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A LASER RADAR SYSTEM FOR THE OBSERVATION OF MINOR ATMOSPHERIC CONSTITUENTS IN THE STRATOSPHERE

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Abstract

A laser radar system was constructed in our institute for observing aerosols and minor atmospheric gas constituents in the stratosphere. The system is composed of a combination of YAG and dye lasers. The YAG laser is used for observing the density distribution of aerosols and obtaining the information on the size distribution of aerosols. The dye laser which is pumped by the YAG laser is used for gaseous constituents such as ozone by applying the DIAL method. A mini computer controls the system operation. This paper describes the composition of the system and some examples of preliminary aerosol observations and estimates the sensitivity of the system.

1. Introduction

Laser radars have been constructed at many places in the 1970's (Schuster, 1970; Russell et al., 1976). After the eruption of Fuego volcano in 1974 large increase of stratospheric aerosols and its decaying with time were reported by many workers (Feglay and Ellis, 1975; Gras, 1976; McCormick and Fuller, 1975; McCormick et al., 1978; Russell and Hake, 1977). Recently the eruption of Mt. St. Helens occured in 1980 (Kondo et al. 1982) and that of Mt. El Chichon in 1982 have been confirmed to give a large amount of aerosol injection into the stratosphere. Laser radar system is a powerful tool to remotely measure these behaviors of stratospheric aerosols. Temporal and spatial variations of aerosols can inform us the dynamical motion of the stratosphere. The Middle Atmosphere Program (MAP) has started from 1982 and many kinds of stratospheric and mesospheric observations by platforms such as aircraft, balloon, satellite and space shuttle are being carried out (Remsberg and Gordley, 1978). The laser radar observation is also one of the major subjects of the program. This ground-based observation has merits through the continual operation in investigating easily long as well as short term variations and in making collaborations with other observations at various places. We have long been interested in constructing a new laser radar system in the course of our stratospheric studies which have been made mainly by occasional balloon observations until now.

Recently the tunable dye laser becomes conveniently usable for a laser radar system and capable of adopting the differential absorption method for laser radar (DIAL) to measure minor atmospheric gas constituents in the stratosphere (Megie et al., 1977 ; Pelon and Megie, 1982). Our present system includes a dye laser which is pumped by a YAG laser. Tunable output of the dye laser scans the absorption band of the minor atmospheric constituents. The difference of receiving signals at adjacent two frequencies is used to derive the concentration of the constituent. The properties of this system will be a great help to comprehensive understanding of physical and chemical aspects of the stratosphere.

2 Composition of the system

The laser radar system constructed in our institute has two transmitters: one is a YAG laser (Quantel YG481-C) for measurements of aerosols and the other is a dye laser (Quantel TDL-IV) which is pumped by the second harmonic of YAG laser for measurements of minor gas constituents in the upper troposphere through the stratosphere. Table 1 shows the specification of the instruments and Fig. 1 shows the diagram of entire system. The light path from the respective transmitters is manually switched over by insertion of dichroic mirrors. The YAG laser emits infrared light (1064 nm). A frequency doubler inserted at the output light path of the YAG laser generates green light (532 nm) and a frequency tripler makes ultraviolet light

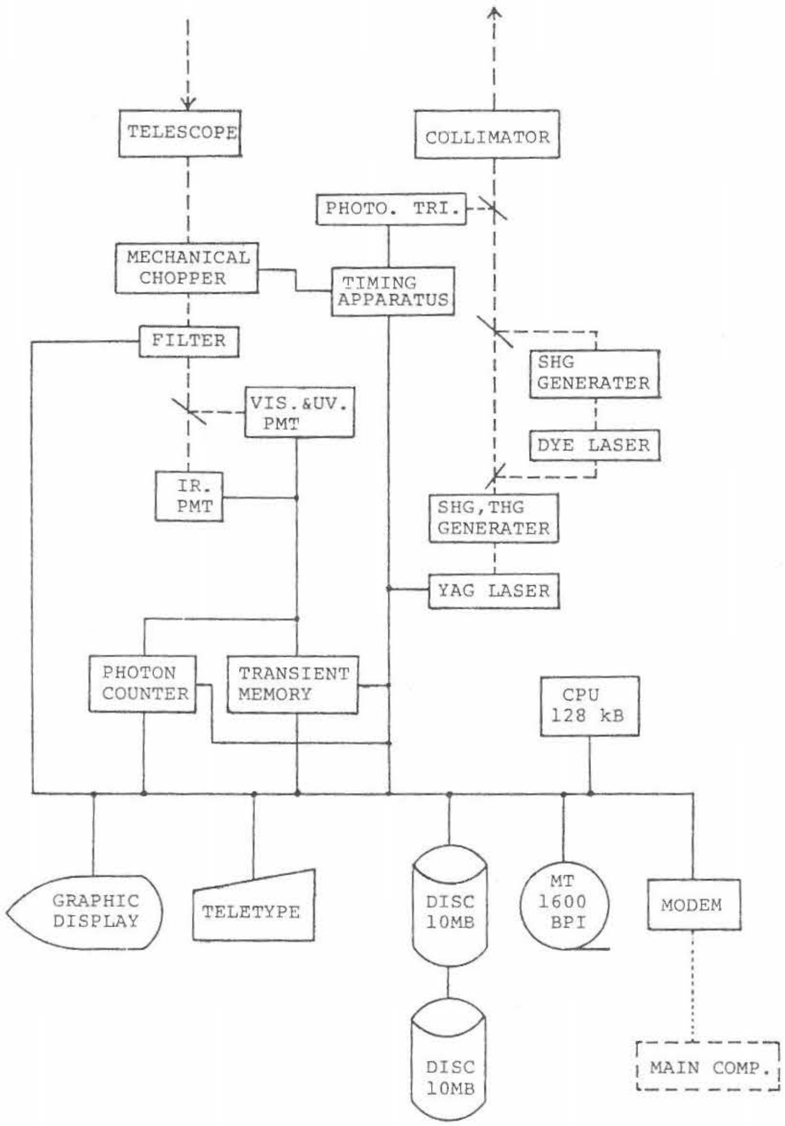

Fig. 1 Block diagram of the laser radar system

PHOTO. TRI.	Photometric trigger
VIS. & UV. PMT	Photomultiplier for visible and ultraviolet light
IR. PMT	Photomultiplier for infrared light

Table 1 System parameters of laser radar

YAG LASER	FUND.	2nd	3rd
WAVE LENG.	1064nm	532nm	355nm
ENERGY/PULSE	1200mJ	500mJ	180mJ
REPT. RATE		10PPS	
PULSE WIDTH		15ns	
DYE LASER	FUND.	2nd	
WAVE LENG.	550 - 730nm	280 - 360nm	
ENERGY/PULSE	130mJ	30mJ	
RECEIV. TELESCOPE	50cm NEWTONIAN		
ND FILTER	50,20,10,3,1 % in transmittance		
TRANSIENT MEMORY	10ns - 0.5s	2048 Words	8 bit
PHOTON COUNTER	2μs - 10μs	128 Memories	12 bit

(355 nm). By using these three lights of different wavelengths alternatively we can obtain the information on the size distribution of stratospheric aerosols. The dye laser is pumped by the green light from YAG laser and emits the light tuned in a wide wavelength range (530-730 nm) covered by using various dyes. The harmonic generator here again makes the doubled frequency in a ultraviolet range (280-360 nm), which covers the main absorption band of ozone. The light energy of one pulse at respective wavelengths is shown in Table 1. The laser beam is expanded to 3 cm diameter by a collimator before emitted vertically into the sky.

The laser light scattered back from the sky is collected by a telescope (Newtonian type 50 cm diameter), and then it passes a mechanical chopper and two stages of filters, and reaches to the photomuliplier. The mechanical chopper cuts off the strong back scattering light near the system. The filters consist of two groups. One is neutral density filters for giving an appropriate attenuation to the received light intensity, and the other is a narrow band interference type for selecting required single light and cutting off extra background. For three YAG laser lights the transmission band widths of the filters are about 1 nm at half power point. Two photomultiplier tubes are used and manually changed according to the emitted wavelength. For infrared light the S-1 type photomultiplier (HMT 7102) and for visible and ultraviolet light the bi-alkali type photomultiplier (HMT R1332) are used respectively. Both photomultipliers are electronically cooled to minimize a thermal noise.

The measurements are made in two different modes. The electrical signals from the photomultiplier are led to a transient memory (IWATSU DM901) for analogue mode of measurements or to photon counters (PAR 1109) for digital mode of measurements. The analogue mode of measurements has a good time resolution but measures only high level signals. The minimum sampling time of transient memory is 10 ns comparable with the laser pulse width and the memory capacity is 2048 words in 8 bit of accuracy. After some delay from a fire of laser we take a set of data of 2048 words and transport it to a mini computer (DEC MNC/DECLAB-23), and 50 ms after the laser shot (i.e. just on half way between successive shots in 10 pps) we take the background noise data of 128 words and transport to the mini computer. Each set of data is accumulated in the computer memories for previously defined times of laser shots in order to improve signal to noise ratio.

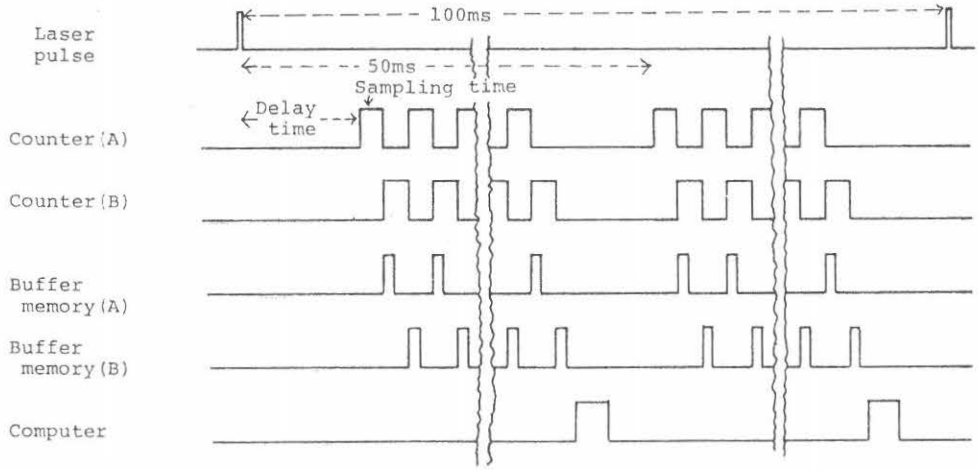

Fig. 2 Time sequence of data acquisition in digital mode

In the digital mode observations, we use two photon counters which operate alternately. One counter(A) operates in a sampling interval (2-10 μs properly selected). In the next interval, where the other counter(B) operates, the counter(A) stores its data into the buffer memories and resets itself to wait for the third interval. The alternate operation of the two counters continues until 128 data are obtained. The content of buffer memories is composed of a set of 128 words in 12 bits of accuracy. One set of data is taken for signal after a defined delay from a fire of laser and transported to the mini computer and accumulated in its memories for defined times of laser shots. The other set of data is taken for back ground noise after 50 ms from the laser shot and accumulated in memories of the mini computer. Time sequence of the data aquisition as above mentioned is shown in Fig. 2. The mini computer controls all the data collecting system. The data collection starts from console (retro graphic display, DEI VT-640) command and ends at the time when the number of laser shots reaches to the one typed in from keyboad formerly.

After one series of observation which involves enough number of laser shots to take a complete profile, the system parameters (delay time to the first sampling from the laser shot, sampling interval, observation time, mode classification of analogue or digital, filters, used photomuliplier, etc.), signals and background noises are stored in the magnetic disc. Display of the collected data on the screen of retro graphic can be made anytime after the data have been stored. The operation system used in the mini computer is RT-11(SJ) and the data collecting program is described by mainly FORTRAN-IV and partly MACRO-11. At the end of measurement the data from the magnetic disc are copied in the magnetic tape and the data processing is carried out by the main computer (ACOS 700) of the institute.

3 Base of data reduction

The DIAL method in laser radar is based on differences in the wavelength dependence of extinction by the respective atmospheric constituents. We show here the case for the measurement of ozone concentration. The similar method to this is applied for other constituents. The well known laser radar equation is expressed as follows,

$$P_{11} = Po_1 \beta_{11} z \frac{A}{Z_1^2} \eta \exp\{-2(\tau_{11}^{o} + \tau_{11}^{e})\} \qquad (1)$$

where P_{11} is the receiving power, Po_1 is the transmitting power, z is the spatial length corresponding to sampling unit time, Z_1 is the distance, β_{11} is the volume back scattering coefficient of the atmosphere, A is recieving area, η is efficiency of the system, τ_{11}^{o} and τ_{11}^{e} is the optical depths of ozone and the others (aerosols and so on), respectively. Double suffix relates with wavelength (λ_1) and distance (Z_1). For the normal laser radar system which measures the density of aerosols by using single wavelength, we consider the following formula.

$$\beta = \beta a + \beta m \qquad (2)$$

where βa is the back scattering coefficient of aerosols and βm is the Rayleigh back scattering coefficient of neutral air molecules. The two back scattering coefficients are proportional to the respective densities. Then we define the scattering ratio R as follows:

$$R = \frac{\beta a + \beta m}{\beta m} \qquad (3)$$

Therefore the value of R - 1 is proportional to the mixing ratio of aerosols. The air density to be used is favorably the measured value, if obtained, at the same site and the same time as the laser radar observation. But as a comparatively good approximation, we actually derive the density of air molecules from the US standard atmosphere and use the matching method (Russel et al. 1977). Thus we obtain the profiles of back scattering ratio from receiving power (range-corrected) and the density of air molecules.

For the DIAL method two equations like eq. (1) are satisfied by using two wavelengths in the measurement. The ratio of the two equations leads to

$$\log \frac{P_{11}}{P_{21}} = \log \frac{Po_1}{Po_2} + \log \frac{\beta_{11}}{\beta_{21}} + 2(\tau^{o}_{21}-\tau^{o}_{11}) + 2(\tau^{e}_{21}-\tau^{e}_{11}) \qquad (4)$$

Taking the same process as above for the distance Z_2 close to Z_1, the difference between the two equations for Z_1 and Z_2 is

$$2(\Delta\tau^{o}_{1} - \Delta\tau^{o}_{2}) = \log \frac{P_{11}P_{22}}{P_{21}P_{12}} + \log \frac{\beta_{21}\beta_{12}}{\beta_{11}\beta_{22}} + 2(\Delta\tau^{e}_{2} - \Delta\tau^{e}_{1}) \qquad (5)$$

Using the two wavelengths adjacent each other but having considerably big difference in the absorption cross sections of ozone (σ_1 and σ_2), the second and third terms of the right side of the above equation can be neglected. Thus the ozone density is derived from the following equation.

$$n_o(Z_2) = \frac{\Delta\tau^{o}_{1} - \Delta\tau^{o}_{2}}{(\sigma_1 - \sigma_2)\Delta Z} = \frac{1}{(\sigma_1 - \sigma_2)\Delta Z} \log \frac{P_{11}P_{22}}{P_{21}P_{12}} \qquad (6)$$

where $n_o(Z_2)$ is ozone density at distance Z_2 and $\Delta Z = Z_1 - Z_2$.

4 Examples of preliminary observation

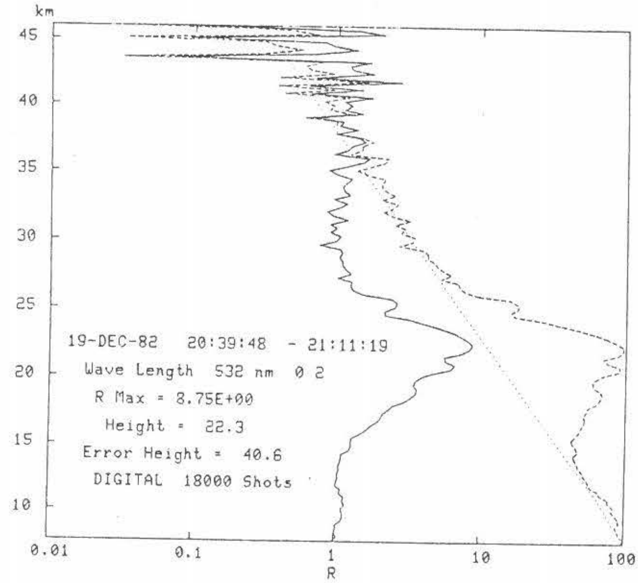

Fig. 3 Digital data example

solid line	scattering ratio
broken line	range corrected back scattering data
dotted line	Rayleigh back scattering calculated by using US standard atmosphere

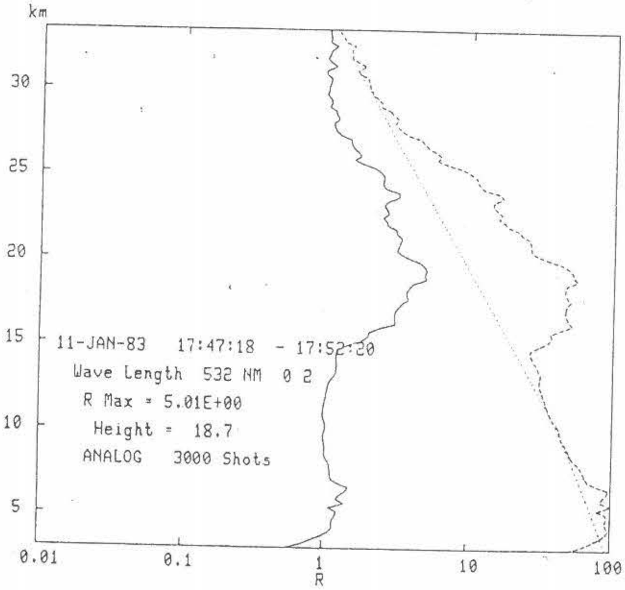

Fig. 4 Analogue data example
Line classification is the same as in Fig. 3

The main purpose of the present system is to measure minor atmospheric components; aerosols and gaseous substances such as ozone and nitrogen oxide which are closely related with the stratospheric environment. The laser radar operation by us has started to detect the distribution and variation of aerosols. It is also the first step to develop DIAL measurement of ozone. By using large power of green light (YAG second harmonic) and high receiving sensitivity at this wavelength, we have measured the lower stratospheric aerosols even in the daytime. At clear moonless night the measurement of aerosols can be made, by accumulating the data for several thousands laser shots, from 4 km up to 30 km in analogue mode and from 29 km up to 65 km in digital mode without attenuation filter. From these results we expect to measure the scattering signal up to

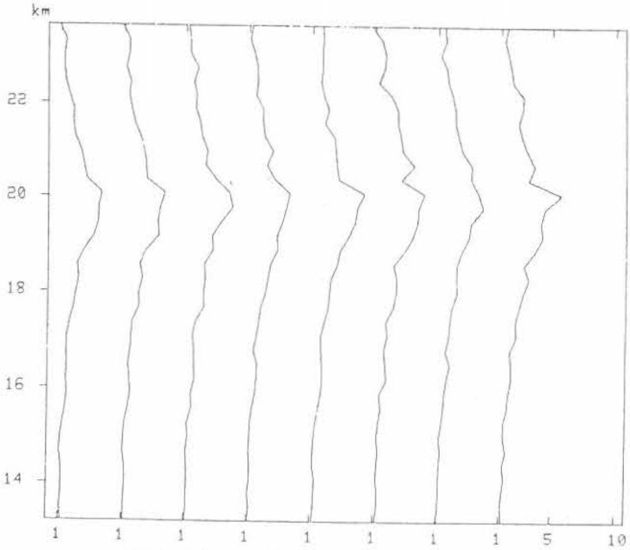

Fig. 5 Scattering ratio profiles shown with about 19 minutes interval. Ratio is indicated in linear scale. From 20:00 to 22:30 on Jan. 4 1983

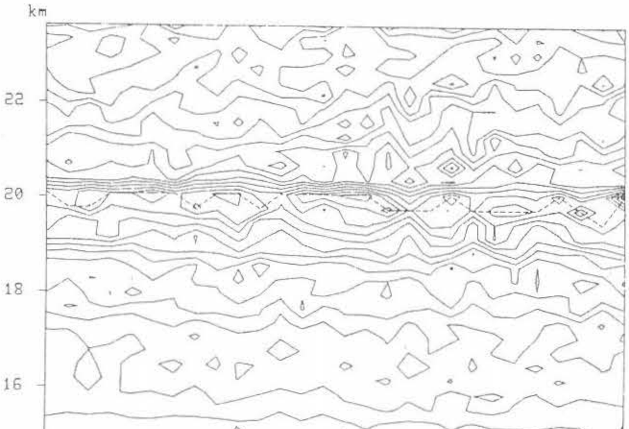

Fig. 6 Contour mapping of scattering ratio deduced from the profiles obtained with about 6.5 minutes interval in the same period as in Fig. 5. Solid lines are drawn at 0.3 interval of scattering ratio. Broken line shows the altitude of maximum scattering ratio.

40 km in the case of using dye second harmonic of lower light energy.

After the eruption of Mt. El Chichon the density of stratospheric aerosols is quite high and changeable in short time. Fig. 3 and Fig. 4 are examples of digital and analogue measurements, respectively. The data sampling height was 300 m in the case of Fig. 3 and that was 15 m in the case of Fig. 4. In Fig. 3 every data was plotted individually but in Fig. 4 plotting points were the average values of 16 sampling data. Both curves show the large increase of the scattering ratio near 20 km altitude. Fig. 3 shows maximum scattering ratio as high as 8.75 at altitude 22.3 km and Fig. 4 shows that of 5.01 at altitude 18.7 km. The values of scattering ratio and their profiles change day by day.

Fig. 5 shows the vertical profiles of scattering ratio obtained with 19 minutes time interval. Fig. 6 is the contour mapping in time versus altitude domain deriving from the

23 profiles of scattering ratio. The data were taken from 20:00 to 22:30 on January 4, 1983. These data are now analyzed to compare with the meteorological data. From Fig. 6, it is clear that the upper boundary of the peak of scattering ratio (shown in broken line) is limited with a sharp inclination at almost constant level of 20.2 km and that on the other hand the lower boundary shows a broad and slow decay. Our measurement is about to start and many works both in hard and softwares are still left to complete the system.

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