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Report

Sodium temperature lidar observation at Syowa Station: Summary of three-year observations and unusually high temperature in 2002

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Abstract: Total 223 nights (2002 hours) of temperature measurement in the mesopause region (80–105 km) was successfully done in wintertime at Syowa Station (69°S, 39°E) starting from 2000 through 2002. Monthly mean temperatures were calculated using nightly mean temperatures and year-to-year variation was examined. The monthly temperature of 2002 shows unusually higher (25 K and 20 K) in June and July compared with previous 2 years. Variations of individual nights showed the temperatures at 80 km, 85 km and 110 km are in good agreement among three years through the observation period. The temperature of 2002 began to increase from the middle of May and was back to normal around the end of July in the limited altitude range of 90–105 km.

key words: lidar, Syowa Station, Antarctica, mesopause region, temperature

1. Introduction

The sodium layer (75–110 km) in the mesopause region originates from meteor ablation and is used as an excellent tracer to search chemical and dynamical activity of the upper atmosphere. The altitude region of the layer covers the coldest part of the atmosphere -the mesopause- which occurs near 86 km in summer and 100 km in winter (She and Von Zahn, 1998; She *et al.*, 2000). Also large planetary, tidal and gravity wave activity in this region plays a vital role in overall global circulation (Holton and Alexander, 2000). Among remote sensing technologies employed to study the middle and upper atmosphere, lidar techniques are unique in their ability to provide high spacial and temporal resolution data on constituent structure of this region. Sodium lidar is one of the most useful instruments which are commonly used for the measurement of sodium density variation, tide and gravity waves (Clemesha *et al.*, 1982; States and Gardner, 1999; Plane *et al.*, 1999). In addition, recent laser technology enabled us to measure both temperature and wind (Sherman *et al.*, 2003 and references therein). Currently, sodium lidars are one of the most accurate remote sensing instruments used to measure the temperatures in this region. Unfortunately these narrow-band sodium lidar systems are so complicated and preclude their use at remote sites such as in Antarctica. For global-scale observations, the development of a robust tempera-

ture lidar was clearly necessary. Antarctica is one of the most attractive places where little temperature information in the middle atmosphere has been obtained. For the purpose of the Antarctic lidar project, Shinshu University group made a solid-state sodium temperature lidar based on injection seeded Nd:YAG lasers (Kitahara *et al.*, 1998). Though other kinds of metallic temperature lidars such as a K lidar (Von Zahn *et al.*, 1996; Friedman, 2003) or an Fe/Boltzmann lidar (Chu *et al.*, 2002) were developed in several groups, our lidar has an advantage of its simple mechanism to produce narrowband 589 nm laser line, lower maintenance, and easy operation.

The temperature in the Antarctic mesopause region has become a great topic of discussion. The lidar observation at Syowa Station (69°S, 39°E) was conducted in wintertime from 2000 through 2002. Based on monthly mean temperatures of the first two years, colder temperature in the Antarctic mesopause region was reported by comparing with the lidar data at Andøya (69°N) (Kawahara *et al.*, 2002). In Antarctic region, Burns *et al.* (2003) discussed the location difference of the temperature at 87 km altitude using OH measurement at Davis (69°S, 78°E) and the lidar data at Syowa. Espy *et al.* (2002) showed from Rothera data (68°S, 68°W) rapid variations in temperature were associated with large swings observed in the meridional component of the mesospheric wind measured. At South Pole, Fe/Boltzmann lidar made temperature measurements in the same observation period at Syowa (Gardner *et al.*, 2001; Pan *et al.*, 2002; Pan and Gardner, 2003). Kawahara *et al.* (2004) made an empirical model from the ground to 110 km using balloon and Na/Rayleigh lidar data, and discussed the difference between the South Pole empirical model (Pan and Gardner, 2003) and MSIS-00.

During the observation period in 2002, the Antarctic vortex split in September, resulting in large increases in stratospheric temperatures. In the mesopause region, Hernandez (2003) reported as much as 35 K colder winter temperature at 88 km in 2002 based on 11 years observation at South Pole. This observation suggested the temperature anomaly occurred in the mesopause region as well.

In this paper, we show the year-to-year variation of the Syowa temperature for the three-years. Unusually high temperature in June and July 2002 is suggested.

2. Summary of observations

The Shinshu University sodium temperature lidar started nocturnal observation from March 2000 to 2002 at Syowa Station (Kawahara *et al.*, 2002). The laser beam (narrowband 589 nm) was pointing zenith direction to measure vertical profiles of sodium density and temperature simultaneously. The observation was limited in nighttime because any ultra-narrowband filters such as a Faraday filters were not used. The lidar was operated in 2-frequency technique which was established by the Colorado State University group (She *et al.*, 1990). The temporal and height resolution is 6 min and 0.96 km, respectively. The observation in Antarctica was successfully done without any instrumental troubles during the observation period. Table 1 shows the number of the observation nights in every month. Only before May 2000, the 2-frequency technique was not applied though the observation was carried out. Each winter, at least ~50 days/year of observation was conducted if weather permitted. Especially in 2002, blessed with great weather, one hundred and four days of observation was successfully achieved. Total observation days in a month are also excellent

Table 1. Observation day numbers of sodium temperature lidar from 2000 to 2002. Two-frequency mode was not applied in March and April 2000.

	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Total
2000	-	<7>	<9>	10	6	12	8	18	1	55
2001	-	8	4	4	15	12	12	7	2	64
2002	3	15	12	13	16	14	11	14	6	104
Total	3	23	16	27	37	38	31	39	9	223

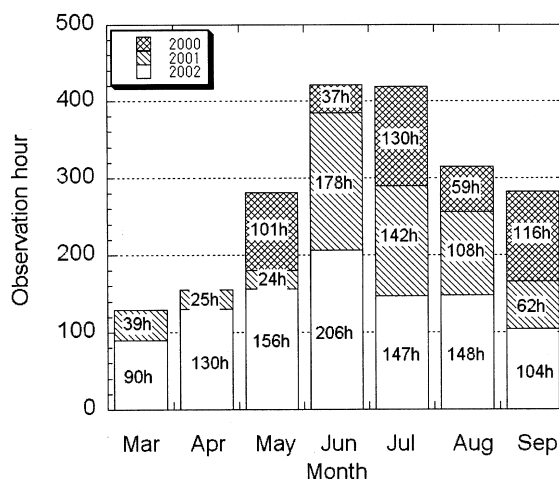


Fig. 1. Monthly observation hours of a sodium temperature lidar observation at Syowa Station between 2000 and 2002.

covering over 30 days/month from June to September. Total observation days for three years are 223. Monthly observational hours are shown in Fig. 1. In June and July, more than 400 hours of observations were achieved in a month. Note that at the Syowa location, night hour is longest (~16 hours) in June and July. In the three years, totally 2002 hours of data were completed. In each night, nightly and hourly mean temperatures and sodium densities were calculated using Hanning window vertical smoothing with 3.7 km FWHM.

3. Monthly mean temperature variation

In Figs. 2a–2g, we show the monthly mean temperatures for three years from March to September. The monthly mean values were calculated using all the nightly mean data in each month. Since the temperature measurement uncertainty (quadrature sum of frequency and photon noise uncertainties) is considerably less than daily variability, we only give the day-to-day standard deviation as error bars in the figures. Temperature variation within a night was typically 7–10 K at 95 km. Kawahara *et al.* (2002) showed monthly mean temperature structures using the 2000 and 2001 data. Here we discuss year-to-year variation of

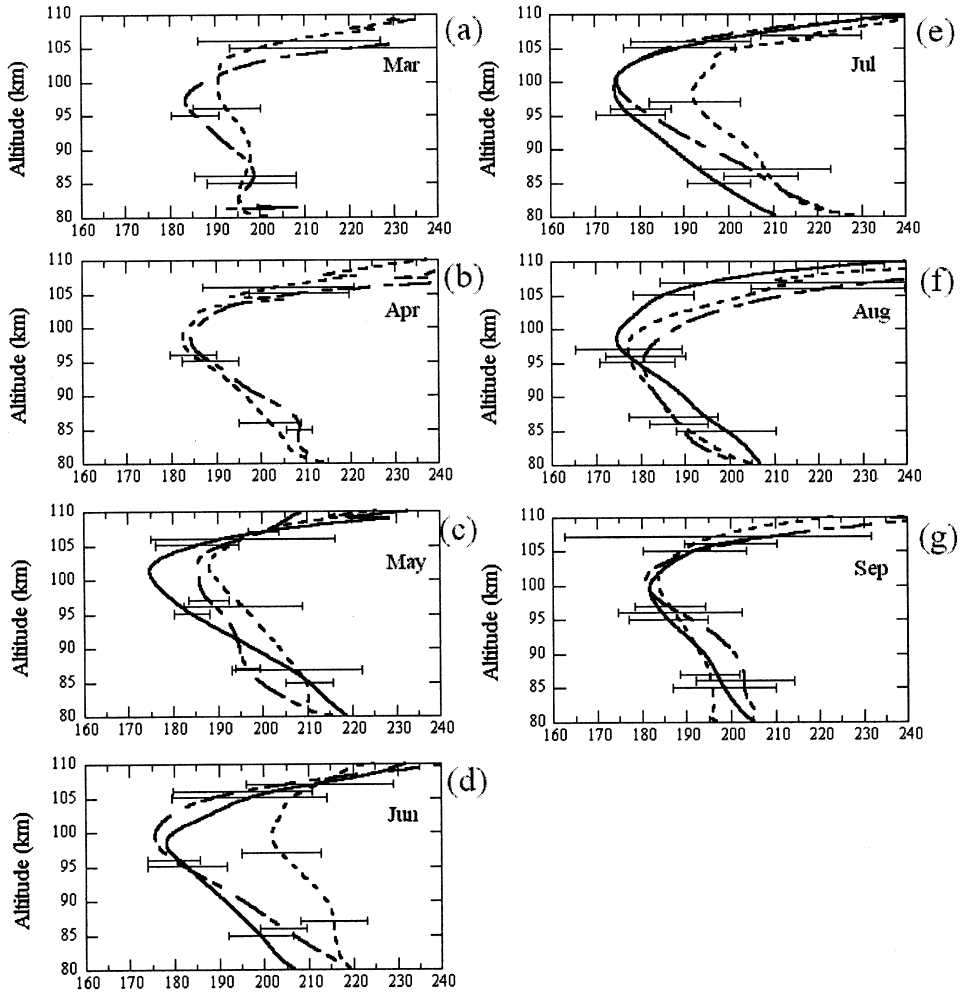


Fig. 2. Monthly mean temperature profiles from March to September. Solid, dot-dashed, and dashed lines indicate the temperature of 2000, 2001, and 2002, respectively. The error bar indicates standard deviation of nightly mean temperatures.

monthly mean temperatures at Syowa. In fall (March, April) and spring (September) month, the temperatures of 2001 and 2002 are in good agreement with each other within error bars, although the errors are large. In July, the temperatures are similar structure above 95 km and mesopause temperatures show about 175 K which is about 20 K lower than Andoya (69°N) in the same month (Kawahara *et al.*, 2002). As for the 2002 data in March and April, the temperature is well consistent with other years. In May, temperature of 2000 drastically decreased, and in June, also temperature of 2001 decreased. However, temperature of 2002 increased in June in contrast. Higher temperature in 2002 continued until July. The mesopause temperature difference is as much as 25 K and 20 K in June and July,

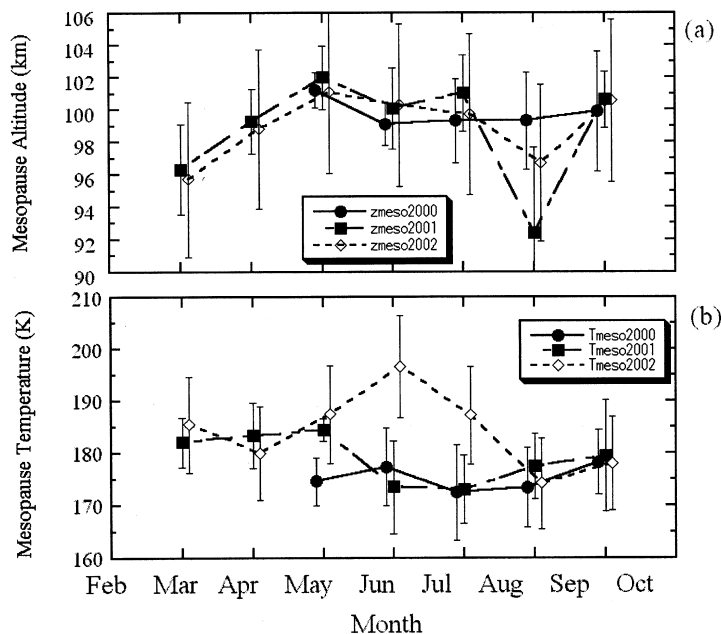


Fig. 3. (a) Monthly mean mesopause altitude and (b) mesopause temperature. The error bar indicates standard deviation of nightly mean mesopause altitude and temperature.

respectively. In August, the temperature of 2002 decreased and the difference between the three years became smaller. Then the three profiles became similar in September. It is noticeable that the temperatures at the edge of the sodium layer (~ 80 km, ~ 110 km) are consistent for three years even in June and July. Clearly the altitude region only around 95–100 km in 2002 indicates higher temperature.

Monthly mean mesopause altitude and temperature are plotted in Fig. 3a and 3b, respectively. The error bar indicates the standard deviation of the nightly mean values. The mesopause altitude of 2002 well agrees with those of previous years. In March and April, the mesopause altitude is in a transition phase from the lower altitude (e.g., ~ 86 km in summer northern hemisphere). In wintertime, it is located around 100 km which is called “winter” or “regular” mesopause level (She and Von Zahn, 1998; Berger and Von Zahn, 1999). The low mesopause altitude of August 2001 is suggested as a local phenomenon inferred by Burns *et al.* (2003) comparing with OH rotational temperature at 87 km measured at Davis (69°S , 78°E). Though the error bar is larger than other years, mesopause altitude of 2002 is in good agreement during the observation period. In Fig. 3b, the mesopause temperature of 2002 is consistent with other years’ except Jun and July.

Daily mean temperature variation

In order to examine the unusual 2002 temperature in detail, day-to-day variation of the temperature at selected altitudes are shown versus day of year (DOY) in Figs. 4a–4f. The temperatures are extracted from nightly mean values of each day. For an emphasis on 2002

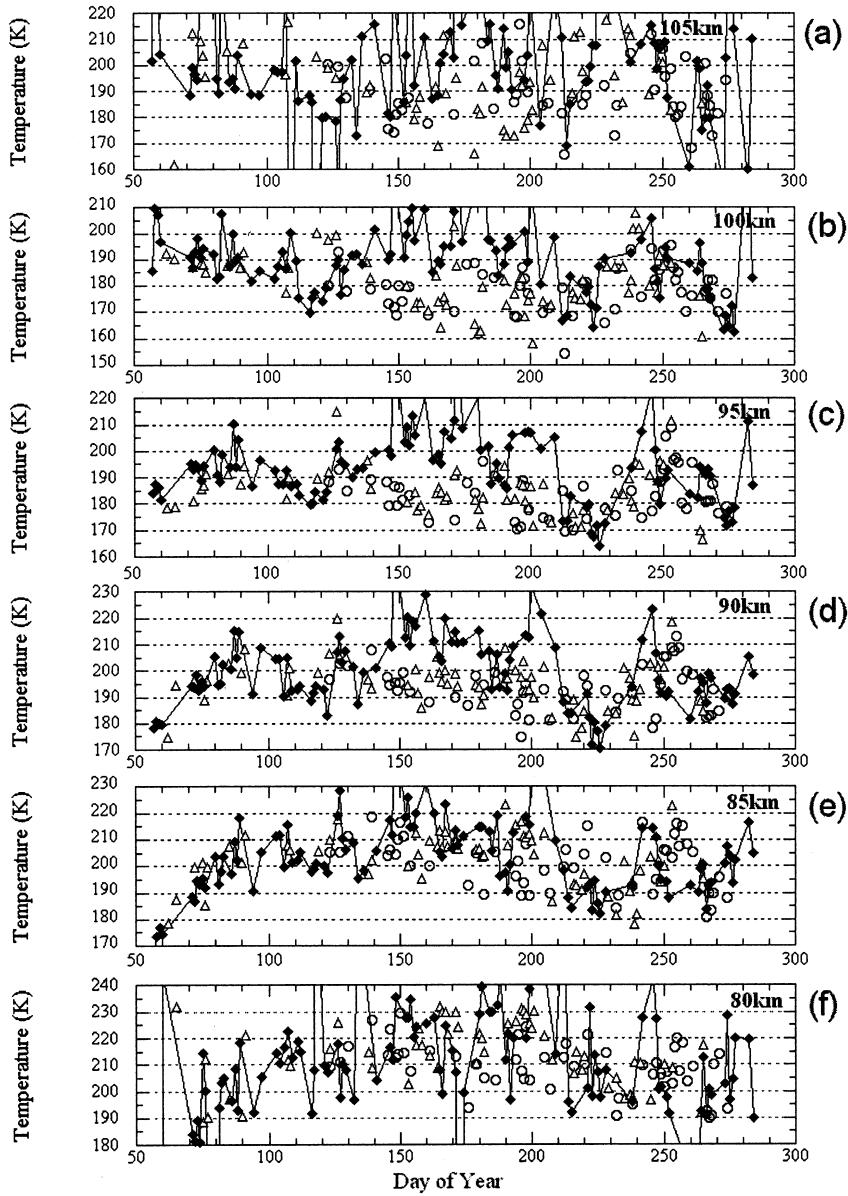


Fig. 4. Day-to-day variation of nightly mean temperatures at the altitude of (a) 105 km, (b) 100 km, (c) 95 km, (d) 90 km, (e) 85 km and (f) 80 km versus day of year. Open circle, open triangle and closed diamond show 2000, 2001 and 2002 data, respectively.

data in the figure, closed diamond with lines is used. Clearly at each altitude, the three-year temperatures are in good agreement before DOY 130 (in the middle of May) and after DOY 210 (in the end of July). At 80 and 85 km, the 2002 temperature is comparable to other years in the observation period. All the monthly mean temperatures at these altitudes are identical within the standard deviation of variation. (*e.g.*, in June, 207 ± 8 K, 220 ± 9 K and 220 ± 12 K, at 80 km for 2000, 2001 and 2002, respectively.) However, the temperatures between 90 and 105 km are different. Those before DOY 130 in 2002 are similar to previous years. Then the temperatures largely increased. The difference of monthly average temperatures becomes more than 20 K in June (*e.g.*, at 90 km, 183 ± 9 K, 182 ± 5 K and 207 ± 8 K, for 2000, 2001 and 2002, respectively). Also, the variation in 2002 is much larger than the others. After the end of July, temperatures of three years become again comparable. At 110 km (not shown in this figure), the temperatures for three years are comparable though the error is large because of the edge of sodium layer. The averages are 231 ± 33 K, 245 ± 25 K, 225 ± 17 K, for 2000, 2001 and 2002 in June, respectively. This indicates the daily mean temperatures in 2002 are unusually higher than previous years between DOY 130 and 210, and between 90 and 105 km.

4. Discussion

Our measurement technique is what is called 2-frequency technique which tunes the narrowband laser wavelength to sodium D_{2a} peak and between D_{2a} and D_{2b} , alternately (She *et al.*, 1990). The signal ratio is a function of temperature. The temperature calculation is based on the tuned wavelengths during the observation. It is possible that wrong wavelength tuning mislead the wrong temperature. However, we checked the wavemeter every couple of months in the observation period and made sure that the condition of the calibration was all the same. If the monitored wavelengths were correct all the time, a personal computer always tunes to the right wavelength. And if the wavelength came into possession of an offset for some reasons, the calculated temperature structure should wholly shift to higher or lower. Since the temperature only between 90–105 km region shows higher, this cannot explain the observational results.

At Syowa, MF radar also shows unusual wind in the mesopause region. Zonal wind in the mesopause region in winter Antarctica is typically eastward (~ 20 m/s). However, in June and July 2002, the wind velocity at 80 km was 10–15 m/s smaller than the other years. Also meridional wind in the same period changed from southward to northward (Tsutsumi, private communication). One of the reasons that the unusual altitude region between the temperature and the wind is different is that MF data is not reliable more than 90 km altitude. It is well known that the wind field in the mesopause region is driven by gravity waves propagated through stratosphere (Holton and Alexander, 2000, and references therein). The wind anomaly in the mesopause region suggests an unusual filtering effect of gravity waves in the stratosphere.

The temperature in the mesopause region in 2002 is controversial. In 2000 and 2001, winter temperatures between Syowa (69°S), South Pole (90°S) and Davis (69°S) were in good agreement (Kawahara *et al.*, 2002, 2004; Pan *et al.*, 2002; Burns *et al.*, 2003). However, Hernandez (2003) suggested that the mean measured 2002 polar night temperatures are about 35 K cooler than the mean for the previous 11 years. In contrast, Syowa temperature

at 87 km in 2002 indicates warmer (*e.g.*, 215 ± 7 K in June) than previous 2 years (194 ± 5 K in 2000, 200 ± 6 K in 2001). At Davis, 2002 temperature is in the range of year-to-year variation based on a long-term observation (Burns, private communication). This discrepancy is not well explained with these individual ground based observations. The temperature data from SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) on board TIMED satellite will make clear the horizontal temperature distribution.

The lower atmosphere in 2002 was also unusual in Antarctica. At Syowa, the temperature in the lower stratosphere was also higher than previous 2 years. In 2000 (2001), polar stratospheric clouds, PSCs, were continuously observed between June 9th (20th) and August 7th (25th). The numbers of observed days for PSCs per observation days between June and August are 16/25 (64%) in 2000 and 21/39 (53%) in 2001. In contrast, the PSCs in 2002 were observed between July 3rd and August 26th and the number of observed day was only 11 for 41 observation days (27%). The warm lower stratosphere in 2002 was clear. And in August and September, a large planetary wave activity in the winter stratosphere weakened and warmed the polar vortex. Polar vortex was split in September. The smallest ozone hole in record was observed in 2002, though it was the largest in 2000 and the third largest in 2001. However it is still unclear that the continuous warming in the stratosphere and the mesopause region are related with unusual planetary wave activity. The temperature anomaly measured by the lidar should be examined further with MF wind data and the stratospheric temperature.

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