25D3 **DUAL-DIAL MEASUREMENTS OF OZONE PROFILES**

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1 INTRODUCTION

Differential absorption lidar (DIAL) technique is an important method for measuring ozone profile with high temporal and spatial resolution[1]. Theoretically, the DIAL technique can measure ozone profile accurately. But, in the ultraviolet wavelength region, it is difficult to make the separation of the two wavelengths small enough to neglect the effect of the aerosol backscattering and extinction associated with the presence of spatial inhomogeneity of aerosol or high aerosol loading along the path of lidar line of sight[1,2]. This could sometimes introduce significant errors into the determination of ozone content. For correcting the effect of aerosol, many methods have been developed. The system errors can be estimated, for example, if information about aerosol extinction, backscattering profile and wavelength dependence along the lidar viewing direction is obtained[2,3,4]. However, the information isn't accurate, some errors still exist. Another experimental method (Raman-DIAL method) was proposed by Signh[5], which can minimize the effect of aerosol backscattering by differential absorption of two wavelength Raman return signals of N_2. This method can be used for stratospheric ozone measurement, but the Raman scatter return signal is two orders lower than Rayleigh and Mie scatter. Moreover, for tropospheric ozone measurement,the effect of aerosol extinction should be taken into account yet.

We propose a new experimental and data processing method, the Dual Differential Absorption Lidar (Dual-DIAL) technique. This technique can minimize effectively the effect of aerosol extinction and backscattering on ozone measurements in both the troposphere and stratosphere. The accuracy of ozone measurement can be improved greatly with this technique. The theoretical basis and experimental scheme are described first, then the results of numerical simulation with different aerosol size distribution and spatial distribution are presented.

2 THEORETICAL BASIS OF DUAL-DIAL

As the conventional DIAL technique, two pairs of wavelengths, $(\lambda_{1on},\lambda_{1off})$ and $(\lambda_{2on},\lambda_{2off})$ are selected. The ozone profile can be calculated with each pair of wavelengths based on the DIAL equation. The ozone profile can also be calculated with tow Pairs of wavelengths. The number density of ozone molecules at Z range, N(Z), can be written as follows:

$$N(z)=\frac{1}{2\Delta\delta(T)}[\frac{d}{dz}(-\ln\frac{P_{\lambda_{1on}}(z)}{P_{\lambda_{1off}}(z)}) - \frac{d}{dz}(-\ln\frac{P_{\lambda_{2on}}(z)}{P_{\lambda_{2off}}(z)}) +B1+E1-B2-E2]$$

$$\Delta\delta(T)=(\delta_{\lambda_{1on}}(T)-\delta_{\lambda_{1off}}(T)) -(\delta_{\lambda_{2on}}(T)-\delta_{\lambda_{2off}}(T))$$

$$B1=\frac{d}{dz}\ln\frac{\beta_{\lambda_{1on}}(z)}{\beta_{\lambda_{1off}}(z)}$$

$$E1=-2\{\alpha_{\lambda_{1on}}(z)-\alpha_{\lambda_{1off}}(z)\}$$

$$B2=\frac{d}{dz}\ln\frac{\beta_{\lambda_{2onn}}(z)}{\beta_{\lambda_{2off}}(z)}$$

$$E2=-2\{\alpha_{\lambda_{2on}}(z)-\alpha_{\lambda_{2off}}(z)\}$$

i.e:

$$N(z)=\frac{1}{2\Delta\delta(T)}[\frac{d}{dz}(-\ln\frac{P_{\lambda_{1on}}(z)}{P_{\lambda_{1off}}(z)} +\ln\frac{P_{\lambda_{2on}}(z)}{P_{\lambda_{2off}}(2)})+B'+E']$$

$$B'=B1-B2$$

$$E'=E1-E2$$

where λ_{1on}, λ_{2on} and λ_{1off}, λ_{2off} corresponding to strong and weak absorption laser wavelength of ozone, respectively. $\delta(T)$ the temperature dependent absorption cross section per ozone molecule, T the temperature, P(z) lidar return signal power or photoelectron number from range Z, $\beta(z)$ total volume backscatter coefficient due to air molecules and aerosols at range Z, and $\alpha(z)$ total extinction coefficient neglecting absorption by ozone at range Z. If the two pairs of wavelengths satisfy the following conditions:

1: $\lambda_{1on}-\lambda_{1off}$ equals to or approximately equals to $\lambda_{2on}-\lambda_{2off}$,

2: $\Delta\delta(T)$ is large enough so that it can meet the needs of measurement sensitivity and spatial resolution,

3: the separation of two pairs of wavelengths isn't too large.

then the differences in B1 and B2, E1 and E2 become very small. Therefore B' and E' can be neglected or only the effect of molecule extinction is taken into account. In this way, the effect of aerosol on ozone measurement will be minimized by this technique.

3 EXPERIMENTAL SCHEME

With the development of laser technique, there are many UV lasers for the ozone measurement lidar. According to the above theoretical analysis of dual-DIAL and the available wavelengths, the following wavelength groups can be selected as the dual-DIAL use:

A: 289., 313; 277.1,299.1 nm

B: 268.4, 289.; 277.1,299.1 nm

C: 299.1, 341.5; 308, 353. nm

$\Delta\delta(T)$ for group A and B equal to 2.759E-18cm^2, 2.691E-18cm^2 respectively, which can meet the need of tropospheric ozone measurement[4]. So the dual-DIAL with group A or B wavelengths can be used for tropospheric ozone measurement. $\Delta\delta(T)$ of group C is 2.63E-19cm^2, the dual-DIAL with group C wavelengths can be used for stratospheric ozone measurement(<30km).

The wavelengths in group A,B and C can be obtained by two fixed frequency lasers and their stimulated Raman scattering(SRS). In terms of the complexity of lasers, It is very easy to obtain those wavelengths. With development of computer control technique and data acquisition technique, the receiving of multi-wavelengths and multi-channels can also be taken out easily. So the dual-DIAL technique can be carried out easily. As the usual multi-wavelengths lidar measurement, the return signals of four wavelengths are received simultaneously, the ozone profile can be calculated accurately with the dual-DIAL technique and the effect of aerosol can be neglected.

4 NUMERICAL STIMULATION

In order to illustrate that the dual-DIAL technique can minimize the effect of aerosol on ozone measurement in the troposphere and stratosphere, the relative error in ozone measurement due to neglecting the term B' or B and the aerosols extinction in the term E' or E in the dual-DIAL or DIAL technique, are estimated by using different aerosol size distributions and spatial distributions.

1: Stratospheric ozone measurement

As mentioned above, the group C wavelengths can be used for stratospheric ozone measurement. For calculating, the following characters of aerosols are assumed: extinction wavelength dependence $\sigma(\alpha_{\lambda1}=\alpha_{\lambda2}(\lambda1/\lambda2)^{-\sigma})$ from -0.5 to 2,

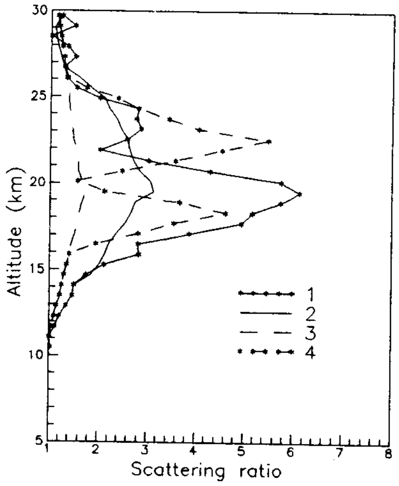

Fig.1 Vertical profile of the aerosol scattering ratio at 532nm

backscattering wavelength dependence

ζ ($\beta_{\lambda 1}=\beta_{\lambda 2}(\lambda 1/\lambda 2)^{-\zeta}$) from -1 to 2, extinction to backscattering ratio(532nm) S from 20 to 70, and profiles of aerosol scattering ratio R ($R = 1+\beta_a/\beta_m$, β_a and β_m are aerosol and molecule volume backscatter coefficient at 532nm) are shown in Fig.1. The calculated results show that the change of σ affects the stratospheric ozone measurement slightly; when ζ is within the range of 0.5-2, the relative error of ozone concentration can be kept within 5% for the aerosol spatial distributions shown in Fig. 1. Figure 2 a,b show the relative errors caused by neglecting the effect of aerosol in the ozone measurement with the conventional DIAL and our dual-DIAL technique respectively. The distribution

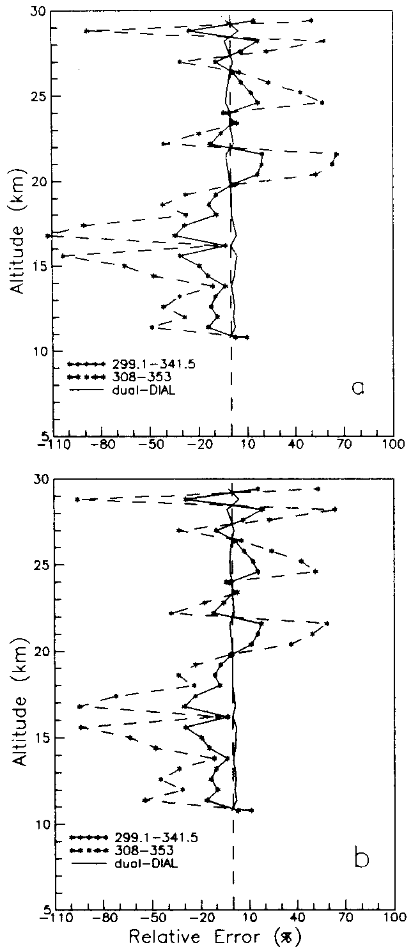

Fig.2 Relative error in the ozone concentration obtained by conventional DIAL and dual-DIAL

of aerosol scattering ratio used for the calculation was curve 1 in the Fig.1. Parameter of Fig.2 a,b are σ=1.0,ζ=0.5,S=45 and σ=1.0, ζ=1.5,S=45 respectively.If changing 353nm with 351nm, this technique can keep the relative error within 5% for the spatial distribution in the Fig.1 when ζ within range of -1 to 2. In addition, the character of aerosol extinction and backscattering were calculated by using different stratospheric aerosol size distributions, and the effect on ozone measurement were also estimated. The results of these calculations show that, compared with the conventual DIAL, the dual-DIAL technique can reduce the effect of aerosol 5-10 times after volcanic eruption and keep the relative error of ozone concentration due to aerosols within 5% .

2:Tropospheric ozone measurement

Group A,B wavelengths can be used for tropospheric ozone measurement. As the stratospheric calculating, different σ,ζ and S are chosen here. The results show that the ozone measurement error caused by aerosol with our technique is about one order of magnitude smaller than the

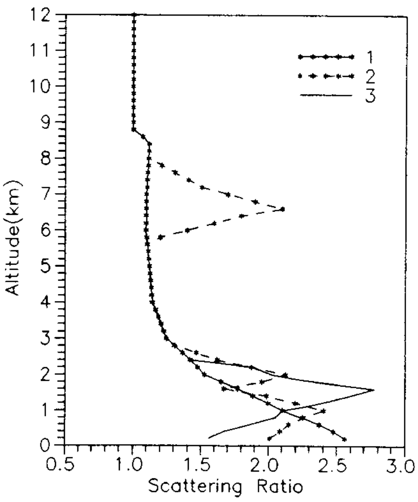

Fig.3 Vertical profile of the aerosol scattering ratio at 532nm

conventional DIAL technique. The relative error of ozone concentration can be kept within 5% for the aerosol spatial distribution in Fig.3 when σ is less than 1.5, ζ within -1 to 2, S within 30 to 80. Figure 4 a,b show the relative errors due to neglecting the effect of aerosols in the conventional DIAL and dual-DIAL technique. Here σ=0.5,ζ=0,S=55 and σ=1. 5,ζ= 2.0, S= 55, respectively. The distribution of aerosols scattering ratio used for the calculation is curve 1 in the Fig.3. The dual-DIAL with group A wavelengths not only minimize the effect of aerosol on ozone measurement in the troposphere, but also can minimize the effect of SO_2 and NO_2 on ozone measurement. When the densities of O_3, NO_2 and SO_2 are equal, the effect of SO_2 is within 2%, the effect of NO_2 is within 0.5%. In the group B, the effect of SO_2 becomes large, but the effect of NO_2 is still small. So the dual-DIAL with group A wavelengths can be used for ozone measurement in the region where pollutant concentration or aerosol loading is high or the distribution of aerosol is inhomogeneous.

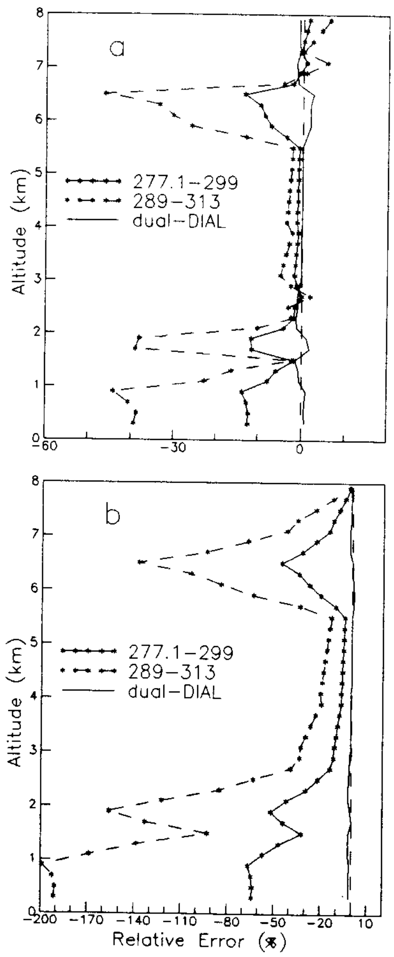

Fig.4 Relative error in the ozone concentration obtained by conventional DIAL and dual-DIAL

5 CONCLUSION

The theoretical analysis and numerical stimulation results show that the dual-DIAL technique can reduce greatly the effect of aerosol on ozone measurement in the troposphere and stratosphere. The dual-DIAL technique is better than the conventional DIAL. The dual-DIAL with group A (289., 313.; 277.1, 299.1nm) or group B (268.4, 289.; 277.1, 299.1nm) wavelengths can be used for lidar ozone measurement in the region, where aerosol loading is high or distribution inhomogeneous in the troposphere. Moreover, the dual-DIAL with group A wavelengths can measure ozone profile accurately in areas polluted by sulfur dioxide, nitric dioxide in the troposphere. The dual-DIAL with group C (299.1, 341.5; 308,353nm) wavelengths can be used for the measurement of stratospheric ozone after the volcanic eruption, which injected large amounts of SO_2 and ash into the stratosphere. The accurate ozone data obtained by the new lidar system can be used in the research of the variation of ozone, the dynamical processes of ozone and the interaction of ozone with aerosols.

References:

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