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Scientific Paper

OBSERVATIONS OF OZONE PROFILES IN THE UPPER STRATOSPHERE USING A UV SENSOR ON BOARD A LIGHT-WEIGHT HIGH-ALTITUDE BALLOON

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Abstract: We have developed a balloon borne optical sensor (BOS) to measure the vertical distribution of stratospheric ozone. The BOS measures solar ultraviolet radiation in ozone Hartley band absorption at wavelength of 302 nm. The balloon used in these observations is a thin-film high-altitude balloon. The balloon can attain an altitude of about 42 km. Observations were carried out at Ny-Ålesund, Spitsbergen on July 23 and 27 and at Sanriku, Japan on May 29, 30 and August 27 in 1994.

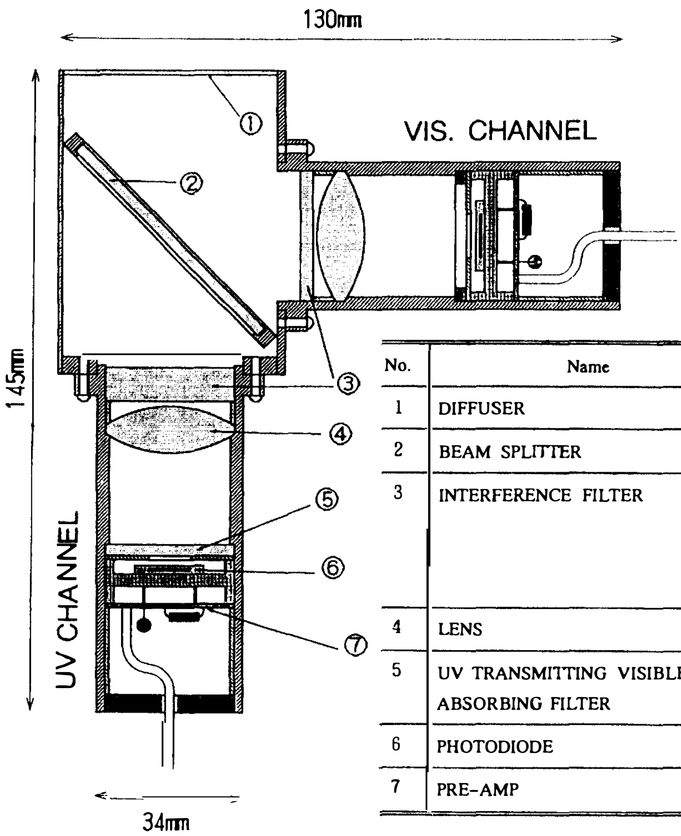
1. Introduction

Intensity change of solar UV radiation against altitude due to ozone absorption has been utilized for in-situ measurement of ozone vertical profiles for more than a decade. This method has been applied mainly to rocket-sounding observations (*e.g.* KRUEGER *et al.*, 1983; HOLLAND *et al.*, 1985; BARNES and SIMETH, 1986; WATANABE and OGAWA, 1992) and employed in a balloon-borne observation by ROELAND *et al* (1983). When applied in rocket observation, this technique can provide ozone vertical profiles in the range of ~ 20–60 km. However, relatively large cost is required for such a rocket experiment. On the other hand, balloon-borne observations can be done with much less cost, but the altitude range is limited. In order to measure ozone vertical profiles even in the upper stratosphere, where measurements with a conventional ECC ozonesonde become unreliable, we have developed a balloon-borne optical sensor on board a thin-film high-altitude balloon (5000 m^3) which can reach an altitude above 40 km. Ozone observations in 1994 were carried out at the Sanriku Balloon Center (39.2°N, 141.8°E) of the Institute of Space and Astronautical Science, Japan in mid-latitude and at Ny-Ålesund, Spitsbergen (78.9°N, 11.9°E) in the Arctic.

2. Balloon-borne Optical Sensor

The balloon-borne optical sensor (BOS) consists of a pair of filter photometers. One photometer measures the altitude variation of solar UV intensity variation against height due to the change of UV absorption by ozone. The amount of solar radiation incident on the photometer varies largely with the atitude change of the payload. Such UV signal variation caused by change of solar radiation incident angle due to attitude change is compensated by another photometer measuring the solar radiation intensity in the same field of view of the ozone channel at a wavelength with no ozone absorption. The ratio of the signals from the two photometers can eliminate the effect of the attitude change. A cross section of the balloon-borne optical sensor is shown in Fig. 1. A diffuser plate made of a sheet of Teflon is illuminated by the sun. The light incident angle dependence of the diffuser plate is shown in Fig. 2. The light beam is separated by a beam splitter made of quartz. The transmitted beam is directed to the UV channel and the reflected beam is directed to the visible channel. The characteristics of interference filters for each channel are shown in Table 1. The lens is also made of quartz. A UV transmitting and visible absorbing filter is also used in the UV channel to completely suppress strong solar spectral components in visible region. Photo detectors for both channels are Hamamatsu S1227-1010BQ silicon photo diodes. The photodiode photocurrent is converted to voltage and amplified by a pre-amplifier located behind the photodiode. A thermistor is also installed to monitor the sensor temperature to correct the effect of temperature drift in the data analysis.

Signals from each channel are held by sample-hold circuit and sequentially telemetered to the ground along with ambient and sensor temperatures and atmospheric pressure. The size and weight of BOS are 315 mm × 150 mm × 260 mm and 1.1 kg including battery, respectively.



No.	Name	Material	Remarks
1	DIFFUSER	Teflon	50 × 70 (mm)
2	BEAM SPLITTER	quartz	60 mm ϕ
3	INTERFERENCE FILTER		VACUUM OPTICS CORP. OF JAPAN UV : λc 300 nm, FWHM 10 nm VIS. : λc 420 nm, FWHM 15 nm 30 mm ϕ
4	LENS	quartz	30 mm ϕ
5	UV TRANSMITTING VISIBLE ABSORBING FILTER		SIGMA KOKI CO. UTVAF-30C-34U
6	PHOTODIODE		HAMAMATSU S1227-1010BQ
7	PRE-AMP		

Fig. 1. A cross section of the balloon-borne optical sensor (BOS).

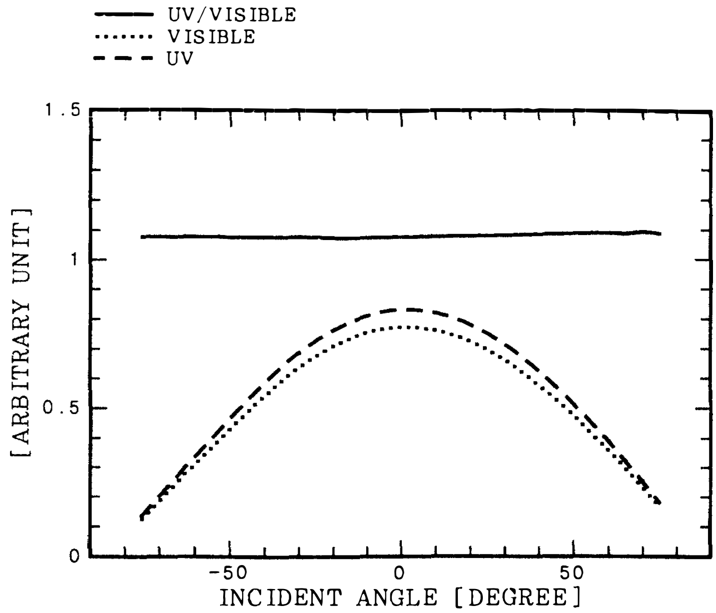


Fig. 2. Light incident angle dependence of diffuser plate. (Dotted line: 420 nm visible. Broken line: 300 nm UV. Solid line: ratio of UV to visible)

Table 1. Characterics of interference filters.

	Center wave length	FWHM
UV channel	300 nm	10 nm
Visible channel	420 nm	15 nm

FWHM: full width of half maximum.

3. Observations

Ozone observations with the BOS were carried out five times in 1994 as given in Table 2. Among them, data of three observations carried out at Sanriku were taken during the ascent of the balloon. In both observations at Ny-Ålesund in Spitsbergen, an ECC ozonesonde was on board in addition to the BOS for simultaneous observations. On July 23, data were taken only during the ascent. On July 27, power failure of the receiving system at the ground occured during the ascent of the balloon in the altitude range of 37 to 42 km and data reception was interrupted during this period. However,

Table 2. Balloon launchings in 1994.

Date	Site	Launch time	Highest altitude	Time at highest altitude
1994.05.29	Sanriku	1018 JST	42 km	1232 JST
1994.05.30	Sanriku	0955 JST	44 km	1213 JST
1994.07.23	Ny-Ålesund	1039 UTC	43 km	1410 UTC
1994.07.27	Ny-Ålesund	0956 UTC	43 km	1211 UTC
1994.08.27	Sanriku	0957 JST	44 km	1222 JST

data were taken on the descent because the payload descended slowly with the balloon on this flight.

4. Data Analysis

4.1. Principle

Extinction of solar radiation intensity at wavelength λ due to the absorption of ozone and Rayleigh scattering by atmospheric molecules is given as

$$I(\lambda) = I_0(\lambda) \bullet e^{-\sigma(\lambda) \bullet u(z)} \bullet e^{-\tau_R(z)}, \quad (1)$$

where $\sigma(\lambda)$ is the ozone absorption cross section, $u(z)$ is the slant column number density of ozone above height z and $\tau_R(z)$ is the slant optical thickness of Rayleigh scattering by atmospheric molecules above z. Since the BOS measures the solar UV intensity integrated over a certain wave length range, the observed value is expressed as

$$\frac{I(z)}{I_0} = \frac{\int F(\lambda) I_0(\lambda) e^{-\sigma(\lambda)u(z)} d\lambda}{\int F(\lambda) I_0(\lambda) d\lambda} \bullet e^{-\tau_R(z)}, \quad (2)$$

where $I(z)$ is the UV channel signal measured by the BOS, I_0 is the UV channel signal to be measured at the top of the atmosphere, $F(\lambda)$ is the wavelength dependence of the sensitivity of the BOS, and $I_0(\lambda)$ is the solar spectrum. Equation (2) can be modified into an equation in u;

$$u = \frac{1}{\alpha(u)} \left(-\ln \frac{I}{I_0} - \tau_R \right), \quad (3)$$

where α is a function of u expressed as

$$\alpha = -\frac{1}{u} \ln \frac{\int F(\lambda) I_0(\lambda) e^{-\sigma(\lambda)u(z)} d\lambda}{\int F(\lambda) I_0(\lambda) d\lambda} \quad (4)$$

The relation between α and u is shown in Fig. 3. The ozone slant column number density is derived by solving eq. (3). For simplicity of calculation, α is approximated by a trinomial of u, and eq. (3) is solved as a biquadratic equation.

Since I_0 is never obtained by balloon observations because the balloon cannot reach the top of the atmosphere, I_0 is determined by

$$I_0 = I(z_{max}) \bullet e^{\alpha u(z_{max})} \bullet e^{\tau_R(z_{max})}, \quad (5)$$

assuming the slant column number density of ozone and atmospheric molecules above the highest altitude, z_{max}, attained by the balloon.

4.2. Data handling

The data taken in an observation are outputs of UV and visible photometers (Fig. 4a and b). The UV photometer data are divided by the visible phtotmeter data (Fig. 4c) to compensate for the data scatter in the UV signal due to attitude change of the payload. After taking this ratio, data scatter still remains. The amplitude of this scattering is less

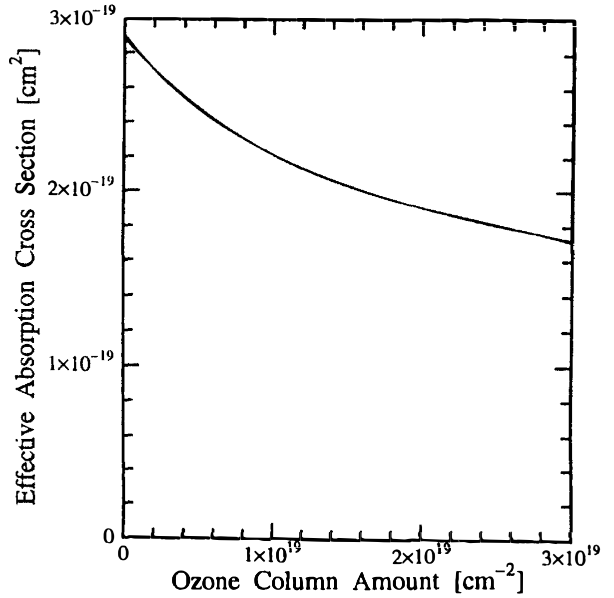


Fig. 3. Relation between effective absorption cross section and ozone column number density.

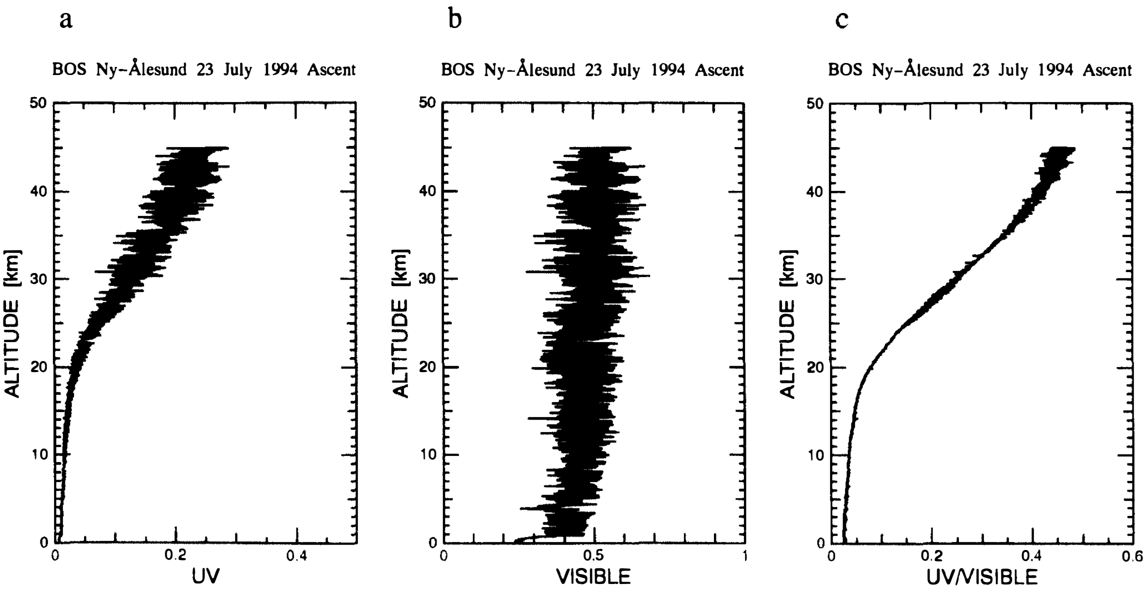


Fig. 4. A sample of photometer signals. a) UV channel. b) Visible channel. c) Ratio of UV to visible.

than about 12% of magnitude of the data. To reduce this remaining scattering, a running mean over a range of 1 km is taken. After smoothing this ratio by taking the running mean, we solve eq. (3), and an airmass factor correction is made taking the change of solar zenith angle into account. In this way, the vertical profile of ozone vertical column number density is derived. By differentiating this profile, the vertical distribution of ozone number density is obtained.

5. Results of Observations

Figure 5a shows vertical distributions of ozone number density observed in May and August 1994 at Sanriku. The large value of ozone number density at an altitude of 31 km on May 29 is due to noise caused by bad receiving condition. Compared with the vertical distribution of ozone on May 29, that on May 30 shows a change confined mainly to the altitude range below 27 km, while little change is seen in the altitude range above 27 km. It is also seen that the ozone number density below 23 km in August is smaller than that in May.

Figure 5b shows the vertical distributions of ozone number density observed at Ny-Ålesund on July 23 and 27 with a BOS (balloon-borne optical sensor) and ECC (electrochemical concentration cell). All data were taken during ascents of balloons except for the BOS data on July 27 that were taken during the descent. Some remarkable points in comparison of BOS data with ECC data are the following. Vertical wave structure over a scale of several kilometers is seen in the vertical distribution of ozone number density observed with the BOS above 25 km, while the ozone number density observed with the ECC decreases monotonically with increasing altitude. Below 25 km, the vertical structures of ozone number density observed with the BOS on July 23 and 27 show good agreement with those observed with the ECC on respective days. Especially, in the altitude range 10–13 km, high ozone number density on July 23 compared with that on July 27 is seen in both BOS and ECC data.

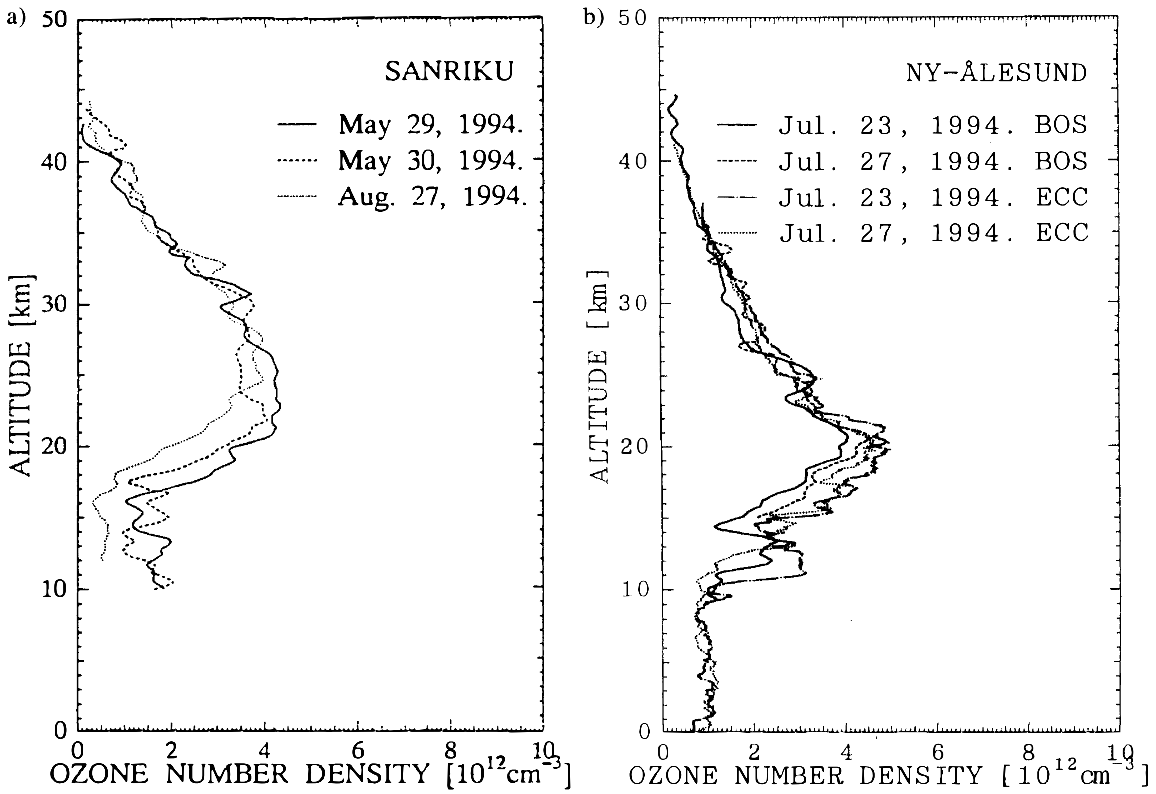


Fig. 5. Vertical distributions of ozone number density observed at a) Sanriku, and b) Ny-Ålesund.

6. Conclusions

In 1994, ozone observations with the BOS were carried out twice in May and once in August at Sanriku, and twice at Ny-Ålesund, Spitsbergen. Vertical distributions of ozone number density are derived from the observed BOS data with good height resolution. Compared with simultaneous ECC observations at Ny-Ålesund, good agreement is seen below altitude of 25 km, while vertical structure on a scale of several kilometers, which are not seen in the ECC data, is seen in the vertical distribution of ozone observed by BOS.

Details of structures of vertical distribution of upper stratospheric ozone will be revealed by this newly developed observation method.

Acknowledgments

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