Measurement of Mesospheric Ozone Concentrations from the 1.27 μm O_2 Airglow at a Middle Latitude

Tadao MAKINO,* Hiroyuki SEKIGUCHI,* and Hiromasa YAMAMOTO**

**Department of Physics, Rikkyo University, Tokyo, Japan*

***Geophysics Research Laboratory, University of Tokyo, Tokyo, Japan*

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The ozone density in the altitude range between 70 and 90 km has been obtained from the twilight 1.27 μm oxygen emission measured by using a rocket launched at Uchinoura, Japan (31°N). The observed density agrees well with the mid-latitude average between 70 and 75 km. It also indicates a nearly constant value of $\sim 4 \times 10^7 \text{ cm}^{-3}$ between 80 and 90 km.

1. Introduction

The observation of the 1.27 μm airglow emission originating from the (0, 0) band of $\text{O}_2(a^1\Delta_g - X^3\Sigma_g^-)$ has been attempted during the twilight in order to determine the ozone concentration in the mesosphere and lower thermosphere (EVANS *et al.*, 1968; EVANS and LLEWELLYN, 1970, 1973; LLEWELLYN and WITT, 1977). While the solar UV absorption technique is useful to measure the mesospheric ozone density up to 80 km, the 1.27 μm O_2 emission technique is usually sensitive enough to deduce the ozone profile even above the mesopause. With the combination of these techniques, LLEWELLYN and WITT (1977) obtained the ozone density profile from the stratosphere to the lower thermosphere.

Almost of all ozone measurements above the mesopause from the observation of the 1.27 μm emission have been concentrated in high latitudes. In mid-latitudes, the ozone density profile above the mesopause is quite uncertain, whereas the mesospheric ozone density is well determined (WATANABE and TOHMATSU, 1976; KRUEGER and MINZNER, 1976).

The present report is concerned with the measurement of the ozone concentration above 70 km at a middle latitude during equinoctial condition.

2. Experimentals

The optical system of the rocket-borne infrared radiometer for measuring the 1.27 μm emission is shown in Fig. 1. The radiometer consists of three pairs of lenses, a light chopper, an interference filter ($\lambda_0 = 1.268 \mu\text{m}$, $\Delta\lambda = 29 \text{ nm}$)

Fig. 1. Optical system of the rocket-borne infrared radiometer.

Fig. 2. A typical intensity distribution of the 1.27 μm O_2 emission for the 200 K rotational temperature and the filter transmission.

and an uncooled lead sulfide detector (4 mm $\times$ 4 mm). The optical axis was set parallel to the rocket spin axis with a field of view of $\pm 4^\circ$. A typical emission spectrum of the 1.27 μm emission (MAKINO *et al.*, 1976) together with the transmission of the filter is shown in Fig. 2. The contamination due to the hydroxyl emissions near the 1.27 μm region was estimated to be less than 5%. The radiometer was calibrated by a black-body radiant source in our laboratory before the flight. In addition, in-flight calibration was carried out by the use of a tungsten lamp. The response time of the radiometer was 70 msec, and the radiometer was able to detect emissions of 5×10^5 to 5×10^8 Rayleighs (1 Rayleigh = 10^6 photons $\cdot$ cm⁻² $\cdot$ sec⁻¹ $\cdot$ column⁻¹).

The rocket S-210-12 was flown from Uchinoura, Japan (31°15'N, 131°05'E) at 1830 JST (135°EST) on Sep. 15, 1977. The solar zenith angle (SZA) was 93° during the rocket ascent.

3. Data Analysis

We analyzed the upleg data only, because the downleg data were modulated by unknown signals. We sampled the output signal every 100 msec and calculated the emission intensity for 1 km altitude intervals. The detector noise was able to be diminished to about 100 kR due to this procedure. The apparent emission change in the zenith direction is shown in Fig. 3. The volume emission rate of change given in Fig. 4 was obtained by differentiating the apparent emission with altitude.

The derivation of the ozone density from the measured emission rate is straightforward. The excitation of O₂(¹ Δ_g) in sunlit condition occurs principally due to the photolysis of ozone:

with the photodissociation coefficient at the atmosphere $J(\infty) = 8.70 \times 10^{-3} \text{ sec}^{-1}$ calculated with the aid of data in BROADFOOT (1972) and HUDSON (1971). One of the removal processes of O₂(¹ Δ_g) is the spontaneous emission

which emits mainly in the (0, 0) 1.27 μm band and much weaker in the (0, 1) 1.58 μm and other bands. The transition probability is given as $A_{00} = 2.6 \times 10^{-4} \text{ sec}^{-1}$ for the (0, 0) band (BADGER *et al.*, 1965), and $A_{01} = 3.5 \times 10^{-6} \text{ sec}^{-1}$ for the (0, 1) band (HASLETT and FEHSENFELD, 1969). Thus the total transition probability for $v' = 0$ of the ¹ Δ_g state is $A = \sum_i A_{0i} \doteq A_{00}$. Also the quenching of O₂(¹ Δ_g) may operate. The principal process is

Fig. 3.

Fig. 4.

Fig. 3. The $1.27\ \mu\text{m}$ apparent emission observed in the zenith direction.

Fig. 4. Volume emission rate at $1.27\ \mu\text{m}$.

whose rate coefficient has been measured as $k = 2.2 \times 10^{-18} (T/300)^{0.8}$ (HAMPSON *et al.*, 1973). The altitude profiles of molecular oxygen and atmospheric temperature are taken from the standard atmosphere of CIRA (1972). Allowance of the photochemical equilibrium between Eq. (1) and Eq. (2)+(3) leads us to calculate the ozone density as

$$n(\text{O}_3) = [A + kn(\text{O}_2)]Q/A_0J, \quad (4)$$

where Q is the volume emission rate of the $1.27\ \mu\text{m}$ photons. The photodissociation coefficient is dependent on the altitude during the twilight condition because of the solar UV attenuation due to the slant incident path. The altitude dependence of J is calculated for the observation condition at $\text{SZA} = 93^\circ$; 8.69×10^{-3} , 8.65×10^{-3} , 8.09×10^{-3} , and 5.91×10^{-3} at 90, 80, 70, and 60 km, respectively.

4. Result and Discussion

Figure 5 represents the ozone density profile calculated with the aid of Eq. (4), together with the observations by other research groups. WATANABE and TOHMATSU (1976) obtained the average ozone profile in summer at Uchinoura by the solar UV absorption technique. Our result is in reasonable agreement

Fig. 5. The deduced ozone concentrations, compared with the other observations.

with it in the over-lapping altitude region of 70–75 km. The other profile obtained by the solar UV absorption technique (MILLER and RYDER, 1973) shows slightly higher concentration than ours above 80 km. However, it cannot be precise above 80 km because of little absorption. The profiles obtained from the $1.27\ \mu\text{m}$ emission by EVANS and LLEWELLYN (1970, 1973) also give much larger concentration than ours. We do not find any clear reason for the difference between Evans-Llewellyn's and our profiles. The higher concentration obtained for the high latitude by EVANS and LLEWELLYN (1973) may be partly due to the latitudinal effect. One possible cause for the difference of mid-latitude might be the contamination due to the sunlight because their observation was made at $\text{SZA} = 75.5^\circ$.

The valley around 80 km found in the profiles by LLEWELLYN and WITT (1977) and others is not obvious in our present measurement. The density in the 80–90 km region is nearly constant $\sim 4 \times 10^7\ \text{cm}^{-3}$. The cause of this difference is uncertain, but may be due to the latitudinal effect.

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