N95- 11109

LIDAR OBSERVATION OF OZONE OVER TSUKUBA (36°N, 140°E)

H. Nakane, S. Hayashida, I. Matsui, N. Sugimoto,
A. Minato and Y. Sasano
The National Institute for Environmental Studies
Onogawa, Tsukuba, Ibaraki 305 Japan

ABSTRACT

An ozone lidar system was installed at the National Institute for Environmental Studies (NIES) in Tsukuba, Japan in March 1988 and has been measuring vertical profiles of ozone (15 - 45 km) since September 1988. The lidar system consists of a XeCl (308 nm) excimer laser, its deuterium Raman shifter (339 nm), a XeF excimer laser (351 nm), a 2 m telescope, a receiving system and a data processing system. The precision of the derived ozone concentration is about 10% at an altitude of 40 km for a 4 hr observation. Temperature profiles (30 - 80 km) are also obtained from the Rayleigh scattering signals at 351 nm. Approximate 50 ozone measurements are carried out in a year and variations of vertical profiles of ozone such as seasonal variations and shorter-term variations are observed. Systematic errors due to aerosols had been negligible until the arrival of the stratospheric aerosols injected by the eruption of Mt. Pinatubo. Effects of the volcanic aerosols on ozone measurements depend on the differences between wavelengths used as the on- and off- resonance.

1. INTRODUCTION

Recently, total ozone in both hemispheres at middle and high latitudes have been decreasing significantly. These decreases in the total ozone are especially large in late winter and early spring at those latitudes, and there are longitudinal inhomogeneities. Therefore, long-term measurements of ozone and related species and parameters are important; especially information on variations of the vertical profiles is valuable. The Network for the Detection for Stratospheric Change (NDSC) and related research activities will meet these requirements.

Lidars (laser radars) are expected to play an important role in NDSC because they can measure vertical profiles of ozone, temperature and aerosols with high accuracy and vertical resolution.

We, at the National Institute for the Environmental Studies (NIES), installed an ozone lidar system in March 1988 (Sugimoto et al., 1989; Sasano et al., 1989) and have obtained ozone profiles since September 1988. After examining the distortions of the signals received and sources of systematic errors, we archive the ozone profiles. Comparisons with the data obtained by the SAGE II satellite sensor show that there are in good agreement with our lidar data and the SAGE II data (Nakane et al., 1992). As we use a high power XeF excimer laser as the source of the off-resonance radiation, we can also measure temperature profiles utilizing Rayleigh scattering from the stratosphere and mesosphere. We carried out an intensive observation of the temperature profiles during the DYANA (DYnamics Adapted Network for the Atmosphere) campaign from January 1990 to March 1990 (Nakane et al., 1992).

In this paper, we will describe the ozone lidar system, its performance and show the results of the first 2.5 years data. Then, we will mention the effects of the stratospheric aerosols injected by the eruption of Mt. Pinatubo.

2. NIES OZONE LIDAR SYSTEM

The NIES ozone lidar system consists of two subsystems; a stratospheric subsystem and a tropospheric subsystem. As we are interested in the stratospheric system here, we will describe it briefly. Table 1 is the specifications of the lidar system. We use an injection-locked XeCl excimer laser (Lambda Physik EMG160TMSC) as the light source for the on-resonant wavelength (308 nm) and the same type injection-locked XeF excimer laser for off-resonant wavelength (351 nm). A Raman shifter with deuterium partly converts the XeCl laser radiation to 339 nm radiation whose intensity depends on the pressure of the gas beeing adjusted to give comparable signal intensity to that of 308 nm around 40 km in altitude. The intensity of the signals at 351 nm is made much larger than those of the others in the upper stratosphere because temperature profiles in the upper stratosphere and mesosphere are also important for studies on the dynamics related to ozone variations.

A convex lens with a 60-cm focal length and a flat window are positioned at the entrance and exit of the Raman shifter, respectively. The diverging output beam from the Raman shifter is collimated using an off-axis parabolic mirror with a 200-cm focal length. A concave lens and an off-axis parabolic mirror are used as a beam expander for the beam from the XeF laser. Thus, the laser beams are expanded 3.3 times. The directions of the beams transmitted are the same for 308 nm and 339 nm radiation and that of the 351 nm radiation can be independently adjusted. As light absorption by ozone both at 339 nm and 351 nm is negligible, the signals received for these wavelengths are useful to check the alignment of the beams transmitted and potential effects of the aerosols on the lidar measurements of ozone.

The backscattered light is collected by a telescope with a 2-m diameter, and then, focused on the chopper for cutting the light scattered at a low altitude. Though the lenses placed just before and after the chopper for focusing and collimation had been single lenses before June 1990, they were replaced by achromatic lenses. This improvement made the alignment of the beams transmitted much easier. Dichroic mirrors, interference filters and color glass filters are used for wavelength separation. Monochromated light is then divided

Table 1. Specifications of the NIES ozone lidar system

Transmitter			
Laser	XeF excimer laser	XeCl excimer laser with deuterium Raman shifter	
Wavelengths	351 nm	308 nm	339 nm
Output energy	75 mJ	140 mJ	adjustable
Pulse repetition rate	250 Hz (maximum) 94 Hz (typical)		
Beam divergence	0.07 mrad	0.07 mrad	
Receiver			
Telescope diameter	2 m		
Field of view	0.6 mrad (typical)		
Filter bandwidth	2 nm	2 nm	2 nm
Total optical efficiency	< 20 %	< 10 %	< 20 %
Chopper	750 Hz		
Detector			
Photomultipliers	Hamamatsu R3235 (6 channels)		
Gate width	1 - 200 µs		
Preamplifiers	100 MHz		
Signal processor			
Photon counters	1 µs gate time, 2048 segments (6 channels)		
Data processor	PDP 11/53		

into two by beam splitters (ratio: 95 to 5%) and is focused on two photomultipliers for each wavelength. The signals from the two photomultipliers with preamplifiers, we call those channels high sensitivity (HS) and low sensitivity (LS) channels, are sent to the discriminators, photon counters and then the computers. The photomultipliers are replaced with those with a low signal induced noise (Hamamatsu R3235) in January 1990. Data acquisition and control of the whole system are carried out using a minicomputer (PDP 11/53).

The tropospheric subsystem has KrF excimer laser (Lambda Physik EMG 201MSC) and Raman shifters with hydrogen and deuterium which generate 277, 292 and 313 nm radiation. The signal with a wavelength of 313 nm can be used for the stratospheric ozone measurements because it has a good signal-to-noise ratio up to 30 km. This wavelength is quite useful in the presence of the volcanic aerosols.

3. DATA PROCESSING

The conventional DIAL equation is used for calculation of the ozone concentration:

$$N(z) = \frac{1}{2\{\sigma_{on}(T) - \sigma_{off}(T)\}} \left[\frac{d}{dz} \left\{ -\ln \frac{n_{on}(z)}{n_{off}(z)} \right\} + B + E \right]$$

$$B = \frac{d}{dz} \ln \frac{\beta_{on}(z)}{\beta_{off}(z)}$$

$$E = -2 \{\alpha_{on}(z) - \alpha_{off}(z)\} \qquad (1)$$

where $n(z)$ is the photoelectron number, $\beta(z)$ the backscattering coefficient due to aerosols and air molecules at the altitude of z, $\alpha(z)$ the extinction coefficient due to aerosols and air molecules, σ (T) the absorption crosssection of ozone, T the temperature and $N(z)$ the number density of ozone molecules. When no aerosol is assumed in the range of interest, terms, B and E, are estimated from the air molecule profile which is given by meteorological measurements using upper-air sondes or by atmospheric models.

Though we do not describe the details of the data processing here, we would like to mention the method for differentiation in Eq. (1). The differentiation is carried out by applying a kind of numerical filter which gives the third order polynomial fitting and differentiation simultaneously. At first we applied the second order polynomial fitting, however, it was found to give systematic deviations in the ozone concentration in the upper stratosphere when we assume realistic vertical resolution.

Temperature profiles are calculated with the algorithm proposed by Chanin and Hauchecorn (1984).

4. EXAMPLES OF OZONE AND TEMPERATURE PROFILES

As three wavelengths are used for measurements of the stratospheric ozone profiles with the NIES ozone lidar, ozone profiles can be obtained from the two pairs of received signals; 308 nm - 351 nm (A-) and 308 nm - 339 nm (B-) signal pairs. Figure 1 shows an example of the ozone profiles obtained from A- and B- signal pairs. The agreement is very good and it is difficult to distinguish the two profiles. This means first that the effects of the stratospheric aerosols on the ozone lidar measurements are negligible within the error bars in this case. This means second that the alignments of the laser beam transmitted are probably good because laser beams with a wavelength of 339 nm and 351 nm are independently aligned. This is a typical example for ozone profiles measured under good atmospheric conditions before the arrival of the stratospheric aerosols due to the eruption of Mt. Pinatubo. Comparison of ozone profiles obtained with the NIES ozone lidar and SAGE II showed good agreement (Nakane et al., 1992). Therefore, data obtained with the NIES ozone lidar under good conditions have sufficient accuracy.

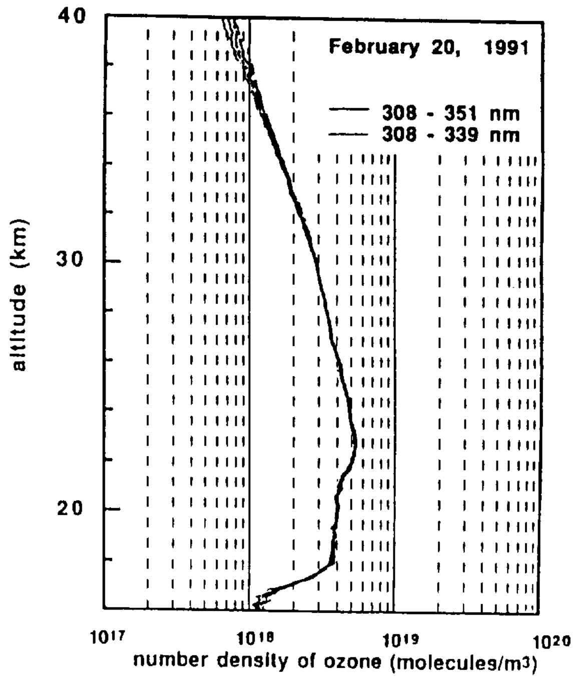

Fig. 1. Ozone profiles with random errors observed with the NIES ozone lidar using two wavelength pairs.

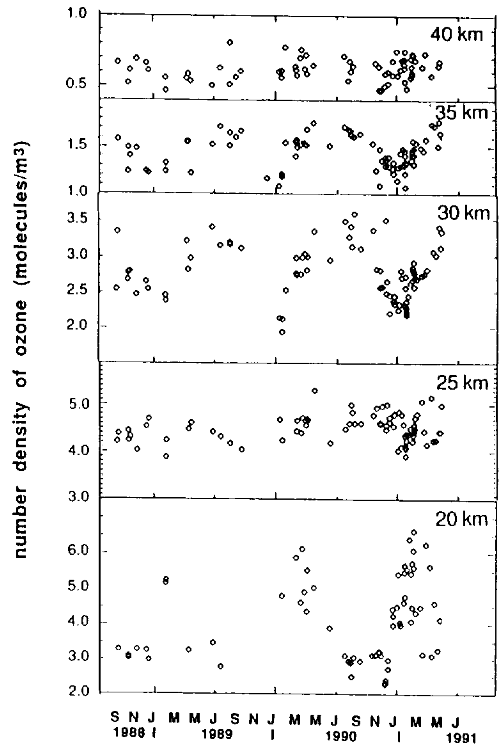

Fig. 2. Ozone concentration observed with the NIES ozone lidar for 2.5 years at 20 - 40 km.

Figure 2 shows the results of the lidar observation for 2.5 years. Different seasonal variations are shown at different altitudes, ozone concentration is high in spring and low in summer and autumn at 20 km; and high in summer and low in winter at 30 km and 35 km. The former is the typical seasonal variation controlled by dynamical processes and the latter by photochemical processes.

Figure 3 shows temperature profiles observed during DYANA campaign (Nakane et al., 1992). Rapid increase and decrease in the temperature can be seen around 55 and 70 km in attitude, respectively.

5. EFFECTS OF VOLCANIC AEROSOLS ON OZONE LIDAR MEASUREMENTS

In the presence of heavy volcanic aerosols like those from Mt. Pinatubo, the wavelength dependence of the extinction and backscattering coefficient of the aerosols may cause systematic errors. The behaviors of the systematic errors were simulated by Sasano et al. (1989) and also by Browel et al. (1985). The systematic errors due to the aerosol backscattering, B in Eq.(1), usually give the negative (positive) error above (below) the peak of the aerosol layer. The systematic errors due to aerosol extinction, E in Eq.(1), is usually small and gives positive errors. These systematic errors should be larger for the larger wavelength differencies between the on- and off-resonant wavelengths.

Figure 4(a) shows the ozone profiles obtained from the different wavelength pairs carried out from 10 UT to 14 UT and Fig. 4 (b) is an aerosol profile measured by the large-scale aerosol lidar in NIES on the same day. There is an ozone profile obtained from an additional wavelength pair (308 nm - 313 nm pair; C-pair). An ozone profile was obtained from the ozonesonde observation carried out by NIES and Tateno Aerological Observatory (TAO) at 6 UT at TAO about 500 m from NIES. As there is a time difference of about 6 hr between the lidar and sonde measurements, the ozone profiles may not behave the same especially in the lower stratosphere. The three ozone profiles with different wavelength pairs agree well in the altitude region with negligible aerosols. However, those profiles change systematically as described above where there was the aerosol layer. Taking the wavelength differences into account, the correct ozone profile should be close to the C-pair profile. This profile is not so different with that obtained from the ozonesonde measurement. This result may suggest the possibility of the correction of aerosol effects (Sasano, 1988) if the lidar signals have enough signal-to-noise ratios.

6. CONCLUDING REMARKS

The stratospheric subsystem of the NIES ozone lidar system is described. The measured vertical profiles have good accuracy. The observed seasonal variations at 20 - 40 km show ozone variations related to typical dynamical and photochemical processes, respectively. The effects of the volcanic stratospheric aerosols on the ozone lidar measurements are discussed.

ACKNOWLEDGMENTS

The assistance of Mr. F. Sakurai and Mr. H. Sato with the lidar measurements are gratefully acknowledged.

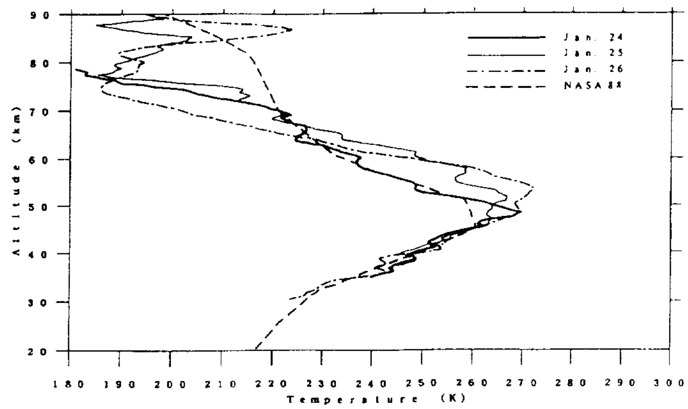

Fig. 3. Temperature profiles changing from January 24 to 26, 1990 during DYANA campaign (Nakane et al., 1992).

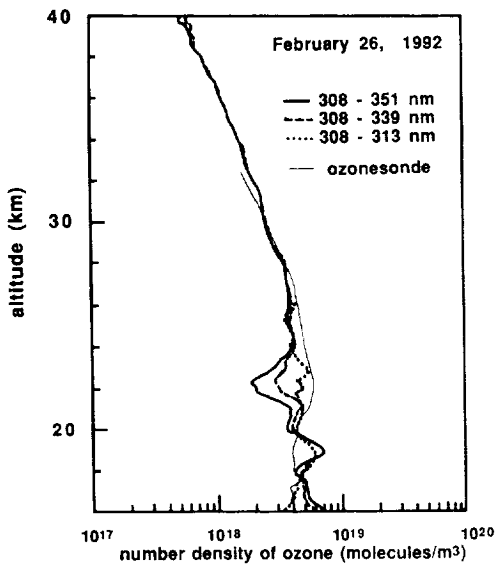

Fig. 4(a). Ozone profiles obtained from 308 nm - 351 nm (A-), 308 nm - 339 nm (B-) and 308 nm - 313 nm (C-) wavelength pairs of the NIES ozone lidar system on February 26, 1992. Ozone profiles observed by NIES and TAO on the same day is also shown.

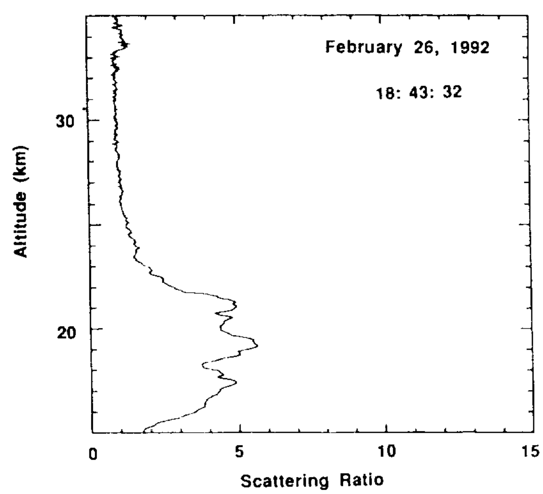

Fig. 4(b). Aerosol profile of the volcanic aerosols due to Mt. Pinatubo measured with the NIES large scale Mie lidar on February 26, 1992.

REFERENCES

Browell, E. V., S. Ismail and T. Shipley, 1985: Ultraviolet DIAL measurements of O_3 profiles in regions of spatially inhomogeneous aerosols. Appl. Opt., **24**, 2827 -2836.

Chanin, M.-L., and A. Hauchecorne, 1984: Lidar studies of temperature and density using Rayleigh scattering , MAP Handbook,13, edited by R.A Vincent, pp87 - 99, SCOSTEP, Urbana,Illinois.

Nakane H., S. Hayashida, Y. Sasano, N. Sugimoto, I. Matsui, and A. Minato, 1992: Vertical profiles of temperature and ozone observed during DYANA campaign with the NIES ozone lidar system at Tsukuba. J. Geomag. Geoelectr. in press.

Nakane, H., Y. Sasano, S. Hayashida-Amano, N. Sugimoto, I. Matsui, A. Minato, and M.P. McCormic, 1992: Comparison of ozone profiles obtained with NIES DIAL and SAGE II measurements. submitted to J. Meteorol. Soc. Japan.

Sasano, Y., H. Nakane, S. Hayashida-Amano, N. Sugimoto, I., Matsui and A. Minato, 1989: Multiple-wavelength DIAL and a new analysis technique to deduce the ozone profile without systematic errors due to aerosol effects. Proc. of the Quadrennial Ozone Symposium 1988 and tropospheric ozone workshop, 743-746.

Sasano, Y., N. Sugimoto, H. Nakane, S. Hayashida-Amano, I. Matsui, A. Minato, 1989: Multiple-wavelength differential absorption lidar (DIAL) for measuring the ozone profiles in the stratosphere and the troposphere, Abstracts of First Tsukuba Workshop on Ozone DIAL, Tsukuba, Japan, December 6 and 7.

Sasano, Y., 1988: Simultaneous determination of aerosol and gas distribution by DIAL measurements, Appl. Opt., **27**, 2640 -2641.

Sugimoto, N., Y. Sasano, H. Nakane, S. Hayashida-Amano, I. Matsui, and A. Minato, 1989: Multiple wavelength laser radar for measuring the stratospheric and tropospheric ozone profiles, Oyobutsuri, **56**, 1385 - 1397 (in Japanese).