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FIVE YEARS LIDAR OBSERVATION OF VERTICAL PROFILES OF STRATOSPHERIC OZONE AT NIES, TSUKUBA (36°N, 140°E)

Hideaki Nakane, Nobuo Sugimoto, *Sachiko Hayashida,
Yasuhiro Sasano and Ichiro Matsui
National Institute for Environmental Studies
Onogawa, Tsukuba, Ibaraki 305 Japan
Phone 81-298-51-6111 Facsimile: 81-298-51-4732
E-mail: nakane@nies.go.jp

1. Introduction

Lidars play important roles in international network observation of the ozone layer such as "Network for the Detection of Stratospheric Change (NDSC)" The National Institute for Environmental Studies (NIES) has been developing aerosol lidars and ozone lidars (DIALs). As one of these lidar activities, an ozone lidar system was installed in March 1988 and observation has been carried out since August 1988. Observed data for more than five years were checked, compared with the SAGE II data (Nakane et al., 1993b) and archived. The ozone lidar to measure the vertical profiles of ozone in the stratosphere at NIES was accepted as an NDSC Complementary Measurement activity in January 1994. In this paper, the outline of the NIES ozone lidar, data processing, obtained data and variations of ozone are reported.

2. Hardware of the NIES Stratospheric Ozone Lidar

The NIES stratospheric ozone lidar system (Sugimoto et al., 1989; Sasano et al., 1989) uses an injection-locked XeCl excimer laser (Lambda Physik EMG160TMSC) as the light source for the on-resonant wavelength (308 nm) and injection-locked excimer laser, XeF laser, as that for the off-resonant wavelength (351 nm) . A Raman shifter with deuterium generates another off-resonant 339 nm laser beam from the 308 nm laser beam. The beams from the XeCl and XeF lasers with three wavelengths are expanded 3.3 times and transmitted to the stratosphere.

The backscattered light is collected by the 2 m telescope and then focused on a chopper blade for cutting the strong light scattered at the lower altitudes. The lenses just before and after the chopper had been single plano-convex lenses, but they were replaced by achromatic lenses in June 1990. This improvement has given us better alignment and higher accuracy especially in the lower altitude region. Dichroic mirrors, color glass filters, interference filters are used for wavelength separation. Beams separated are then divided by beam splitters (ratio: 95 to 5 %). The signals from the 95% channel and 5% one are called high sensitivity (HS) and low sensitivity (LS) channels, respectively. The signals of HS and LS channels are combined to make signals with larger dynamic range. The splitted beams are finally focused on the photomultipliers (Hamamatsu R3235) with electrical gates and pre-amplifiers. Signals are processed with the discriminators, photon-counters. Data processing and system control had been carried out using minicomputer (PDP 11/53), but Sun workstation has been used since February 1994. Signals at 351 nm have been used for measurements of temperature profiles (Nakane et al., 1991).

3. Calculation of ozone

The vertical profiles of ozone were calculated based on the conventional DIAL equation from the lidar signals;

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* Present address; Nara Women's University

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

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

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

where n(z) is the photoelectron number, $\beta(z)$ and $\alpha(z)$ the backscattering coefficient and extinction coefficient due to aerosols and air molecules at the altitude of z, $\sigma(T)$ the temperature dependent absorption cross section of ozone, T the temperature and N(z) the number density of ozone molecules.

When aerosol effects are negligible in the range of interest, terms, B and E, are estimated from the air molecule profile. However, B and E should be calculated after major volcanic eruptions such as the case of Mt. Pinatubo. We assume the power law for the aerosol extinction coefficient $\alpha_1(z,\lambda)$ and the aerosol backscatter coefficient $\beta_1(z,\lambda)$. That is:

$$\alpha_1(z,\lambda) = \alpha_1^0(z,\lambda^0)(\lambda/\lambda^0)^{-\gamma}$$

$$\beta_1(z,\lambda) = \beta_1^0(z,\lambda^0)(\lambda/\lambda^0)^{-\sigma}$$

$$s_1(\lambda^0) = \alpha_1(z,\lambda^0)/\beta_1(z,\lambda^0) .$$

When s_1=10, γ =0, σ=1.0 are used, substantial reduction of systematic errors due to aerosols was obtained. The sensitivities of ozone profiles with the values of s_1, γ and σ were examined. Only slight changes were found within the range of parameters, s_1=5 - 20, γ=-1 - 1 and σ=0.5 - 1.5. Therefore, we assumed the value of these parameters as above and calculated the vertical profiles of the ozone concentration for the data after the eruption of Mt. Pinatubo. In spite of the usefulness of this aerosol correction, residual systematic errors are still remain where and when there are large amount of aerosols. Therefore, we set the minimum altitudes of the ozone profiles above the aerosol layers in those cases.

4. Diagnosis of the data

The data with statistical errors less than 10 % and without systematic errors are archived. Statistical errors for ozone number densities calculated are estimated by assuming that the statistical errors are determined only by the shot noise of the received signals. Usually the maximum height is limited by the statistical noise. The data with unusual oscillation larger than 10 % are eliminated. The minimum height is determined by the signal distortion due to the effect of the chopper or dead time of the photon counter, which is detected by the ratio between HS and LS signals.

Systematic errors are usually estimated by comparisons between independent measurements. We are comparing the ozone profiles derived from a pair of signals for 308 nm and 339 nm, and 308 nm and 351 nm. Figure 1 depicts an example of these comparisons. The agreement is very good and it is difficult to distinguish the two profiles. This means the first that the effects of the stratospheric aerosols on the ozone lidar measurements are negligible within the statistical errors. This means the second that the alignment of the laser beam transmitted are probably good as mentioned above. This is a typical example for ozone profiles measured under good atmospheric conditions before arrival of the stratospheric aerosols due to the eruption of Mt. Pinatubo.

5. Variations of ozone

Temporal variations of ozone at 20, 25, 30, 35 and 40 km from September 1988 are depicted

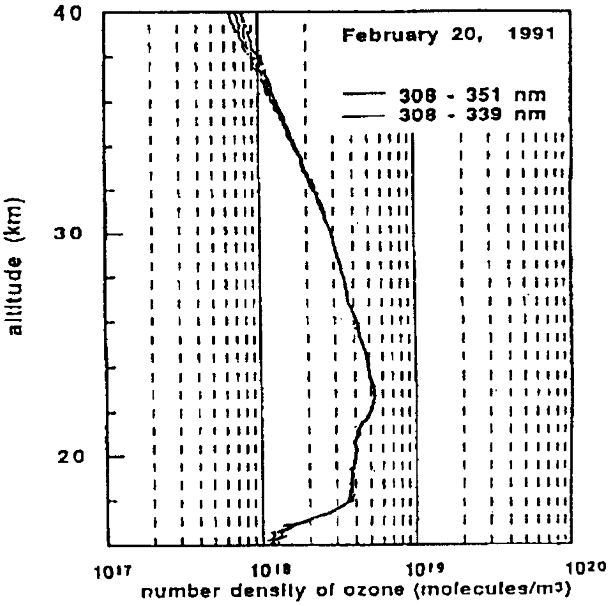

Fig.1 Ozone profiles with statistical errors derived from a pair of signals for 308/339 nm (thin curves) and 308/351 nm (bold curves)

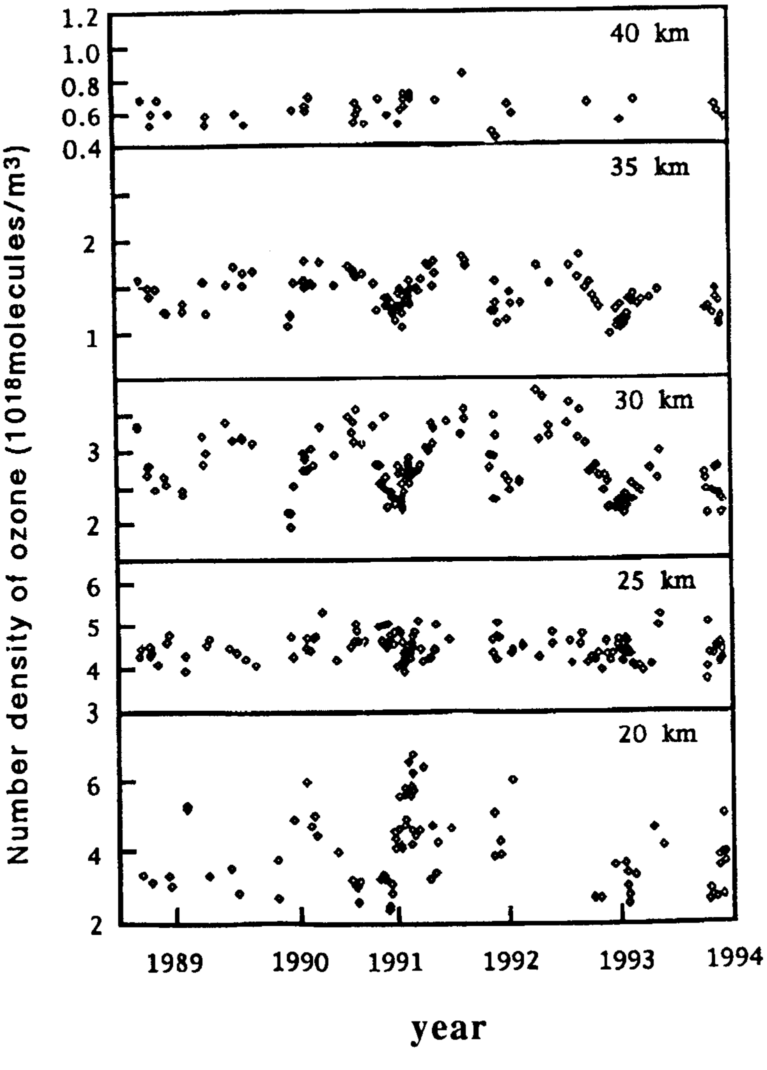

Fig. 2 Variations of ozone at an altitude of 20, 25, 30, 35 and 40 km.

in the Fig. 2. Seasonal variations are different with altitude. Ozone density is high in winter and low in summer at 20 km; high in summer and low in winter at 30 and 35 km. This difference of the seasonal variation with altitude is consistent with the mechanism of the seasonal variations in the lower and upper stratosphere generally understood: Transport effects are of dominant in the lower stratosphere and photochemical effects in the upper stratosphere. After the arrival of the stratospheric aerosols due to the eruption of Mt. Pinatubo, the aerosol correction were applied. However, many data at 20 km should have been eliminated because the effects of the stratospheric aerosols were too large to correct. Trends of ozone number densities at 25, 30, 35 and 40 km are negligible. Longer term monitoring is necessary for the detection of trends of the vertical profile of ozone.

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