Proc. NIPR Symp. Polar Meteorol. Glaciol., 2, 8-15, 1989

UPPER STRATOSPHERIC TEMPERATURE PROFILES OBTAINED BY LIDAR AT SYOWA STATION, ANTARCTICA

Akio NOMURA[1], Hiroshi KANZAWA[2] and Tetsuo KANO[1]

[1]*Faculty of Engineering, Shinshu University,*
500, Wakasato, Nagano 380
[2]*National Institute of Polar Research,*
9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173

Abstract: The upper stratospheric temperature profiles in the height range of 20 to 50 km were measured by use of Rayleigh scattering signals obtained at lidar measurements of the sodium layer during the period from March to October, 1985, at Syowa Station (69°00'S, 39°35'E), Antarctica. At first, in order to test the ability of temperature measurement by lidar, the simultaneous co-operative measurements were carried out by lidar, meteorological rocket (MT-135JA), and sonde soundings. The comparison among those results indicated that the temperature profile obtained by lidar almost agreed with that by rocket sounding in the height range of 20 to 40 km and matched well with that below the height of 20 km by sonde sounding. From the data of 18 nights, it was found that the measured temperature profiles in winter were available because of no disturbance by the aerosol layer which had moved downwards below 25 km as polar stratospheric cloud (PSC). On the other hand, it was found that the profiles in autumn and spring were partly disturbed by the aerosol layer.

1. Introduction

There has been no effective measurement method of temperature profile with fine spatial resolution in the height range of 25 to 80 km except an *in situ* rocket sounding. Recently two methods have been developed by a ground-based lidar technique. In one the temperature profile is estimated from the atmospheric density profile obtained by Rayleigh scattering signals from the air molecules in the height range of 30 to 80 km (HAUCHECORNE and CHANIN, 1980). The other utilizes Doppler broadening of the resonance scattering spectra of the sodium layer in the height range of 80 to 100 km (GIBSON *et al.*, 1979; THOMAS and BHATTACHARYYA, 1980; FRICKE and VON ZAHN, 1985). The former is applied to the work described here.

This paper presents the tempreature profiles in the height range of 20 to 50 km obtained by lidar measurements at Syowa Station (69°00'S, 39°35'E), Antarctica, 1985. Moreover, these results are discussed compared with the results by meteorological rocket (MT-135JA) soundings and those by meteorological sonde soundings.

2. Temperature Profile Measurement

This section describes the procedure of estimating the temperature profile from the data obtained by lidar measurements. As for the lidar system, refer to previous papers (NOMURA *et al.*, 1985, 1987).

The temperature profile is derived from the density profile by assuming that the atmosphere obeys the perfect gas law and is in the hydrostatic equilibrium. Then, the equations are given by:

$$P(z)=\frac{RT(z)}{M}\rho(z)\ , \tag{1}$$

$$\mathrm{d}P(z)=-\rho(z)g\mathrm{d}z\ , \tag{2}$$

where $P(z)$, $T(z)$, and $\rho(z)$ are the air pressure, the temperature, and the atmospheric molecular density at the height of z, respectively, R the gas constant, g the acceleration of gravity, and M the air molecular weight.

Here if temperature is assumed to be constant in the layer between z_1 and $z_2(z_2>z_1)$, the ratio $\rho(z_1)/\rho(z_2)$ is approximately given by

$$\frac{\rho(z_1)}{\rho(z_2)}=e^{\frac{Mg}{RT}(z_2-z_1)}\ . \tag{3}$$

From this equation, the temperature at the height of $\bar{z}(=(z_1+z_2)/2)$ is obtained as

$$T(\bar{z})=\frac{Mg(z_2-z_1)}{R\ln\{\rho(z_1)/\rho(z_2)\}}\ . \tag{4}$$

On the other hand, the density profile is obtained from lidar measurements. The received signals from the layer of thickness Δz at the height of z are given by the lidar equation as

$$n(z)=n_0\frac{CAT_r^2\{\rho(z)(\mathrm{d}\sigma/\mathrm{d}\Omega)_R+\rho_m(z)(\mathrm{d}\sigma/\mathrm{d}\Omega)_M\}}{z^2}\Delta z\ , \tag{5}$$

where n_0 is the emitted photon number, C the optical constant of the lidar system, A the area of the receiving telescope, T_r the transmission of atmosphere, $\rho_m(z)$ the density of the Mie particles, and $(\mathrm{d}\sigma/\mathrm{d}\Omega)_R$ and $(\mathrm{d}\sigma/\mathrm{d}\Omega)_M$ are the Rayleigh and the Mie differential scattering cross section, respectively.

If the atmosphere consists of only neutral molecules without aerosols, the receiving signal $n(z)$ is proportional to the atmospheric density $\rho(z)$. Then, the ratio of the density is approximated to that of the receiving signal as

$$\frac{\rho(z_1)}{\rho(z_2)}=\frac{n(z_1)}{n(z_2)}\ . \tag{6}$$

Consequently we could estmate the temperature profile from the equations of (4), (5), and (6). The relative uncertainty on the temperature profile due to shot noises is given by

$$\frac{\Delta T(\bar{z})}{T(\bar{z})}=\sqrt{\frac{2}{N}}\cdot\frac{1}{\ln\{n(z_1)/n(z_2)\}}\cdot\frac{\Delta n(\bar{z})}{n(\bar{z})}\ , \tag{7}$$

where N is the number of accumulated data.

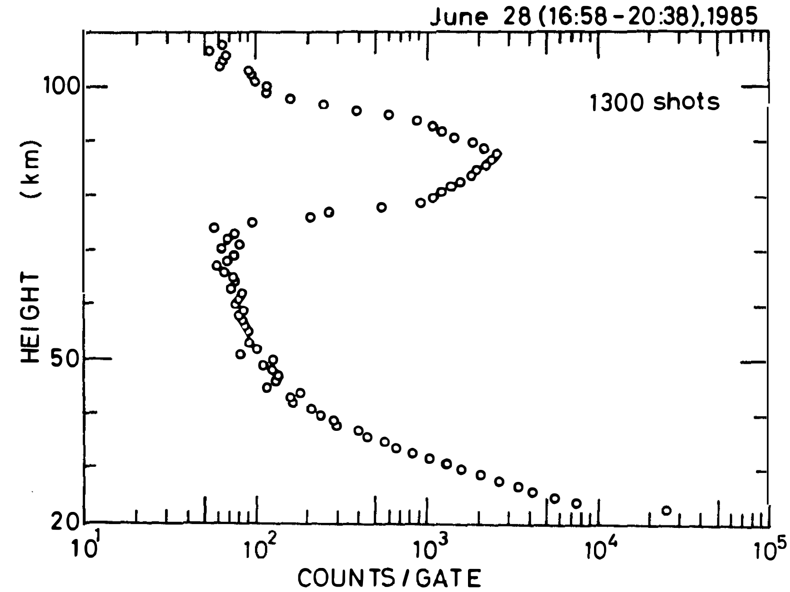

Fig. 1. Vertical profile of echo signals (A-scope) by accumulating the returns of 1300 laser shots on June 28 (1658–2038 LT or 1358–1738 UT), 1985. The height resolution is 1 km.

An example of the lidar echo signals used to estimate the temperature profile is shown in Fig. 1, which has been obtained for the measurement of the mesospheric sodium layer. Rayleigh scattered signals are shown in the height range of 20 to 40 km and the resonance scattered signals are also shown around the mesopause. Although the echo signals are obtained with the height resolution of 1 km, the resolution of the temperature profile is reduced to 2 km by a running average in order to decrease the standard deviation. The time resolution is more than 5 h because of a low repetition rate (10 ppm) of the trasmitting laser. We present the nightly average temperature profiles in this paper.

3. Results and Discussion

3.1. Comparison with meteorological rocket (MT-135JA) soundings

The simultaneous measurements of temperature profile from upper stratosphere to lower mesosphere by lidar and meteorological rockets were made at Syowa Station on June 28–29, 1985. Five rockets were successively launched at intervals of about 2 h (KANZAWA *et al.*, 1986). The temperature profile obtained by lidar is shown in Fig. 2 compared with that by rocket sounding. The meteorological sonde data in the height range of below 21 km is also shown in the same figure. The comparison with each other gives the satisfactory result below 40 km although the values by lidar are slightly lower than those by rocket. Moreover, it is indicated that the profile by lidar matches well with that below 21 km by sonde sounding.

3.2. Seasonal variation of temperature profiles

Data collected for 18 nights during the period from April to October, 1985, are shown in Figs. 3(a)–(r). Meteorological sonde data are also presented in each figure. From these results, it is found that temperature profiles by lidar matches well with

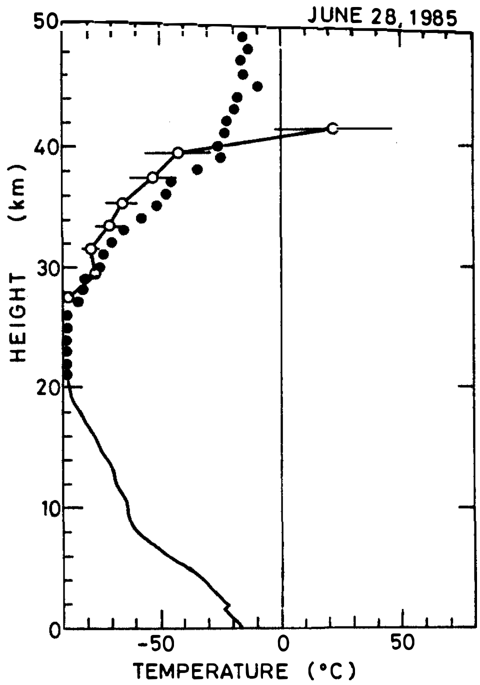

Fig. 2. Comparison of the temperature profile by lidar measurements (○) with that by rocket sounding (MT-135JA) (●). The solid curve below 21 km indicates the temperature profile by meteorological sonde sounding.

those by meteorological sonde only in winter (May to August). During other months (April or September to October), besides mismatching, profiles by lidar show oscillatory variations, which may originate in the disturbance by the aerosol layer. If the aerosol layer is presented, it is expected that the temperature is overestimated in the lower part of the layer and underestimated in the upper part since the temperature is calculated from differentiation of density profile. As an example of the disturbance by the aerosol layer, the data of April 8–9 given in Fig. 3(a) show the oscillatory variation in the height of around 38 km. On the other hand, in winter, it is inferred that the aerosol layer moves downwards below 25 km as polar stratospheric clouds (PSC). Then it is expected that the estimated temperature profiles above 25 km give the available one because of clear atmosphere without aerosols.

The results described above indicate that the data obtained by lidar give qualitatively the seasonal variation of temperature in the upper stratosphere. However, it is difficult to estimate exactly the temperature profile because the estimated profile is easily disturbed by the aerosol layer. It may be possible to eliminate this disturbance by use of multi-wavelengths of laser. In other words, this method can more sensitively measure aerosols.

4. Summary

This paper describes, from an engineering viewpoint, the temperature profile measurement by lidar in the polar middle atmosphere.

The authors made, for the first time, lidar measurements of the upper strato-

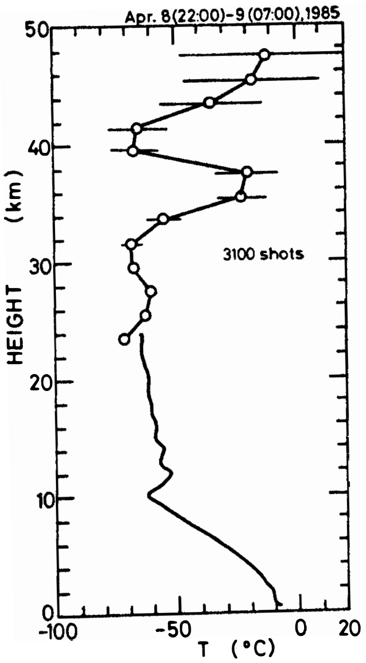

Fig. 3(a)

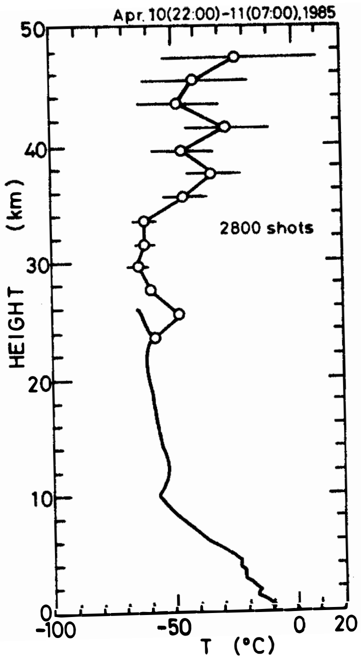

Fig. 3(b)

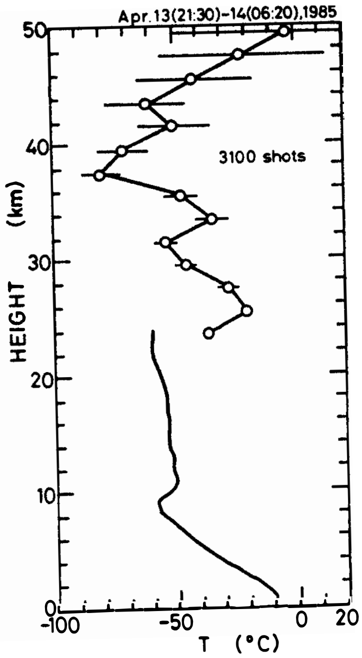

Fig. 3(c)

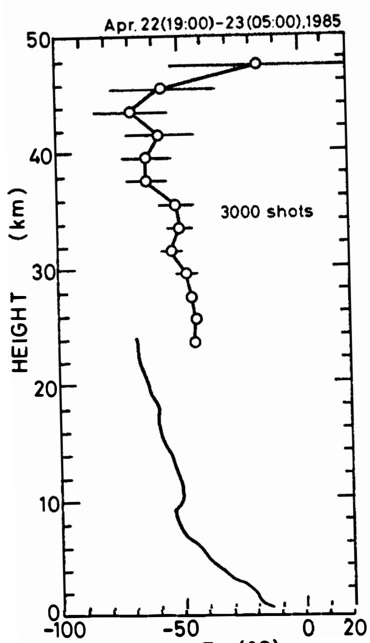

Fig. 3(d)

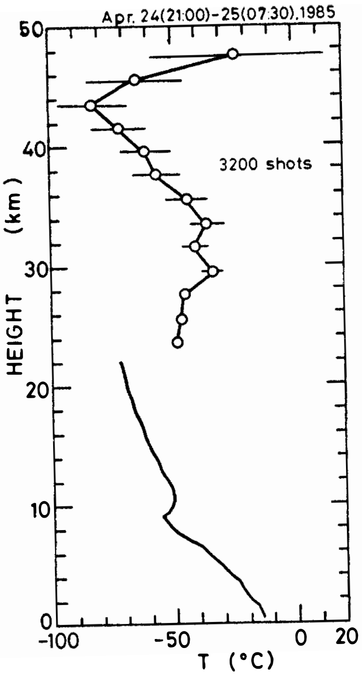

Fig. 3(e)

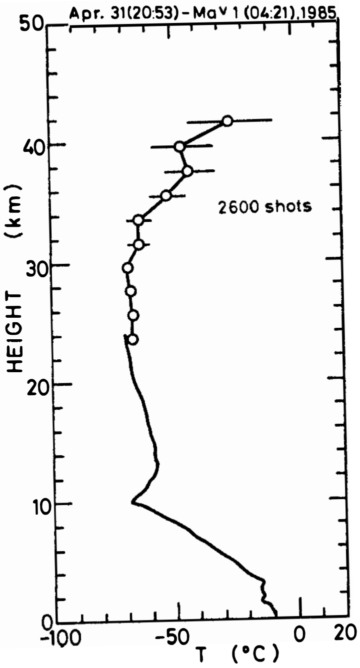

Fig. 3(f)

Fig. 3(a)-(r). Temperature profiles for 18 nights obtained by lidar measurements at Syowa Station during the period from April to October, 1985. Standard deviations by shot noises are indicated by bars. Each temperature profile in the height range of below 25 km is meteorological sonde datum at each night. Date and local time for measurement are shown on the top of each figure. The number of accumulated returns of laser shots is indicated in each figure.

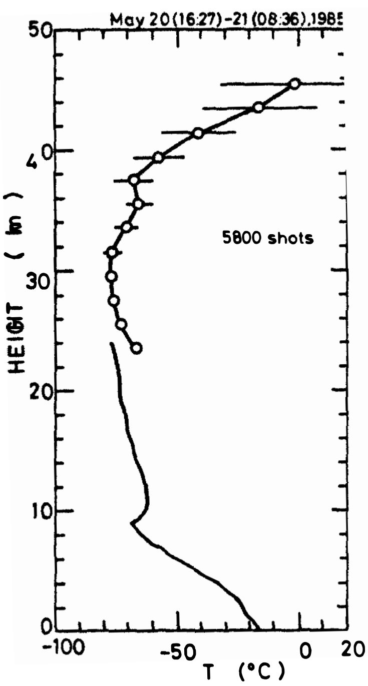

Fig. 3(g)

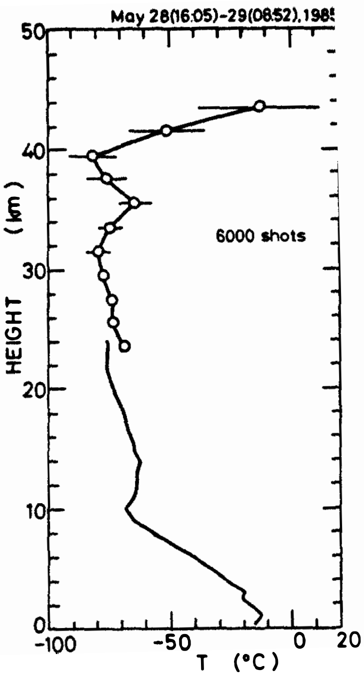

Fig. 3(h)

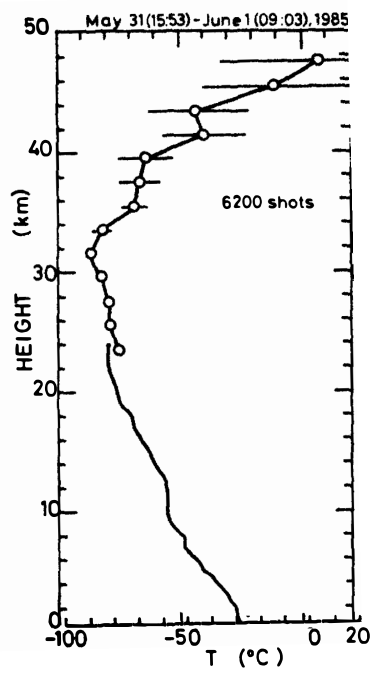

Fig. 3(i)

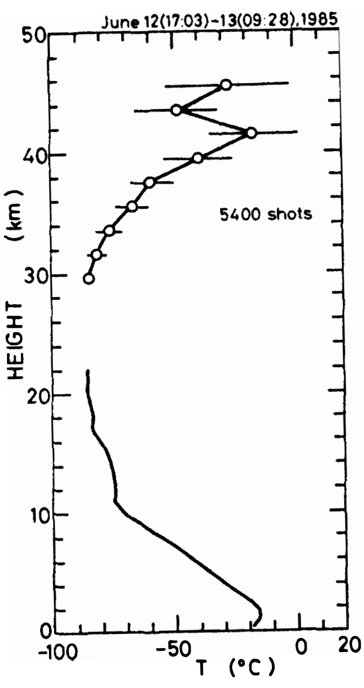

Fig. 3(j)

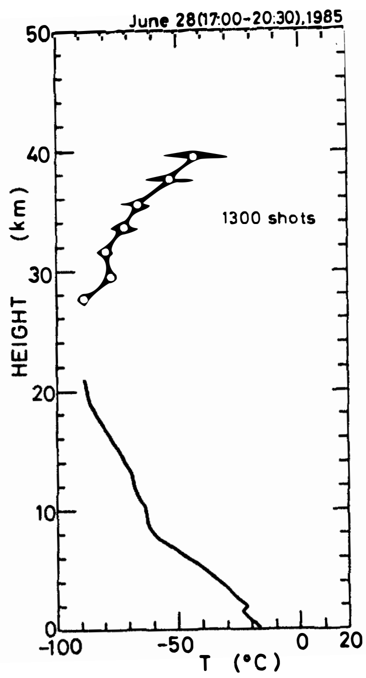

Fig. 3(k)

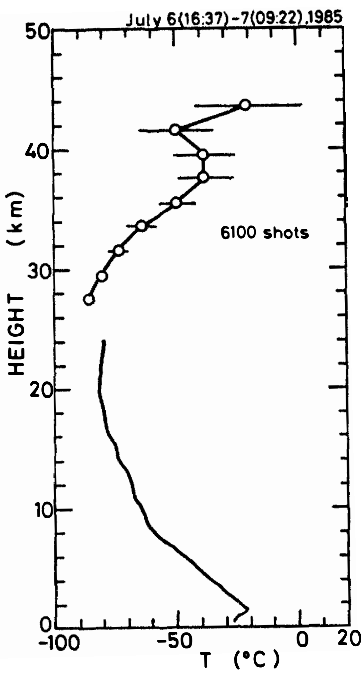

Fig. 3(l)

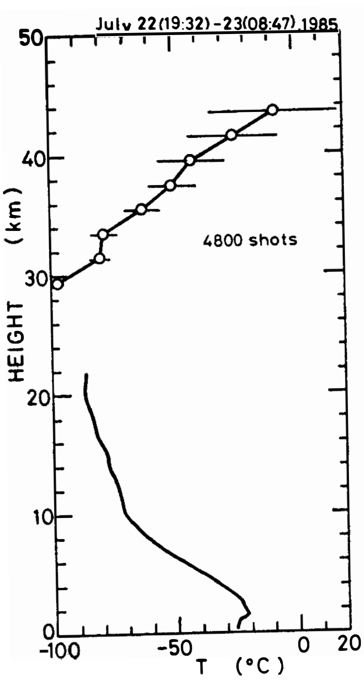

Fig. 3(m)

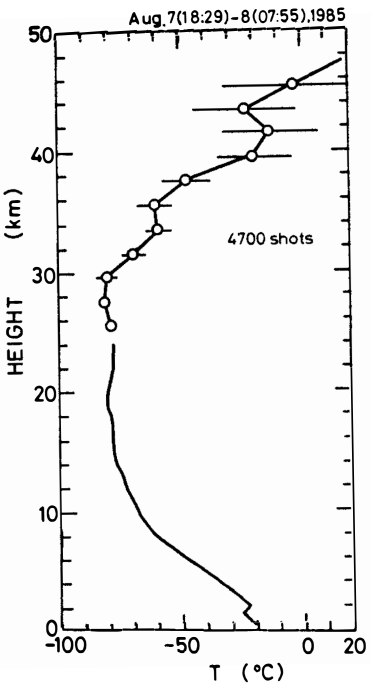

Fig. 3(n)

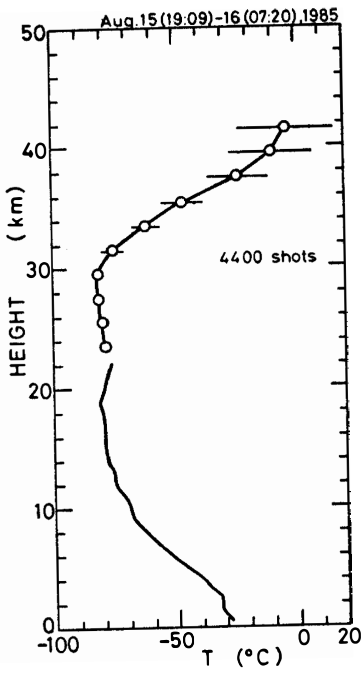

Fig. 3(o)

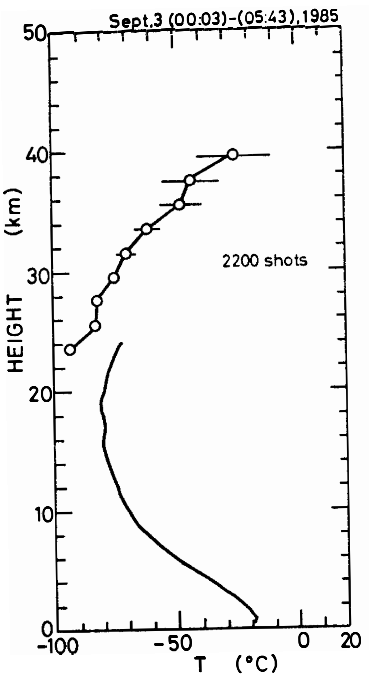

Fig. 3(p)

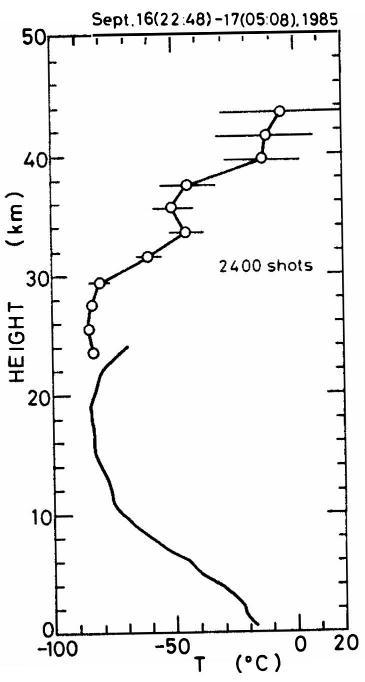

Fig. 3(q)

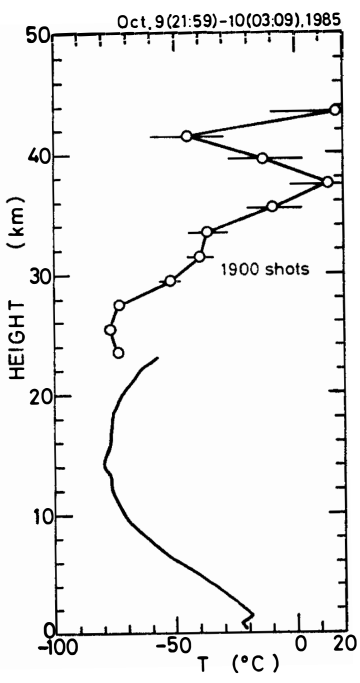

Fig. 3(r)

sphere at Syowa Station in 1985. The comparison with meteorological rocket sounding gives the satisfactory result in the height range of 25 to 40 km. It is found from the seasonal variation of the measured temperature profiles that the profiles are partly disturbed by the aerosol layer in autumn and spring, but that the reliable profiles are obtained in winter because the aerosol layer moves downwards below 25 km.

Although the lidar measurements described here give no good temporal resolution (5 to 12 h) for a low repetition rate (10 ppm) of a flashlamp pumped dye laser, it is possible that temporal resolution reduces to about 10 min and that height range is extended to 70 km if a YAG laser or an excimer laser pumped dye laser is used.

Finally, we suggest that a lidar technique with fine spatial and temporal resolution is one of the powerful ground-based facilities for clarifying the middle atomosphere in the polar region.

References

FRICKE, K. H. and VON ZAHN, U. (1985): Mesopause temperatures derived from probing the hyperfine structure of the D_2 resonance line of sodium by lidar. J. Atmos. Terr. Phys., **47**, 499–512.

GIBSON, A. J., THOMAS, L. and BHATTACHARYYA, S. K. (1979): Laser observations of the ground-state hyperfine structure of sodium and of temperatures in the upper atmosphere. Nature, **281**, 131–132.

HAUCHECORNE, A. and CHANIN, M. L. (1980): Density and temperature profiles obtained by lidar between 35 and 75 km. Geophys. Res. Lett., **7**, 565–568.

KANZAWA, H., ITO, Y., FUKUSAWA, S., YAMAGISHI, H. and KAWAGUCHI, S. (1986): MT-135JA kishô roketto jikken hôkoku (JARE-26) (Report on the MT-135JA meteorological rocket experiment (JARE-26)). Nankyoku Shiryô (Antarct. Rec.), **30**, 219–245.

NOMURA, A., IWASAKA, Y., FUKUNISHI, H., KANO, T., HIRASAWA, T. and KAWAGUCHI, S. (1985): Plan for lidar observations of the polar middle atmosphere in the 26th Japanese Antarctic Research Expedition. Nankyoku Shiryô (Antarct. Rec.), **85**, 62–67.

NOMURA, A., KANO, T., IWASAKA, Y., FUKUNISHI, H., HIRASAWA, T. and KAWAGUCHI, S. (1987): Lidar observations of the mesospheric sodium layer at Syowa Station, Antarctica. Geophys. Res. Lett., **14**, 700–703.

THOMAS, L. and BHATTACHARYYA, S. K. (1980): Mesospheric temperature deduced from laser observations of the Na D_2 line profile. Proceeding of the Vth ESA-PAC symposium on European rocket and balloon programmes and related research, ESA SP-152, 49–50.

(Received February 25, 1988; Revised manuscript received September 17, 1988)