this event.

key words: Antarctic, inland, meteorology, inversion, blocking

1. Introduction

Deep ice core drilling was conducted at Dome Fuji Station (77°19′S, 39°42′E), located on the high plateau of the Antarctic Ice Sheet, inland Antarctica (Watanabe *et al.*, 1999). It is indispensable to know the meteorological features of the station to analyze the ice core obtained at the station. Since there are only a few inland stations in Antarctica (Schwerdtfeger, 1984; King and Turner, 1997; Rusin, 1964), it is also worth while to study the meteorological characteristics of the station.

The present paper describes the meteorological characteristics of Dome Fuji Station from three-year observations of the surface meteorology during 1995 and 1997 and extended atmospheric science observations in 1997. General meteorological features are explained based on monthly mean data, and noticeable phenomena, abrupt warming events, are introduced.

2. Description of Dome Fuji Station

Dome Fuji Station, located on the high plateau of the Antarctic Ice Sheet, at the altitude of 3800 m a.s.l. and about 1000 km from the coast, was established as the fourth station of the Japanese Antarctic Research Expedition (JARE) in 1993 (Fig. 1). The primary objective to settle the station was to conduct deep ice core drilling, which was successfully accomplished, down to 2503 m depth, in 1996. In 1997 (JARE-38), an extended program of atmospheric science observation was carried out at the Station.

This observation program, as a sub program of “Atmospheric Circulation and Material Cycle in the Antarctic (1997–2001)”, is composed of aerological soundings using GPS sondes (Vaisälä) for temperature, humidity and wind, together with some ozone and aerosol (OPC) sondes, surface radiation budget measurements (downward and upward shortwave and longwave measurements), lidar remote sensing of particles such as aerosols and clouds and surface measurements of aerosols (counting and sampling), radon concentration, ozone concentration and sunphotometer measurements of optical depth (Yamanouchi *et al.*, 1999). Surface meteorological observations (synoptic) were continued during three years of wintering between 1995 and 1997 (Japan Meteorological Agency, 1996, 1997, 1998). The objective of this observation program was to understand variations of atmospheric constituents related to the atmospheric circulation and to supply useful information for ice core analyses such as how the atmospheric components were taken into the ice core.

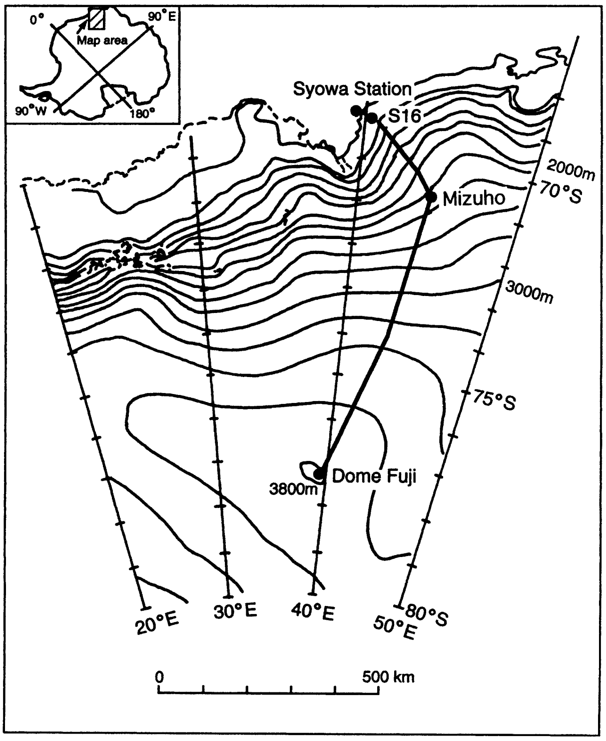

Fig. 1. Location of Dome Fuji Station.

3. General meteorological features

General meteorological features of Dome Fuji Station are as given in Table 1. The monthly mean surface air temperature ranged between –69°C in May 1996 and –31°C in December 1997, with an annual mean temperature of –54.4°C. These extremely low surface temperatures were due to a strong surface inversion, up to around 25°C on a normal winter day. Variations of daily temperature for 1995, 1996 and 1997 are shown in Fig. 2. Seasonal variation of surface temperature shows a "coreless winter" shape. Rapid decrease of temperature is common until day number 100 (beginning of April) and sudden increase of temperature starts around day number 300 (end of October). During 200 days between April and October, winter temperature continues with large short term variability. Several large temperature increases are noticeable in the winters. They will be explained in the next section.

Table 1. Monthly summaries of surface synoptic data at Dome Fuji Station, 1995–1997.

Item	Jan.*	Feb.*	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year*
P_{st} (hPa)	607.0	605.7	596.8	596.2	589.4	597.0	596.1	593.8	591.7	593.3	605.8	608.0	598.6
T (°C)	–35.4	–43.8	–56.4	–60.9	–66.5	–64.0	–61.2	–65.5	–63.6	–57.2	–43.8	–33.0	–54.4
T_{xx} (°C)	–18.6	–18.9	–37.4	–36.9	–49.4	–29.2	–38.2	–41.5	–44.1	–38.4	–25.0	–21.1	–18.6
T_{mm} (°C)	–48.9	–60.9	–67.9	–75.0	–79.7	–79.6	–79.7	–79.6	–78.3	–72.3	–64.8	–47.2	–79.7
V (m/s)	4.4	5.0	5.6	6.5	6.0	6.2	6.6	6.5	6.1	5.9	5.6	4.8	5.8
V_{xx} (m/s)	11.1	11.3	9.4	12.1	11.8	16.5	18.4	1.0	13.5	14.5	13.5	13.3	18.4
N (1/10)	3.9	3.5	2.5	3.3	2.5	2.2	4.0	2.7	3.2	2.9	3.4	4.6	3.0
Snow	29	21	27	29	31	29	30	28	28	30	27	26	318

*: Mean of 1996 and 1997; P_{st}: Station pressure; T, T_{xx}, T_{mm}: Monthly mean, extreme of maximum and minimum temperatures, respectively; V, V_{xx}: Monthly mean and maximum wind speed; N: Monthly mean cloud amount; Snow: Number of days with snow and/or diamond dust.

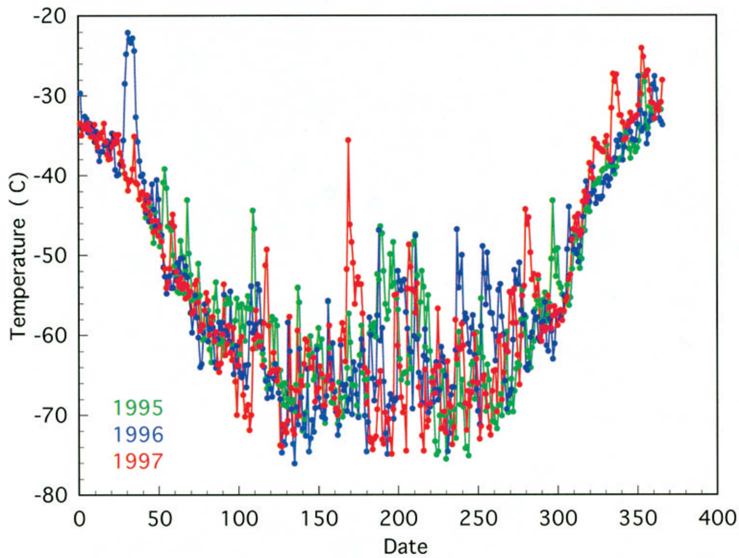

Fig. 2. Variations of daily temperature at Dome Fuji Station in 1995, 1996 and 1997.

The minimum temperature during three years was –79.7°C, not the lowest record on the globe, even though it can be expected to be the lowest on Earth, since Dome Fuji Station is the highest manned station in Antarctica; the lowest temperature, –89.2°C, was recorded at Vostok Station, the altitude of which is more than 300 m lower than Dome Fuji Station. Even in recent years, when measurements were made at both stations simultaneously, the surface air temperatures were higher at Dome Fuji Station than at Vostok Station. The annual mean temperature of Vostok Station, –55.5°C, and that of Plateau Station, –56.4°C, which was the highest manned station in the 1960s, are both lower than that at Dome Fuji Station, –54.4°C. The temperature difference is evidently not caused simply by the altitude difference, but possibly by the difference in the surface topography. Dome Fuji Station is located at the top of summit of Dome F, on a wide plateau. On the other hand, Vostok Station is located on the slope, in a basin over the lake Vostok (Kapista *et al.*, 1996). It is possible that the surface air was stagnant over the region and radiative cooling occurs much more effectively than at Dome Fuji. This hypothesis is supported by the lower mean wind speed at Vostok Station.

The mean wind speed at Dome Fuji Station was 5.8 m/s. This wind speed is much lower than that at Mizuho Station (10.6 m/s), which is located on the slope where a strong katabatic wind prevails. However, this is still the highest among the mean wind speeds at inland high plateau stations such as Vostok, 5.1 m/s, or Plateau, 4.9 m/s. No clear prevailing wind direction, such as a katabatic wind, was found.

From the surface radiation budget measurements, longwave radiative fluxes at Dome Fuji Station are compared with climatological values at other Antarctic stations (in different

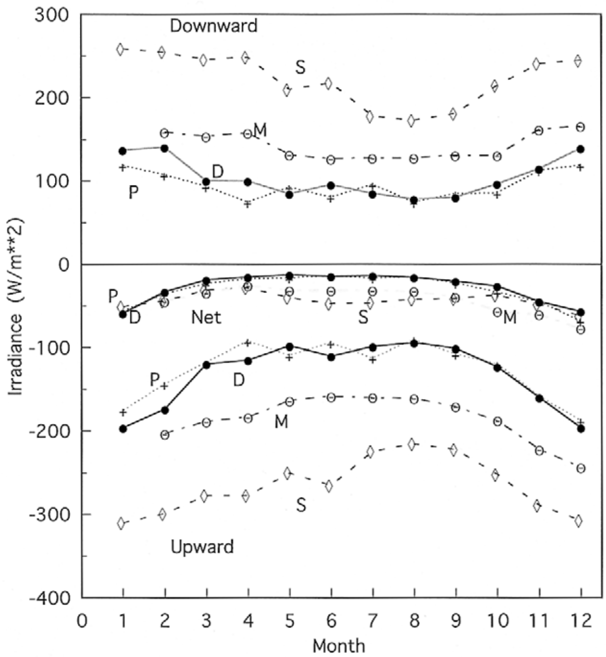

Fig. 3. Surface longwave radiation fluxes at Dome Fuji Station (D) in 1997, compared with those at three other Antarctic stations, Plateau (P; 1967), Mizuho (M; 1979) and Syowa (S; 1987).

years), such as Plateau (1967; Kuhn *et al.*, 1977), Mizuho (1979; Yamanouchi and Kawaguchi, 1982) and Syowa (1987; Yamanouchi, 1989) Stations, in Fig. 3. The present values at Dome Fuji Station compare well with those at Plateau Station, except for some larger downward and upward (in absolute amount) fluxes in January, February and April. Together with Plateau Station, downward and upward longwave fluxes at Dome Fuji Station are much smaller than those at Mizuho and Syowa Stations. Finally, absolute amounts of net longwave fluxes at Dome Fuji Station are very small, only 10 to 15 W/m^2 during the winter months.

Annual mean station pressure was 598.6 hPa, the lowest among manned stations in Antarctica. The higher pressure is seen in summer months and lower in winter months, with smaller bi-annual oscillation is seen just as common with many stations in Antarctica (Van Loon, 1972; Wada, 1985).

As seen in Table 1, annual mean cloud amount was 3.0 in 1995–1997. The seasonal trend is not so clear; however, smaller cloud amounts in winter months and larger cloud amounts in summer months were seen in 1996 and 1997. This small cloud amount is a typical characteristic of inland stations. The last line in Table 1 shows an extraordinarily large number of snow days, 318 per year. This large number of snow days with low cloud amount means a large occurrence of precipitation under clear sky, that is to say "clear sky precipitation" or "diamond dust". It was found that diamond dust phenomena occurred often throughout the year at Dome Fuji Station, this was confirmed from snow deposition measurements (Motoyama *et al.*, 1998). At Plateau Station, it was reported that the number of days with ice crystals was 316 per year in 1967–68 (Orvig, 1970). We plan to attempt to find the spatial distribution of diamond dust using satellite visible and infrared imagery; however, it is still difficult to obtain. Even ordinary clouds are not easy to detect from those data (Yamanouchi

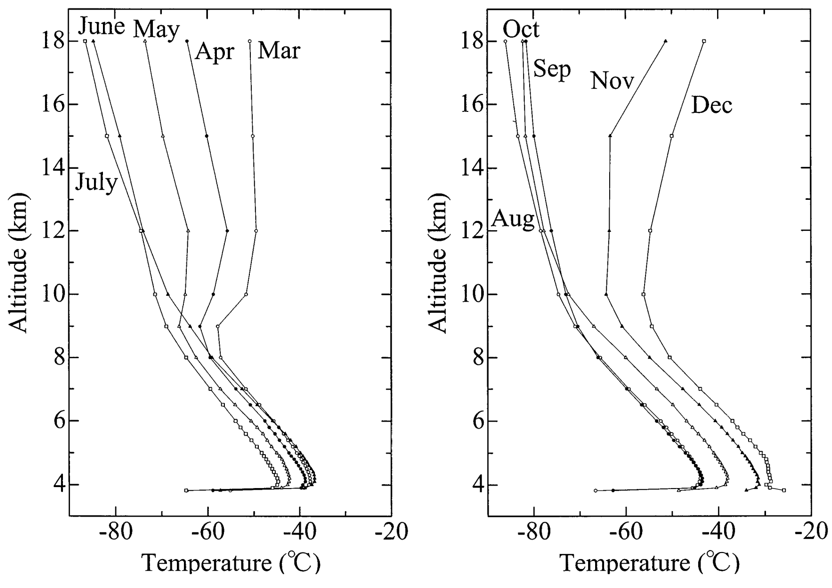

Fig. 4. Monthly mean temperature profiles at Dome Fuji Station from aerological soundings in 1997.

et al., 2000).

From the aerological soundings in 1997 (Hirasawa, 1999; Hirasawa *et al.*, 1999), typical temperature profiles in each month are shown in Fig. 4. These are simple averages of all the measured profiles in the respective months, which are not necessarily made regularly; sometimes once a day and sometimes once every five days. The annual range of temperature in the troposphere between 4 and 8 km is only about 15 degrees, much smaller than that of the surface temperature (about 35°C in monthly mean) and of the temperature in the stratosphere at 18 km, 40°C. A strong temperature inversion near the surface is seen, especially during the winter months, as much as 25°C on a normal winter day. Tropospheric temperatures above 500 hPa are similar to those at Syowa Station, even more than 8 degrees in latitude (1000 km in a distance) away. As the cold winter develops, the stratospheric temperature decreases greatly, the height of the tropopause ascends and the clear tropopause disappears from the end of May until October. During these months, a polar vortex develops in the stratosphere, with Dome Fuji Station located at the inner core of the vortex. Due to the disappearance of the clear tropopause, stratospheric constituents might be easily transferred to the troposphere and then to the surface, consist with observations at the surface reported by Kamiyama *et al.* (1996) and Kanamori *et al.* (1997). A similar tropopause condition is common at Syowa Station when it is located inside the polar vortex.

4. Abrupt warming

An abrupt warming event occurred during June 17 to 19, 1997 at Dome Fuji Station. Figure 5 shows the time series of surface air temperature, pressure and wind speed, obtained through surface observation at the station during this warming event (Hirasawa *et al.*, 2000). The surface air temperature increased from –70°C to –29°C within two days, and following this temperature increase the surface pressure rose 25 hPa. Also wind speed exceeded 15 m/s during this two day period, recording the maximum wind speed in this year. The warming event was associated with the intrusion of an anticyclone, a strong "blocking" ridge onto the

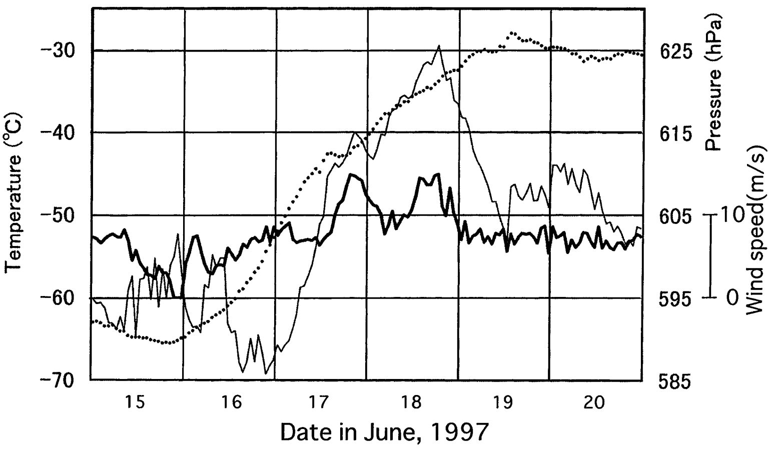

Fig. 5. Time series of surface air temperature (thin solid line), pressure (dotted line) and wind speed (thick solid line) at the surface of Dome Fuji Station during the abrupt warming in June 1997 (in LT; Hirasawa et al., 2000).

plateau. Figure 6 shows the time developments of the atmospheric circulation pattern, shown as the 500 hPa geopotential height field, from Japan Meteorological Agency operational analysis (Hirasawa *et al.*, 2000). On June 16, the polar vortex is well defined, but the westerly jet blowing along its edge meanders with deep pressure troughs. By June 18, one of the troughs further deepened and a pressure ridge amplified downstream of it. Then, the polar vortex started to break down due to the poleward penetration of anticyclonic circulation. The ridge pumped up heat and moisture from lower latitudes into inland Antarctica with a strong poleward flow along its upstream edge.

Figure 7 shows downward and upward longwave radiative fluxes in June 1997 at the station. More than 100 W/m^2 increase of longwave fluxes is clearly seen during 16 to 18 of this month corresponding to temperature increase. Enhanced downward longwave radiation from clouds and humid atmosphere and enhanced vertical mixing associated with the record-high horizontal wind speed resulted in a sudden and drastic increase in the surface air temperature and breakdown of the developed surface inversion.

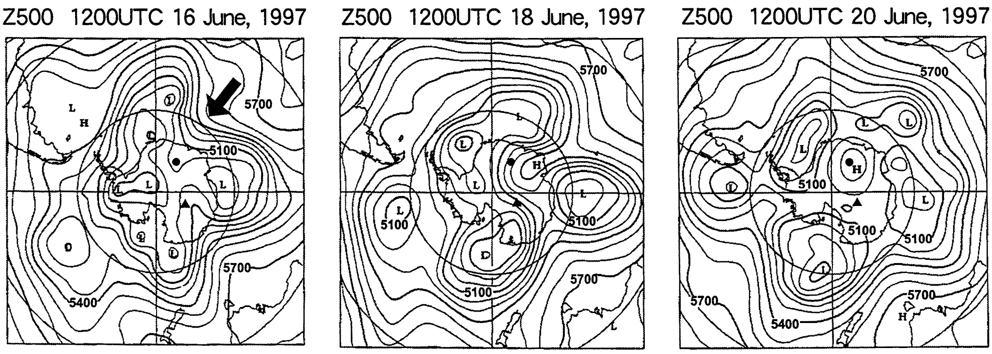

Fig. 6. 500 hPa geopotential height field for 1500 LT (1200 UTC) on 16, 18 and 20 June 1997, from Japan Meteorological Agency operational analysis (Hirasawa et al., 2000). Locations of the Dome Fuji and Vostok Stations are indicated by a solid circle and triangle, respectively, and the blocking ridge is indicated by an arrow (16 June).

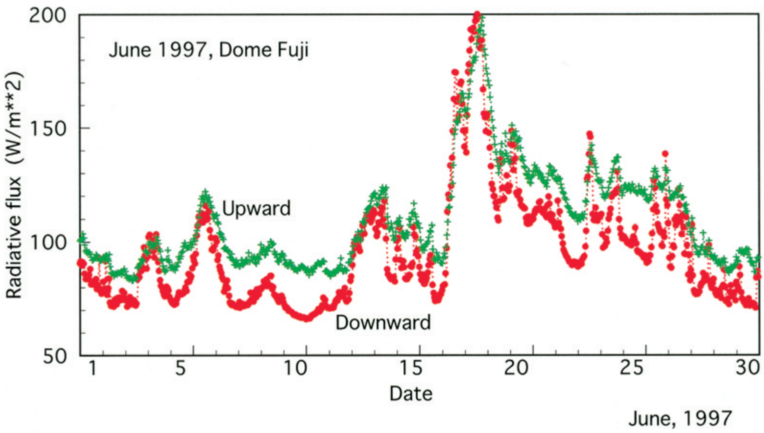

Fig. 7. Downward and upward longwave radiative fluxes at Dome Fuji Station in June 1997 (in LT).

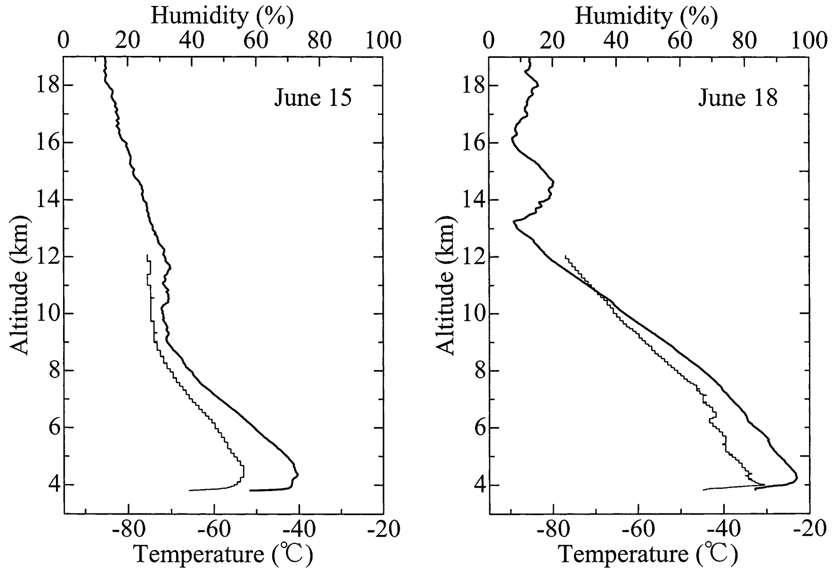

Fig. 8. Vertical profiles of temperature (thick line) and humidity (thin line) obtained by aerological sounding at Dome Fuji Station, 15 and 18 June 1997.

Vertical profiles of temperature and humidity obtained by aerological observation at the station before (June 15) and during (June 18) the warming are compared in Fig. 8. Great change in the temperature profile is noticeable. A great increase in the surface temperature is seen as explained in the foregoing paragraph. Also the temperature of the whole troposphere shows an increase of more than 15°C. Following this temperature increase, a definite tropopause appeared at 13 km height, much higher than that in June 15, and much lower temperature, –90°C, is seen in the lower stratosphere. The temperature profile of June 18 suggested that the polar air mass was replaced by a mid-latitude air mass, accompanied by the blocking high. This kind of warming event following a blocking high is seen several times every year (Enomoto *et al.*, 1998).

It was confirmed from backward trajectory calculations using ECMWF operational analyses that during this warming event, most of the air parcels that arrived at the station originated from mid-latitudes (Hatsushika and Yamazaki, 2000).

At the same time, as shown in Fig. 9, the lidar backscatter signal showed a greatly enhanced layer at 8 to 13 km height, together with rather higher humidity (Hayashi, 1999). This corresponds to the rise of the tropopause seen in Fig. 8, from 9 km to higher than 13 km; the height region from 10 to 13 km had changed from stratosphere to troposphere and a large amount of cloud particles appeared in this layer. Moreover, an additional enhanced backscatter layer also appeared in the upper layer, 13–16 km (not shown in the figure). Even after the blocking event, when the temperature profile recovered to the normal winter profile, this high backscatter layer remained in this height region, and then moisture and particles seemed to remain in the stratosphere. The blocking situation supplies water vapor into the lowermost stratosphere, and greatly affects the troposphere-stratosphere exchange of atmospheric constituents.

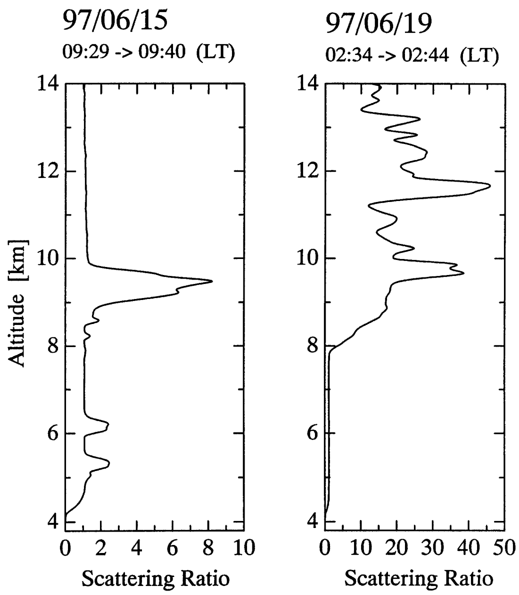

Fig. 9. Vertical profiles of lidar backscatter signal at Dome Fuji Station, 15 and 19 June 1997.

On the other hand, at the surface, the large amount of moisture must affect the precipitation and then the accumulation (Motoyama *et al.*, 1998; Enomoto *et al.*, 2000) and a non-negligible effect on annual layers in the ice core are to be expected (Pook and Gibson, 1999). Large accumulation during the blocking event might contribute to the annual accumulation.

5. Summary

Meteorological characteristics of Dome Fuji Station were obtained from surface meteorological observations made during 1995 and 1997, and from extended atmospheric science observations made in 1997 as a sub program of "Atmospheric Circulation and Material Cycle in the Antarctic (1997–2001)". A strong surface inversion, clear sky and frequent clear sky precipitation characterized the surface meteorological condition at Dome Fuji Station. The annual mean surface air temperature was –54.4°C with the lowest record of –79.7°C. The mean wind speed was 5.8 m/s with no clear prevailing wind direction. A strong surface inversion of 25°C was seen on a normal winter day. Stratosphere–troposphere exchange might be enhanced in winter, due to the vertical temperature profile with vague tropopause; however, a detailed explanation is left for future discussion.

An abrupt warming occurred several times a year; the largest showed a temperature increase of 40 degrees within two days between 17 and 19 July 1997. The event was associated with the intrusion of an anticyclone, a "blocking high", which brought about an abrupt temperature rise by a strong pole ward flow of air from lower latitudes with heat and moisture. The blocking situation also greatly affected the stratosphere–troposphere exchange. The large amount of moisture must affect the accumulation at the surface and its effect on annual layers in ice cores might not be negligible.

Acknowledgments

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References

Enomoto, H. and 8 collaborators (1998): Winter warming over Dome Fuji, east Antarctica and semi-annual oscillation in the atmospheric circulation. J. Geophys. Res., **103**, 23103–23111.

Enomoto, H., Tateyama, K., Surdyk, S., Motoyama, H., Kameda, T., Azuma, N. and Fujita, S. (2000): Impacts of winter blocking on the sea ice and snow accumulation in the Antarctic. The 23rd Symp. Polar Meteorol. Glaciol., Programme and Abstract, November 29-30, 2000. Tokyo, Natl Inst. Polar Res., 80–81 (in Japanese).

Hatsushika, H. and Yamazaki, K. (2000): Heat and moisture budget and trajectory analysis of a warming event observed in June 1997 at Dome Fuji Station, Antarctica. Polar Meteorol. Glaciol., **14**, 78–91.

Hayashi, M. (1999): Observations of aerosol and trace constituents at Dome Fuji Station in Antarctica. Tenki, **46**, 153–156 (in Japanese).

Hirasawa, N. (1999): Summary of the atmospheric observation with meteorological sonde and of radiation and cloud at Dome Fuji station in Antarctica and the preliminary results. Tenki, **46**, 147–152 (in Japanese).

Hirasawa, N., Hayashi, M., Kaneto, S. and Yamanouchi, T. (1999): Aerological sounding data at Dome Fuji Station in 1997. Data of Project on Atmospheric Circulation and Material Cycle in the Antarctic, Part 1. JARE Data Rep., **238** (Meteorology 32), 183 p.

Hirasawa, N., Nakamura, H. and Yamanouchi, T. (2000): Abrupt changes in meteorological conditions observed at an inland Antarctic station in association with wintertime blocking formation. Geophys. Res. Lett., **27**, 1911–1914.

Japan Meteorological Agency (1996): Meteorological data at Syowa Station and Dome Fuji Station in 1995. Antarct. Meteorol. Data, **36**, 358 p.

Japan Meteorological Agency (1997): Meteorological data at Syowa Station and Dome Fuji Station in 1996. Antarct. Meteorol. Data, **37**, 223 p.

Japan Meteorological Agency (1998): Meteorological data at Syowa Station and Dome Fuji Station in 1997. Antarct. Meteorol. Data, **38**, CD-ROM.

Kamiyama, K., Motoyama, H., Fujii, Y. and Watanabe, O. (1996): Distribution of hydrogen peroxide in surface snow over Antarctic ice sheet. Atmos. Environ., **30**, 967–972.

Kanamori, S., Kanamori, N., Watanabe, O., Nishikawa, M., Kamiyama, K. and Motoyama, H. (1997): The behavior of chemical components in the snow and atmosphere on the Mizuho Plateau. Nankyoku Shiryô (Antarct. Rec.), **41**, 291–309 (in Japanese with English abstract).

Kapista, A. P., Ridley, J. K., Robin, G. de Q., Siegert, M. J. and Zotikov, I. A. (1996): A large deep freshwater lake beneath the ice of central East Antarctica. Nature, **381**, 684–686.

King, J. C. and Turner, J. (1997): Antarctic Meteorology and Climatology. Cambridge, Cambridge Univ. Press, 408p. (Cambridge Atmospheric and Space Science Series).

Kuhn, M., Kundla, L. S. and Streschein, L. A. (1977): The radiation budget at Plateau Station, Antarctica, 1966-1967. Meteorological Studies at Plateau Station, Antarctica, ed. by J. A. Businger. Washington, D. C., Am. Geophys. Union, 41–73 (Antarct. Res. Ser., **25**).

Motoyama, H., Kawamura, Y., Kamiyama, K. and Watanabe, O. (1998): Snow depositional condition around Dome F area Antarctica. The 21st Symp. Polar Meteorol. Glaciol., Programme and Abstract, November 25–26, 1998. Tokyo, Natl Inst. Polar Res., 38–39 (in Japanese).

Orvig, S. (1970): Climate of the Polar Regions. New York, Elsevier, 370 p. (World Survey of Climatology, 14).

Pook, M. and Gibson, T. (1999): Atmospheric blocking and storm tracks during SOP-1 of the FROST Project. Aust.

Meteorol. Mag., Special Edition, 51–60.
Rusin, N. P. (1964): Meteorological and radiational regime of Antarctica. Translated from Russian by Israel Program for Scientific Translations 1964 for DOC and NSF, Jerusalem, IPST, 355 p.
Schwerdtfeger, W. (1984): Weather and Climate of the Antarctic. Amsterdam, Elsevier, 261 p. (Developments in Atmospheric Science, 15).
Van Loon, H. (1972): Pressure in the southern hemisphere. Meteorology of the Southern Hemisphere, ed. by C.W. Newton. Boston, Am. Meteorol. Soc., 59–86 (Meteorol. Monogr., Vol. 13, No. 35).
Wada, M. (1985): Statistical studies of snow accumulation and snowfall in the coastal and katabatic areas of Antarctica—Observations at Syowa and Mizuho Stations in 1979 and 1980—. Nankyoku Shiryô (Antarct. Rec.), **85**, 1–11.
Watanabe, O. and 12 collaborators (1999): Basic analyses of Dome Fuji deep ice core, Part 1: Stable oxygen and hydrogen isotope ratios, major chemical compositions and dust concentration. Polar Meteorol. Glaciol., **13**, 83–89.
Yamanouchi, T. (1989): Antarctic Climate Research data, Part 2. Radiation data at Syowa Station, Antarctica from February 1987 to January 1988. JARE Data Rep., **144** (Meteorology 22), 193 p.
Yamanouchi, T. and Kawaguchi, S. (1982): Properties of the surface radiation budget at Mizuho Station, Antarctica in 1979. Mem. Natl Inst. Polar Res., Spec. Issue, **24**, 13–18.
Yamanouchi, T., Hirasawa. N. and Hayashi, M. (1999): Report of observation project on “Atmospheric Circulation and Material Cycle in the Antarctic” by JARE-38. Polar Meteorol. Glaciol., **13**, 159–164.
Yamanouchi, T., Hirasawa, N., Kadosaki, G. and Hayashi, M. (2000): Evaluation of AVHRR cloud detection at Dome Fuji Station, Antarctica. Polar Meteorol. Glaciol., **14**, 110–116.

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