UV LIDAR FOR OZONE SOUNDING

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Received March 11, 1990

Attention is drawn to the medical and biological aspects of the problem of ozone monitoring. A single-frequency lidar based on an excimer laser is described. The preliminary results of ozone sounding in the resort region of Tuapse are presented.

The solution of problems in environmental protection requires new systems for remote monitoring of the effect of SO_2, aerosols, and other pollutants, which significantly affect, in particular, the change in the concentration of atmospheric ozone, on the stratosphere. It is also important to investigate atmospheric ozone from the geophysical viewpoint, since ozone determines the energy balance in the stratosphere and affects the thermodynamic regime in the stratosphere.

It is well known that the ozone layer, as an absorber of ultraviolet solar radiation, protects plants and animals from the destructive effect of such radiation. Man-made changes in the ozone concentration in a column of the atmosphere makes it necessary to setup regular global monitoring of the ozone distribution, including the altitude distribution of ozone (ADO). The successful solution of this problem will make it possible to perform comprehensive medical and biological investigations, especially during a period of elevated solar activity, when owing to the formation of ozone holes of different size significant fluxes of UV radiation in the B subband ((UVB) 290–300 nm) can reach the earth's surface. It is now known that the flux of radiation in this wavelength range is most harmful to human health. It has been found that Langerhans cells play a special role in the human immune system and that the UVB solar and artificial laser radiation affects the internal organs.

We described the program of medical-biological and ecological investigations and presented the first results of laser sounding of ADO in the resort region of Tuapse at the 10th All-Union Symposium on Laser and Acoustic Sounding (Tomsk, 1988) and at the All-Union Conference on Ecological Monitoring of Air at Resorts (Kislovodsk, 1989).

There exist different methods (chemical and optical, direct and passive) for studying the UVB solar radiation on earth, together with data on the ozone concentration, which were obtained with the help of ozone probes on rockets and balloons, ozonometers, UV meters, microwave radiometers, etc. Virtually none of the known methods for measuring atmospheric ozone on any selected path provide immediately accessible information with high spatial resolution.

The first works on the use of laser sounding for determining ozone in the .stratosphere were performed in 1977 using a differential absorption lidar (DAL) in investigations of ADO.[1] In the Soviet Union similar work was first performed at the Central Aerological Observatory. The latter work was performed using an organic-dye laser, whose wavelength could be tuned from 580 to 630 nm; a KDP crystal was used to double the frequency of the radiation. The pump source consisted of a high-power neodymium glass laser with frequency doubling, and the required power (of the order of 1 GW) was obtained with the help of a generator-amplifier system.[2]

Most of the atmospheric ozone is located at altitudes of 15–25 km. The ozone content in the troposphere is comparatively low. For this reason, by choosing the correct frequency of the sounding radiation it is possible to achieve adequate (for measurements) absorption in the stratosphere, if the transmission of the lower-lying air layers is relatively high. The region of the spectrum where the absorption cross section of ozone varies over wide limits (290–310 nm) is most suitable for this purpose.

In developing a DAL a great deal of attention is devoted both to the development of the most flexible variable-frequency system for investigating the effects which affect the sensitivity of the measurements for different altitudes and to methods for processing the sounding data.

In the experiments of Refs. 1 and 2 two close-lying wavelengths, chosen in sections of the spectrum where the absorption coefficients of the gas being sounded are different, were employed. This method often entails great difficulties, since lasers having the required energy and spectral and power characteristics are not available. In this case sounding is often performed at one main wavelength, which falls within the spectral absorption band of the gas. The absorption by the aerosol is estimated from measurements at an auxiliary wavelength (for example, 553 nm (Ref. 3)), different from the wavelength of the main radiation and at which radiation is not absorbed by ozone and other atmospheric gases.

In this paper we present preliminary results of ozone sounding at the wavelengths 308 and 589 nm. These wavelengths were chosen because an lexcimer XeCl laser and an auxiliary dye lidar were used.[4]

0235-6880/90/10 965-4 $02.00

It is well known that the dependence of the signal strength at the output of the laser photodetector on the sounding altitude R in the far zone is determined by the lidar equation

$$N(R) = W_0 A K \beta_{\pi\lambda}(R) R^{-2} \exp\left\{ -2 \int_0^R n_{O_3}(R) \sigma_{O_3}(\lambda) dR - 2 \int_0^R \alpha_a(R;\ \lambda) dR - 2 \int_0^R \alpha_м(R;\ \lambda) dR \right\}, \quad (1)$$

where W_0 is the energy of the laser; A is the area of the receiving antenna; K is the efficiency of the receiving-transmitting system; $\beta_{\pi\lambda}$ is the total volume scattering coefficient of atmospheric air; and, α_a, α_m, n_{O_3}, and σ_{O_3} are the aerosol and molecular scattering coefficients, the ozone concentration, and the absorption cross section of ozone, respectively. The exponential term characterizes the absorption of UV radiation on the propagation path. From the formula (1) the following relation can be derived, assuming that the sounding is performed at one wavelength, for estimating the ozone concentration n_{O_3} :

$$n_{O_3}(R) = -\frac{d}{dR}\left\{ \ln \frac{N(R) R^2}{W_0 A K \beta_{\pi\lambda_1}(R) T_a^2 T_м^2} \right\} \times \left[2\sigma_{O_3}(\lambda_1;\ T) \right]^{-1}, \quad (2)$$

where T is the temperature; dR is the altitude interval; $\sigma_{O_3}(T(R); \lambda_1]$ is the absorption cross section of the ozone molecule; $N(R)$ is the total signal at the wavelength $\lambda_1 = 308$ nm; and, T_m^2 and T_a^2 are the transmission functions of the molecular and aerosol components.

The relation (2) was used to calculate the altitude profile of the ozone concentration from the measurements.

The lidar method is the most efficient method for measuring the altitude behavior of the ozone concentration, since it makes it possible to obtain an altitude resolution of up to 0.1 km and to follow the change in the layer as a function of time. As one can see from the layout of the lidar employed (Fig. 1), the transmitted pulse from the excimer XeCl laser 1 is emitted with the help of a rotating mirror 12 vertically upwards. Investigations of the divergence of the laser radiation showed that 80% of the laser energy is concentrated in an angle of approximately 4 mrad. The scattered signal enters a zenith receiving telescope 13 with a mirror diameter of 0.7 m (assembled according to the Newton scheme), is separated from the background with an interference filter F having a bandwidth of 10 nm, and enters a photodetector 4 of the type FÉU-136. A mechanical obturator 8 was used to reduce the backscattering noise. The photomultiplier signal, which has the form of a sequence of pulses of separate photoelectrons and is preamplified in a preamplifier 5, is fed into a multichannel recording system 10 with a minimum altitude interval of $\Delta R = 0.5$ km.[4] Synchronized pulses from a quartz oscillator, which is included in the block 9, and signals from the photodiodes PD1 and PD2 are employed to form the signals that trigger the XeCl laser and the recorder. The display and documentation devices (11) consist of a graphical display (for monitoring the measurement process as well as for photographing the altitude profiles of the signal) and a digital cassette tape recorder. The UV radiation was produced by an electric discharge XeCl laser with a pulse energy of 0.1 J, pulsewidth of 30 ns, and pulse repetition frequency of 0.5 Hz.

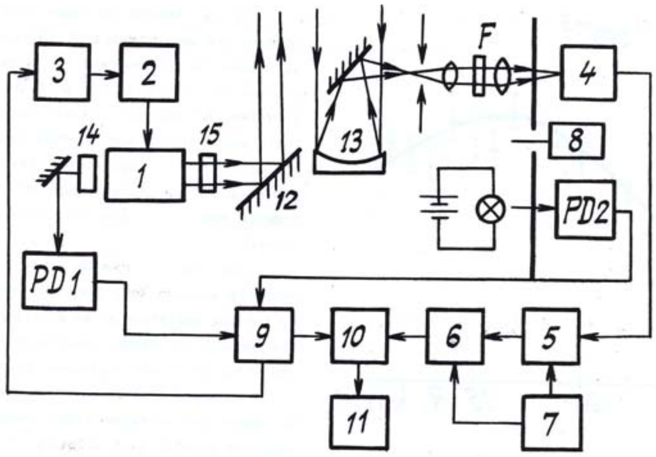

FIG. 1. Diagram of the lidar: 1) excimer XeCl laser; 2) power supply system; 3) control and triggering system.; 4) photomultiplier; 5) preamplifier; 6) circuit forming the altitude intervals; 7) power supply; 8) obturator motor; 9) strobe pulse unit; 10) multichannel recorder; 11) display and recording apparatus; 12) rotating mirror; 13) zenith receiving telescope; 14, 15) mirrors of XeCl laser; F is an interference filter; PD1 and PD2 are photodiodes.

Since the effective cross section for molecular and aerosol absorption at the wavelength 308 nm, equal to $5.8 \cdot 10^{-26}$ cm^{-2}, is significantly smaller than the absorption cross section of ozone $1.3 \cdot 10^{-19}$ cm^{-2}, the error in the altitude interval 15–20 km owing to aerosol and molecular absorption will not exceed several percent. This result was also obtained based on simultaneous sounding at $\lambda_2 = 589$ nm.

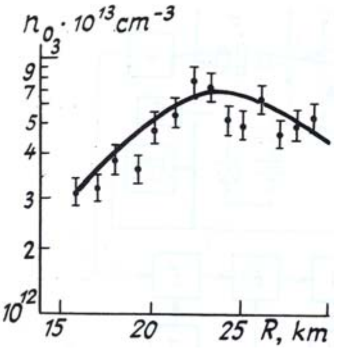

FIG. 2. Altitude distribution of ozone.

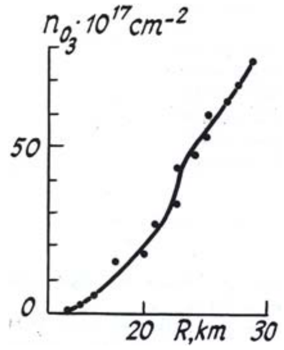

FIG. 3. Ozone concentration in a column of the atmosphere.

Ozone profiles up to an altitude of 30 km were obtained based on the standard atmosphere model and molecular scattering data at wavelengths of 308 and 589 nm. The investigations were performed in the Laboratory of Laser Sounding of the Atmosphere at the Khar'kov Institute of Radioelectronics in 1986 (at Tuapse). The preliminary measurements are presented in the form of plots (Figs. 2 and 3). The maximum ozone concentration, equal to $6.5 \cdot 10^{12}$ cm^{-3} was obtained at altitudes of 22–24 km. At an altitude of 30 km the ozone concentration was 1.5–2 times lower than the maximum concentration. Measurements are being performed at Tomsk using a similar method.[5,6]

In conclusion we note that in order to improve the measurements of ADO the lidar systems will have to be improved by using highly stable sources of UV radiation with a long operating lifetime (10^8 pulses). Lasers based on halides of inert gases with a high average power (1–40 W) are such sources. Significant progress has been achieved in the development of flashlamp-pumped tunable dye lasers that can compete with excimer lasers.

The main drawback of single-frequency sounding with an XeCl laser is usually eliminated by forming radiation at an auxiliary wavelength by the method of Raman conversion of the excimer radiation in a cell (hydrogen or ammonium).

It would also be useful to develop a tunable UV laser for an ozone lidar based on a titanium sapphire crystal with tripling of the wavelength. Such UV lasers are useful for airborne lidars for obtaining the spatial characteristics of ADO because they have better mass-to-size ratio and energy and technological characteristics than excimer lasers.[7] This should be taken into account when implementing ecological programs that can be solved with the help of lidars.

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