NOTES AND CORRESPONDENCE

Simultaneous Measurements of Ozone
by UV Lidar and Chemical OzonesondeBy Takashi Shibata*, Mitsuo Maeda*,
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1. Introduction

The atmospheric ozone has important roles in the energy budget of the atmosphere, and protects the surface of the earth from the harmful solar ultraviolet (UV) light. Ozone is also the main constituent of oxidant in the polluted air at urban areas. Human activity may change the concentration or distribution of ozone in the upper and lower atmosphere (e.g. Nicolet 1975; Logan 1985). Therefore, in order to estimate the anthropogenic effect for ozone variation, continuous ozone monitoring is very important.

Ozone lidar with DIAL (differential absorption lidar) method has been developed as a new method to measure the atmospheric ozone distribution (Gibson and Thomas, 1975; Megie *et al.* 1977; Uchino *et al.* 1978). The excimer lidar with a XeCl excimer laser is one of the most powerful tools to observe ozone profile in the stratosphere (Uchino *et al.*, 1979), and is going to be widely used for continuous monitoring of the upper stratospheric ozone distribution (Megie 1984).

For the observation of tropospheric ozone distribution, Shibata *et al.* (1987) proposed a new ozone lidar system, utilizing Raman lasers pumped by a KrF excimer laser. They show theoretically and experimentally that the observation of the vertical ozone distribution in the

troposphere and lower stratosphere is possible by the careful choice of the transmission Raman wavelengths. Now, with the UV ozone lidar based on powerful excimer lasers, it is possible to determine the ozone profile from the ground to about 50 km in altitude.

Simultaneous measurements of vertical ozone profiles were made by this new ozone lidar with Raman laser and by conventional chemical ozonesondes at Fukuoka, Japan in May 1987. In this note, we present a brief report on these first comparative measurements.

2. Equipments

The Raman laser wavelengths used in the ozone lidar were 2nd Stokes line of D_2 (291.6 nm), and 2nd and 3rd Stokes lines of H_2 (313 and 359.8 nm) pumped by a KrF excimer laser (248.4 nm). The wavelength pair 291.6 and 313 nm were used to observe the height range between 5 and 16 km, and the wavelength pair 313 and 359.8 nm higher than about 15 km. The further detailed description about the lidar system can be found in a paper reported by Shibata *et al.* (1987).

The used ozonesonde (KC79-type) is that of using electrochemical reaction of ozone with potassium iodide solution. The details of the ozonesonde are found in the papers by Kobayashi and Toyama (1966) and Hirota and Muramatsu (1986).

3. Measurements

Three ozonesonde measurements were made in May, 1987 at Fukuoka. Table 1 shows the date and time of the each flight of ozonesondes, and also shows the time of the corresponding lidar observations. The observations were made almost simultaneously about the flights 2, and 3. About flight 1, the difference in observation time is about 2 hours. The lidar station is located at Kyushu University. The ozonesondes were launched at Fukuoka Environmental Research Center (FERC) which is located about 15 km south-east of Kyushu University. The horizontal trajectory of these flights are shown in Fig. 1. The horizontal distance of the lidar and the balloon is within 70 km.

The sky was covered with thin cirrus clouds just below the tropopause in every cooperative observation. Fig. 2 shows the range compensated lidar echo at 313 nm on May, 19. The peak of

Table 1. The measurement time intervals of each flight of ozonesonde, and that of corresponding lidar observations.

Flight Number	Ozonesonde Date (May 1987) Time (JST)	Lidar Date (May 1987) Time (JST)
1	19 2245-2344	19 2056-2124
2	24-25 2248-0016	24 2244-2334
3	25 0120-0244	25 0115-0209

Fig. 1. The horizontal trajectories of ozonesonde launched from Fukuoka Environmental Research Center (point 0). The point A indicates Kyushu University. The triangle indicates Mt. Sangun. The numbers in the figure show the flight number of each flight.

Fig. 2. Range compensated lidar echo $P(z)$ versus altitude z . The wavelength is 313 nm. The observation time interval is from 2106 to 2111 JST, on 19, May, 1987. The echo peak between 10 and 13 km in altitude is due to the cirrus clouds.

the echo between 10 and 13 km in altitude is due to the cirrus clouds. The ozone profile near the cirrus clouds can not be obtained by lidar because of these clouds.

4. Results and Discussions

Figs. 3, 4, and 5 show the ozone profiles obtained in each flight and lidar observation. The profiles by the ozonesonde are calibrated by multiplying the factor R that is the ratio of lidar observed values to the value estimated from raw data of the ozonesonde observation above about 20 km in altitude, assuming that the vertical ozone profile is much more stable in the stratosphere than in the troposphere. The R values are 1.43, 1.40 and 1.45 for flights 1, 2 and 3, respectively. Similar calibration procedure is usually used for official routine observation of ozone by ozonesonde, utilizing total ozone obtained with the Dobson spectrophotometer.

There is a continuous ozone monitoring station at the top of Mt. Sangun that is 920 m high, and about 10 km north-east of FERC (Fig. 1). The ozone measurement system at Mt. Sangun is the ultraviolet absorption type ozone monitor (Model 1006-AJH, Dylec corp., Japan). This ozone monitor is carefully and regularly calibrated. The calibration factors of

Fig. 3. Ozone concentration profiles by lidar and ozonesonde for flight 1. The triangle shows the value at Mt. Sangun.

Fig. 4. Ozone concentration profiles by lidar and ozonesonde for flight 2. The triangle shows the value at Mt. Sangun.

ozonesonde using the data of this station at the times when the sondes passed through the altitude of 920 m and the ozonesonde data at about 920 m in altitude are 1.48, 1.59 and 1.45 for flights 1, 2 and 3. These factors coincide with the factors R within 15% difference. This coincidence supports the above calibration procedure with lidar data. The results from the three different observation methods are consistent with this calibration method, though the method can not be proved to be appropriate.

In flight 1 (Fig. 3), though the observation time difference is about 2 hours, the altitudes of ozone concentration minimums and maximums coincide with each other between the both profiles. However, the ozone concentration by sonde below about 17 km is about 30% larger than that by lidar. In flight 2 (Fig. 4) coincidence is greater than in flight 1. The concentration by sonde below 10 km is, however, about 20% larger than that by lidar, and is also about 30% larger in flight 3 (Fig. 5). Totally, in each case the profiles by balloon and lidar coincide with each other in rough tendencies of the vertical variations. In the troposphere, however, the ozone concentration by the ozonesonde is about 20-30% larger than the value by

Fig. 5. Ozone concentration profiles by lidar and ozonesonde for flight 3. The triangle shows the value at Mt. Sangun.

the lidar, with the calibration procedure mentioned above.

The following sources are considered possible reasons for the above discrepancies: (1) Temporal and spatial fluctuations of the ozone density are larger in the troposphere than in the stratosphere. The difference is caused by these fluctuations. Fig. 6 shows the profiles of flights 2 and 3. Though the profiles in stratosphere coincide with each other, the concentration in troposphere differs about 30% between flights 2 and 3. The wind speed in the upper troposphere on May, 24 was about 18 m/sec. The observation time difference between flights 2 and 3 is about 2 hours (Table I). Therefore, the distance between the air parcels, which include ozone observed by each sonde, is about 120 km. The position of the sonde observation in flights 2 and 3 are about 50 km (Fig. 1) from the lidar station. The discrepancies in ozone density are due to the variation within this distance. (2) Fig. 6 indicates that the data for flight 3 is about $2 \times 10^{11} \text{ cm}^{-3}$ larger than those for flight 2 in troposphere, and it suggests that there may be some systematic error in the ozonesonde measurement. Because of this error, the density obtained by the lidar is smaller than those by the ozonesonde in the troposphere. Further-

more, the chemical ozonesonde can be contaminated by minor constituents (PAN, etc.) other than ozone in the troposphere. This contamination also makes the positive error in ozone density by sonde. (3) Since the temperature compensated absorption cross section by Bass (1984) was used in the lidar data analysis, the discrepancy can not be caused by the temperature dependence of the absorption cross section. There may be some error of about a few percent in the absorption cross section of ozone (Molina and Molina, 1986). The errors in the absorption cross section at the each wavelength cause a few percent systematic errors in lidar observed ozone profile between troposphere and stratosphere, because the different wavelength pairs are used to observe ozone in the troposphere and the stratosphere with the lidar (section 2). Aerosols can be vertically distributed as to make such a systematic errors in lidar observation between the troposphere and stratosphere. However, the error is several percent at the most (Shibata *et al.*, 1987).

We can not determine which is the main origin of the difference in the results by each instrument. Further careful concurrent observations are needed to confirm the source of difference in both methods.

The ozone profile near cirrus clouds can not be obtained by lidar in the observations, mainly because of the time difference of the measurements in each wavelength, and the rapid variation of the cirrus clouds in that time interval. As indicated by Shibata *et al.* (1987), the completely simultaneous two wavelength transmission is possible in the ozone lidar with Raman lasers. If the optical thickness of the cloud is small enough, the ozone profile near the cirrus cloud can be estimated by improving the lidar system to receive the echo at each wavelength simultaneously.

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Fig. 6. Ozone concentration profiles by ozonesonde for flight 2 and 3. The numbers in the figure represent the flight number.

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紫外線ライダーとオゾンゾンデによるオゾン同時観測

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