Mesospheric Ozone Density Profiles in the Polar Region

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Altitude distributions of mesospheric ozone were measured by rocket-borne radiometers in the polar region. The rocket observations were carried out in February and November, 1994 at Andoya (69°N, 16°E), Norway in the twilight condition. Mesospheric ozone densities in 60–100 km altitude region were measured by using the O$_2$ 1270 nm emission as well as the measurements of nitric oxide and stratospheric ozone densities. A clear secondary maximum of ozone density around 88 km and a deep valley around 78 km were seen in both months. The densities of the secondary maximum in February and November were 3.9 x 10$^7$ cm$^{-3}$ and 7.1 x 10$^7$ cm$^{-3}$, respectively.

1. Introduction

The study of atmospheric ozone is one of the most important subjects of the middle atmosphere. It is well known that ozone provides the heat source of the atmosphere and works as the shield of the harmful ultraviolet radiation from the sun. Many works have been done on stratospheric ozone study (for example, McPeters et al., 1984), but few investigations of mesospheric ozone have been carried out, especially in polar region. The global distribution of mesospheric ozone above about 70 km is provided from only the data obtained by the O$_2$ 1270 nm measurement on the Solar Mesosphere Explorer (SME) satellite (Thomas et al., 1984b; Keating et al., 1990; Thomas, 1990). The longitudinal coverage of the SME is principally from 40°W to 100°W. Because of insufficient solar illumination in winter season, no data was obtained in high latitude regions by SME.

For mesospheric ozone above about 70 km in high latitude regions, several rocket observations by using the solar occultation and O$_2$ 1270 nm methods have been carried out (for example, Evans and Llewellyn, 1972; Miller and Ryder, 1973). The higher the altitude, the lower the sensitivity of the solar occultation method. The 1270 nm method is believed in to provide the most accurate ozone distribution in the altitude region above about 70 km. There are not so many mesospheric ozone observations by using the 1270 nm method onboard scientific rockets (for example, Evans and Llewellyn, 1972; Yamamoto et al., 1983; Batista et al., 1996). In polar region, only the observation by Llewellyn and Witt (1977) provides the density profile of the mesospheric ozone.

A possibility that NO produced in the lower thermosphere by auroral particles perturbs stratospheric ozone in polar regions has been pointed out (for example, Solomon et al., 1982). Two rocket experiments to investigate the possibility were carried out from Andoya Rocket Range (ARR) in Norway (69°N, 16°E). The first one was done on Feb. 16, 1994 and the second one on Nov. 24, 1994. Near infrared radiometers including the 1270 nm region were loaded on the both rockets to measure the ozone density distribution in 60–100 km. The paper presenting the observational results on the NO disturbance on stratospheric ozone is now in preparation (Iwagami et al., private communication). Mesospheric ozone density profiles obtained by the two rockets are shown in the present paper.

2. Instrument

The filter radiometers to measure the O$_2$ 1270 nm radiation were loaded on the sounding rockets S-
310-22 and S-310-23 together with the other scientific instruments. A brief explanation of the instruments on board the rockets has been presented elsewhere (Iwagami et al., 1994).

The instrument to measure the airglow emissions in the near infrared wavelength region (AIR) loaded on board the S-310-23 rocket is shown in Fig. 1. The instrument on the S-310-22 rocket was similar to what shown in Fig. 1. Each of them had three-filter radiometers. All radiometers were mounted, looking forward, with their optical axes parallel to the rocket spin axis, and consisted of an optical hood, an interference filter with 30 mm diameter, an optical lens and a sensor with electronic components. To modulate the incoming radiation, a rotating chopper with a frequency of 190 Hz was set in front of the filters. The effective diameter and the focal length of each lens were 25 mm. As the diameter of each sensor was 2 mm, maximum slant incident angle of the filter was about 4.5°. There is an effect of wavelength shift for the radiation with the incident angle larger than 0°, although the effect is small (see Yamamoto et al., 1995). However, the transmission functions of the filters were corrected by taking account of this effect.

The filter radiometers measured near infrared radiation at three different wavelengths in both rocket observations. The central wavelengths were 1269.4 nm, 1260.9 nm, 1245.8 nm for the S-310-22 rocket, and 1267.7 nm, 1259.7 nm, 1384.6 nm for the S-310-23 rocket, respectively. The filter transmission function for the 1270 nm radiation of the S-310-23 rocket is shown in Fig. 2. The band spectrum of the \( \text{O}_2(1\Delta_g - 3\Sigma_u^-) \) (0,0) transition, assuming its rotational temperature to be 200 K, is also shown in the same figure. In case of the filter shown in Fig. 2, the band capture function for the \( \text{O}_2(1\Delta_g - 3\Sigma_u^-) \) (0,0) transition,
which expresses the efficiency of a filter for a transmission of certain bands or lines, is 0.272. As the filter passband was very narrow (about 6 nm), the band capture functions for other airglow bands, for example for the OH(7–4) and OH(8–5) bands, are negligibly small. The altitude profiles of the 1270 nm radiation were obtained by using only the radiometer output of which central passband were 1269.4 nm for S-310-22 rocket and 1267.7 nm for the S-310-23 rocket, respectively.

The photo sensors used in the present experiments were Ge photodiodes for the S-310-22 and InGaAs photodiodes for the S-310-23. Each sensor was cooled by a thermo-electric cooler with an electric power of 0.7 W (1.0 V, 0.7 A). The Ge sensors were operated at about −40°C and the InGaAs sensors at about −20°C during each flight. The radiometers were calibrated by using the blackbody radiant source before the flights. As an onboard calibration source, near infrared LEDs of which the central emitting wavelength is 1300 nm was used, no variation of the response was found during the flight. The time constants of all the lock-in amplifiers were 30 ms. The noise equivalent radiance of the radiometer, measuring the O\(_2\) 1270 nm emission was determined to be 38 kR for the S-310-22 and 9.8 kR for the S-310-23 with electronic time constants of 30 ms from the flight data.

3. Rocket Flight

The S-310-22 rocket was launched from ARR in Norway at 07:52 UT on February 16, 1994. It was just after the local sunrise, and the solar zenith angle (SZA) was 89°. The S-310-23 rocket was also launched from ARR at 10:20 UT on November 24, 1994. It was just before the polar night condition, and SZA was 90°. In both cases, the magnetic conditions were quiet and the atmosphere above about 70 km were under full sunlit condition during the measurements. The apogees of each rocket were 192 km and 199 km, respectively. The periods of spins and precessions of both rockets were nearly the same, being about 1 s and 150 s, respectively. The rocket angles to the zenith were around 20° for the S-310-22 and 11° for the S-310-23 when the rocket flew through 60–100 km altitude region in ascent phase.
4. Results

4.1 Zenith radiance of the O$_2$ 1270 nm emission

The overhead radiance measured above about 120 km showed constant values in both flights. To obtain the zenith radiance, the Van Rhijn correction were made after subtraction of the constant value from the output signals. Figure 3 shows the altitude profiles of zenith radiance of the O$_2$ infrared atmospheric band obtained in ascent measurements. The data points shown in the figure represent the averaged radiance in 0.38 sec, which corresponds to about 0.6 km height width around 60–80 km height and about 0.5 km in 80–100 km. Each overhead radiance point shown in Fig. 3 has the error of about 7.6 kR for the February measurement and about 1.0 kR for the November one. In all altitude region, the radiance obtained in November was about 30–100% stronger than that in February.

4.2 Volume emission rate

In order to get the volume emission rate (VER) profiles, subtraction between the successive two data points shown in Fig. 3 was made for the November measurement. On the other hand, because of the larger instrumental noise, the fifth polynomial fitting to the data points in 8 km height width was adopted for the February measurement. The polynomial was differentiated with respect to height to obtain VER profile. Therefore, the altitude resolution of the November measurement was about 1 km and that of the February one was about 3 km. VER profiles obtained in the ascent measurements are shown in Fig. 4. The descent profiles are nearly the same as the ascent ones above 80 km. As the rockets began to tumble at around 80 km in descent phase, it was difficult to correct the Van Rhijn effect, then only the ascent profiles are used to obtain the ozone density distributions. The VER around 88 km in November was about twice as strong as that in February, and the November VER in 65–73 km was stronger than the February one.

4.3 O$_2$(1$\Delta_g$) density

O$_2$(1$\Delta_g$) densities are obtained from VER profiles by the relation of

$$[\text{O}_2(1\Delta_g)] = \frac{\text{VER}}{A_{00}}, \quad A_{00} = 2.58 \times 10^{-4} \text{ s}^{-1} \quad \text{(Badger et al., 1965)}$$

(1)

Fig. 3. Altitude profiles of the O$_2$ 1270 nm zenith radiance obtained in ascent measurements. ○: S-310-22 (Feb. 16, 1994), □: S-310-23 (Nov. 24, 1994).
where bracket represents the density and $A_{00}$ is the transition probability of the $O_2(^1\Delta_g - ^3\Sigma_g^-) (0,0)$ transition. Density profiles of $O_2(^1\Delta_g)$ in February and November are shown in Fig. 5. Except for the valley around 77 km, $O_2(^1\Delta_g)$ densities in November are higher than those in February at 65–95 km. Most noteworthy feature was a wave-like structure with a vertical wavelength of about 5 km in the November profile. As the detection sensitivity of the February measurement was about five times as low as the November one, the February instrument could not observe such a wave-like structure even if there was same structure in February.

![Graph showing density profiles](image)

**Fig. 4.** The $O_2$ 1270 nm volume emission rates obtained from the zenith radiance profiles shown in Fig. 3. •: S-310-22, ○: S-310-23.

![Graph showing density distributions](image)

**Fig. 5.** The $O_2(^1\Delta_g)$ density distributions deduced from the profiles shown in Fig. 4. •: S-310-22, ○: S-310-23. Horizontal bars associated with the solid circles represent the one sigma deviation from the average. The deviations for S-310-23 data are smaller than the size of the open circles.
5. Ozone Density

5.1 Production processes of \(O_2(1\Delta_g)\) in sunlit atmosphere

The dominant production source of \(O_2(1\Delta_g)\) is the photodissociation of ozone by solar ultraviolet radiation in 210–310 nm (Hartley band), that is

\[
O_3 + h\nu(210 < \lambda < 310 \text{ nm}) \rightarrow e_{H} \rightarrow O_2(1\Delta_g) + O(1D),
\]

where \(e_{H}\) represents the photodissociation rate of ozone in Hartley band. It is about \(8.4 \times 10^{-3} \text{ s}^{-1}\) at the top of the atmosphere. The production efficiency of \(O_2(1\Delta_g)\), \(\varepsilon\), is 0.9 (Thomas et al., 1984b).

Although main production process of \(O_2(1\Delta_g)\) is reaction (2) in sunlit atmosphere, the following three processes have to be taken into account. Excess energy of \(O(1D)\) produced by the reaction (2) may also be transferred to the \(O_2(1\Delta_g)\) state through the following steps.

\[
O(1D) + O_2 \rightarrow k_1 \rightarrow O_2(1\Sigma) + O,
\]

and the \(O_2(1\Sigma)\) produced in reaction (3) is de-excited and produces \(O_2(1\Delta_g)\):

\[
O_2(1\Sigma) + M \rightarrow k_2 \rightarrow O_2(1\Delta_g) + M,
\]

where \(M\) represents any molecule. Otherwise, \(O(1D)\) is quenched by

\[
O(1D) + N_2 \rightarrow k_3 \rightarrow N_2 + O.
\]

The reaction coefficient \(k_1\) is \(3.2 \times 10^{-11}\exp(70/T) \text{ cm}^3\text{s}^{-1}\), \(k_2\) is \(3.9 \times 10^{-17} \text{ cm}^3\text{s}^{-1}\) for \(M = O_2\) and \(2.1 \times 10^{-15} \text{ cm}^3\text{s}^{-1}\) for \(M = N_2\), and \(k_3\) is \(1.8 \times 10^{-14}\exp(110/T) \text{ cm}^3\text{s}^{-1}\) (JPL, 1992). This process contributes about 10–20% to the main source (2). The next one is resonance absorption of sunlight at \(\lambda = 762 \text{ nm}\) by ground state \(O_2\). That is

\[
O_2 + h\nu(\lambda = 762 \text{ nm}) \rightarrow J_{762} \rightarrow O_2(1\Sigma),
\]

where \(J_{762}\) represents the rate of solar resonance absorption. It is about \(5.2 \times 10^{-9} \text{ s}^{-1}\) (Makino et al., private communication) at the top of the atmosphere. Following (6), \(O_2(1\Delta_g)\) is produced through the reaction (4). The contribution of this process can reach about 80% of the total production of \(O_2(1\Delta_g)\) at 75–80 km at SZA = 90°. The last process is three-body atomic oxygen recombination,

\[
O + O + M \rightarrow k_4 \rightarrow O_2(1\Delta_g) + M.
\]

Here \(k_4\) represents the rate of the three body reaction, which is \(9.4 \times 10^{-34}\exp(484/T) \text{ cm}^3\text{s}^{-1}\) (Campbell and Gray, 1973), and Yamamoto et al. (1992) reported that the production efficiency of \(O_2(1\Delta_g)\) through the reaction (7), \(\eta\), was 0.75 from the rocket observation of the \(O_2\) 1270 nm nightglow. The recombination process does not contribute significantly below 90 km.
5.2 Ozone density

The loss mechanisms of $O_2(1\Delta_g)$ are the radiation process at 1270 nm and a quenching process by $O_2$, i.e.,

$$O_2(1\Delta_g) \rightarrow A_{90} \rightarrow O_2 + h\nu(\lambda = 1270 \text{ nm}) \quad (8)$$

and

$$O_2(1\Delta_g) + O_2 \rightarrow k_5 \rightarrow O_2 + O_2, \quad (9)$$

where $k_5$ is $3.6 \times 10^{-18} \exp(-220/T) \text{ cm}^3\text{s}^{-1}$ (JPL, 1992). Therefore, ozone density at an altitude $z$ is expressed as follows under the equilibrium condition between the source and loss mechanisms of $O_2(1\Delta_g)$ (Evans et al., 1988).

$$[O_3(z)] = \frac{A_{00}}{A_T + k_5[O_2]} \left( \frac{k_2[M]J_{762}(z)[O_2]}{A_\Sigma + k_2[M]} + \eta k_4[M][O]^2 \right) \quad (10)$$

where $A_T$ and $A_\Sigma$ are the total transition probabilities of $O_2(1\Delta_g)$ and $O_3(1\Sigma)$ states, respectively. In Eq. (10), $A_{00}/(A_T + k_5[O_2])$ represents the ratio of 1270 nm emission to total loss of $O_2(1\Delta_g)$. It is 0.75 at 80 km and almost 1 above 90 km. $k_2[M]J_{762}(z)[O_2]/(A_\Sigma + k_2[M])$ represents the component of the resonance absorption of solar 762 nm radiation. $\eta k_4[M][O]^2$ is the component of three body recombination process. The term in the second line in Eq. (10) gives the contribution of the $O(1D)$ process to the $O_2(1\Delta_g)$ production. It is around 15% of the total production of 60–90 km.

As shown in Fig. 6, in twilight condition (SZA ~ 90°), the resonance absorption is the most important process at 75–80 km. Altitude distribution of the $O_2(1\Delta_g)$ produced through the resonance absorption process in twilight condition (SZA = 85–95°) was calculated. In this calculation, altitude profiles of molecular oxygen density and atmospheric temperature of CIRA 1986 were used. Figures 6(a) and (b) illustrate the calculated profiles of the $O_2(1\Delta_g)$ density produced through this process for the conditions of the two rocket experiments. In CIRA86 (1990) model atmosphere at 70°N, O2 density is highest in July and is lowest in December. The calculated profiles of the $O_2(1\Delta_g)$ density produced through this process for the two months are also shown in Figs. 6(a) and (b). The transmission of solar 762 nm radiation to an altitude of interest in major part is smaller than that in December because of higher O2 density. Then, the produced $O_2(1\Delta_g)$ density at the altitude in July is smaller than that in December below about 75 km. On the other hand, as almost all the 762 nm emission can transmit to the altitude above 80 km, the produced $O_2(1\Delta_g)$ density is higher in July than in December. Therefore $O_2(1\Delta_g)$ density produced through this process shows almost constant value around 78 km, though O2 density varies about factor of three in a year at 70°N. Estimated profiles through the recombination processes are also shown in Figs. 6(a) and (b) as well as the observed profiles in the two rocket observations. The atomic oxygen distributions used in the estimation are after Ratkowski and Ulwick (1993) for February condition and Brasseur and Offermann (1986) for November one (see Fig. 9). In both cases, the $O_2(1\Delta_g)$ produced through the resonance process accounts for the major part of the observed densities around 78 km. The contribution from the recombination process can be negligible below 90 km.
Fig. 6. (a) Relative importance of the $O_2(^1Δ_g)$ production processes. ●: observed profile by S-310-22 rocket shown in Fig. 5, △: three body recombination process, (Feb.), (July), (Dec.): resonance absorption process. (b) Same as (a) for S-310-23 rocket. ○: observed profile by S-310-23 rocket shown in Fig. 5, △: three body recombination process, (Nov.), (July), (Dec.): resonance absorption process.
Fig. 7. Calculated values of photodissociation rate $J_H$ as a function of altitude for the two rocket experiment conditions. $\cdash-\cdash$: S-310-22 (SZA = 89°), $\cdash-\cdash$: S-310-23 (SZA = 90°).

Fig. 8. Altitude distributions of the ozone densities derived from the two rocket measurements. $\bullet$: S-310-22, $\bigcirc$: S-310-23. Horizontal bars represent one sigma deviation from the average. For the S-310-23 data, the deviations are smaller than the dot size except for 75–80 km region.

The altitude distributions of ozone concentration in February and November are derived from Eq. (10), where profiles of atmospheric density and temperature were taken from the model atmosphere of CIRA 1986. $J_H(z)$, the number of ozone dissociation per second per molecule in Hartley band, is calculated by using the cross section data of Molina and Molina (1986), the solar flux data of Mount and Rottman
(1983) and the ozone concentration profiles of Krueger and Minzner (1976) in 50–68 km, Yamamoto et al. (1983) in 70–88 km and Allen et al. (1984) in 90–104 km. The calculated profiles of $J_H(z)$ for the S-310-22 (SZA = 89°) and the S-310-23 (SZA = 90°) are shown in Fig. 7. The value of $J_H(z)$ mainly depends on SZA and little on ozone density profile, especially above about 70 km. $J_H(z)$ above 70 km is $8.4 \times 10^{-3}$ s$^{-1}$ in each case. Then the inferred ozone profile above 70 km does not depend on the assumed ozone density. The inferred profiles of ozone are shown in Fig. 8. A secondary maximum around 88 km existed in both observations. The densities and the heights of the secondary ozone maximum were $3.9 \times 10^7$ s$^{-3}$ and 87.0 km in February and $7.1 \times 10^7$ s$^{-3}$ and 88.6 km in November, respectively. The densities around the valley in 76–78 km were lower than $1 \times 10^7$ s$^{-3}$ in both cases.

5.3 Atomic oxygen density

Atomic oxygen density can be inferred from the following relation under an equilibrium condition of ozone in sunlit atmosphere.

$$[O(z)] = \frac{J_H(z) + J_C(z)}{k_6 [O_2(z)] [M(z)]} [O_3(z)]$$

(11)

where the ozone hydration reaction is neglected. $J_C(z)$ represents photodissociation rate of ozone in Chappuis band ($\lambda > 400$ nm), which is $1.9 \times 10^{-4}$ s$^{-1}$ (Allen et al., 1984), and $k_6$ is the reaction coefficient of $O + O_2 + M \rightarrow O_3 + M$, which is $6.0 \times 10^{-34}(T/300)^{-2.3}$ cm$^6$s$^{-1}$ (JPL, 1992). The derived altitude distributions of atomic oxygen are represented in Fig. 9. We only show the density profile below 90 km, because Eq. (11) does not hold good above the altitude. The atomic oxygen profiles used for the estimation of the recombination process are also shown in the figures. The profile of Ratkowski and Ulwick was obtained by a rocket measurement from Kiruna (68°N, 21°E) at 04:41 UT on March 6, 1990. Brasseur and Offermann’s one was also taken at the same place at 23:12 UT on December 1, 1980. As the present atomic

![Fig. 9. Altitude distributions of deduced atomic oxygen densities. The profiles obtained by Ratkowski and Ulwick (1993) and Brasseur and Offermann (1986) are also shown. ●: S-310-22 (07:52 UT, Feb. 16, 1994 at Andoya (69°N, 16°E)), ○: S-310-23 (10:20 UT, Nov. 24, 1994 at Andoya), —: Ratkowski and Ulwick (1993) (04:41 UT, Mar. 6, 1990 at Kiruna (68°N, 21°E)), —: Brasseur and Offermann (1986) (23:12 UT, Dec. 1, 1980 at Kiruna).]
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Oxygen profiles taken at twilight condition show good agreement with the previous rocket results between 80 and 90 km, it is suggested that there is little diurnal variation of atomic oxygen above about 80 km. On the other hand, the present profile in 60–80 km region is nearly the same one obtained from many model calculations under daytime condition (for example, Allen et al., 1984).

6. Discussion and Conclusion

The most prominent feature on the ozone obtained by the two rocket measurements is very deep valley around 78 km. The densities in both cases are below $1 \times 10^7$ cm$^{-3}$. The secondary maximum around 88 km, which was first suggested by Evans et al. (1968), are clearly seen in both ozone profiles. The densities of the secondary maximum in February and November were $3.9 \times 10^7$ cm$^{-3}$ and $7.1 \times 10^7$ cm$^{-3}$, respectively. The densities in February were about a half of those in November in 60–100 km.

Only one rocket measurement of the mesospheric ozone by using the 1270 nm method has done in polar region (Llewellyn and Witt, 1977). It was carried out at 1702 UT (SZA = 94°) on March 13, 1975 at Kiruna (68°N, 21°E). As shown in Fig. 10, all the three mesospheric ozone density profiles obtained in polar region have clear secondary maximum around 88 km and valley around 78 km, and they have the similar slope of the ozone profile in 60–75 km. The minimum ozone density at the valley of Llewellyn and Witt’s data is about 10 times as high as the February one. They did not take the resonance process into account in their analysis. In fact, according to our calculation, $O_2(1\Delta_g)$ abundance produced through the resonance process at SZA = 94° is about 50 times as low as that at SZA = 90° at 70°N in 70–80 km. Therefore the resonance absorption process does not play an important role in their data analysis.

The 1270 nm measurement onboard the SME satellite presents the global ozone distribution in 50–85 km (Thomas et al., 1984b; Keating et al., 1990). No profile is shown in November, December and

![Fig. 10. Comparison of mesospheric ozone densities obtained in polar region.](image-url)
January in polar region. The secondary maximum around 85 km and small valley around 80 km are shown in February profile of the SME, although the upper altitude boundary of the SME ozone profile is about 85 km (see Fig. 10). The difference of the magnitude of the ozone density at the secondary maximum between SME and the present two rocket results is within about factor of 3, but the minimum densities around the valley of the SME ozone are 10–100 times as high as the present ones. This may be due to the very long horizontal span of the SME observation and its low altitude resolution, it is more than 3 km. As shown in Fig. 11, both of the ozone density profiles observed in mid-latitude regions and those calculated under mid-latitude condition have no such a very deep valley around 78 km. Ozone concentration around 78 km can be treated in a photochemical equilibrium, so atomic oxygen density profile which has sharp cut around 80 km may cause the small ozone density. The distribution of atomic oxygen above the mesopause is dependent on dynamical conditions. The dynamical conditions near polar region are not so stable in February and November, because sunlit condition varies rapidly. Another possible explanation may be the difference of the longitude region, as the SME covers 40–100°W region and the rocket was launched from the location at 16°E.

The two-weeks averaged profile of ozone near summer solstice at 65°N obtained by the SME 1270 nm observation is presented by Clancy et al. (1987). As also shown in Fig. 10, its secondary maximum is around 88 km and the valley around 83 km. The altitude of the secondary maximum is close to the present results. The SME ozone distributions (Keating et al., 1990) shows that the altitude of the valley in summer is a few kilometers higher than that in winter at high latitudes. The seasonal altitude difference may be due to the transport process of the atomic oxygen. For example, Thomas et al. (1984a) pointed out the possibility of the seasonal variability in ozone due to the variation of gravity wave-induced transport.

The ozone distribution in the mesosphere and lower thermosphere in mid-latitude was obtained by using the rocket-borne measurement with several techniques in June at Wallops Islands (38°N) (Weeks et al., 1978). The 1270 nm method provided the ozone densities in 70–100 km. Yamamoto et al. (1983) reported the ozone profile obtained in January at KSC, Japan (31°N) from the 1270 nm and solar UV radiation data. They are shown in Fig. 11. The ozone densities at the secondary maximum in mid-latitudes

![Fig. 11. Comparison between mesospheric ozone densities obtained by rocket measurements in mid-latitudes and in polar region. Mid-latitude ozone model profile (Allen et al., 1984: —) is also shown. ●: S-310-22 (Feb., Andoya (69°N)), ○: S-310-23 (Nov., Andoya), ▲: Weeks et al. (1978) (Jun., Wallops (38°N), SZA = 53°), Δ: Yamamoto et al. (1983) (Jan., KSC (31°N), SZA = 93°).]
are nearly the same as the present results, they are \((3-7) \times 10^7 \text{ cm}^{-3}\). Though the result obtained by Weeks et al. (1978) has the valley at 81 km, there is no valley in that by Yamamoto et al. (1983). The model prediction in mid-latitude (Allen et al., 1984) is also shown in Fig. 11. All of the altitude distributions are in good agreement above about 80 km except for that of Yamamoto et al. (1983). The model and Week et al.'s profiles have a significant departure from the present ones about the magnitude of the minimum ozone. Large depression on the minimum ozone density around 75–78 km may be a unique feature of the polar mesospheric ozone.

Recently Mlynczak and Nesbitt (1995) reported new value of \(A_{00}\) according to new laboratory results for the \(\text{O}_2(1\Delta_g - 3\Sigma_g^-)(0,0)\) band strength in absorption (Hsu et al., 1992). It is \(1.47 \times 10^{-4} \text{ s}^{-1}\), which is 57% smaller than the Badger’s value of \(2.58 \times 10^{-4} \text{ s}^{-1}\). As main quenching process of \(\text{O}_2(1\Delta_g)\) is the collision with \(\text{O}_2\) (reaction \(9\)) below about 75 km, ozone density is approximately proportional to \(\text{VER}(z) \cdot k_5[\text{O}_2]/A_{00}\). Then if we adopt this new \(A_{00}\) value, deduced ozone density increases about 75% below about 75 km.

On the other hand deduced ozone density changes little above about 85 km. Pendleton et al. (1996) showed that observational results of their ground-based \(\text{O}_2\) 1270 nm radiation by using the Fourier transform infrared technique during late evening twilight supports the Badger’s value, which is \(2.58 \times 10^{-4} \text{ s}^{-1}\). The same conclusions is given by Yamamoto et al. (1997) from the ground-based measurements by using 4 colors near infrared radiometer system. Comparison of ozone profiles using two \(A_{00}\) values are shown in their paper.

The two rockets were flown at SZA close to 90°. Though the atmosphere above about 70 km can be treated as the full sunlit condition, ozone density is mainly controlled by atomic oxygen and atomic hydrogen densities above 70 km. Generally, mesospheric atomic oxygen is transported from the thermosphere and the mesospheric atomic hydrogen is controlled by local water vapor which is transported from lower atmosphere. In case of insufficient solar radiation in polar region, odd oxygen in altitude region of 50–100 km is controlled mainly by the dynamical process (see for example, Garcia and Solomon, 1985). There is few useful information on the density profiles of mesospheric atomic oxygen and atomic hydrogen in polar region as well as the dynamical process. The two present mesospheric ozone profiles can provide useful information on the understanding of the polar atmosphere in 50–100 km region.

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