LIDAR INVESTIGATIONS OF M-ZONE

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The creation of pulse dye lasers tuned to resonant line of meteor-produced admixtures of atmospheric constituents has made it possible to begin lidar investigations of the vertical distribution of mesopheric sodium concentration and its dynamics in the upper atmosphere. The Kharkov Institute of Radioelectronics began this method in 1973 by developing the resonance lidars which were subsequently used to measure sodium in the atmosphere over the Kharkov region. The initial experiments, the first of their kind in the world, were carried out in the Antartic, in the region of energetic particle downpour above the Molodezhnaya (LAGUTIN et al., 1983) and Mirny (LAGUTIN et al., 1981) stations. In cooperation with the Tajik Physical Technology Institute, observations were started in the Ashkhabad region to study the altitude-longitudinal characteristics of the sodium layer (LAGUTIN et al., 1981). The seasonal and latitudinal winter anomaly of sodium was investigated taking into account both the photochemistry and the meteor source (LAGUTIN et al., 1983). The altitude distribution in the layer was analyzed. Using the photochemical balance equations for turbulent diffusion conditions, altitudinal variations of sodium atom formation from all ablating meteor sources (LAGUTIN et al., 1976) and acoustical/gravity wave parameters were estimated.

The observed morning increase of sodium concentration in the vertical column is probably caused by diurnal variations of sporadic meteors. To obtain a satisfactory agreement with experimental observations of the uppermost layer of sodium, the meteor source must either act in a narrow height interval (about 2 km for the height of 95 km) or turbulent diffusion and the sink for meteor matter in the mesosphere must be extremely high. The sink channel of mesosphere sodium is supposed to be transport by alkaline $NaOH$, NaO_2 and the water cluster aerosol down to the stratosphere.

The altitude stratification of the sodium layer of meteor origin must be closely connected with electrodynamic agents affecting sodium/water cluster ions which recharge very quickly through recombination with the basic ionospheric components of the D, E_s, and E layers.

The study of the dynamics of the sodium column concentration in the period of meteor streams activity confirms the suggestion of cosmic origin of these atoms. The short-lived increase of sodium concentration brought about by a meteor stream, however, exceeds by one order the level of the sporadic background. This contradicts the common estimate of meteor matter flux due to streams (LAGUTIN, 1977). These and other problems may be investigated by means of simultaneous probing of neutral and ionized components of the resonantly scattering admixtures of meteor origin. In this respect admixtures of mesopheric sodium, calcium, lithium and potassium are the only ones that can be investigated as far as ground-based laser probes are concerned. The lidar methods of distant resonance spectroscopy of basic atoms and ions of a meteor matter stream (such as Fe, Mg, Si, etc.) can be successfully realized only by satellite-based observations.

The monostatic lidar, used by the authors for studying mesopheric sodium, is equipped with a transceiver mounted at one point. The signal $S(z)$ returned from a height z of such a lidar is estimated from the following equation:

$$S(z) = \sigma_e(z) \; n(z) \; A\Delta z \; N_e T^2 \eta / z^2 \qquad (1)$$

where $S(z)$ is the signal received from the height interval of $z - \Delta z/2$ to $z + \Delta z/2$. $\sigma_e(z)$ is the value of a resonance backscatter coefficient for the range Δz, $n(z)$ is the density value at a distance z, A is the surface area of the receiving telescope, Ne is the pulse energy, η is the overall efficiency of the receiver and, T is the loss of energy in the atmosphere.

In the case of a resonant scatter, the signals dispersed by alkaline metals of the mesophere are so weak that a photon counting technique is needed to measure it.

The effective backscatter coefficient $\sigma_e(\lambda)$ depends on the laser emission spectrum:

$$\sigma_e(\lambda) = \int_0^\infty N_e(\lambda)\sigma(\lambda)d\lambda \; / \int_0^\infty N_e(\lambda)d\lambda \qquad (2)$$

where both $N_e(\lambda)$ the laser energy, and $\sigma(\lambda)$ the alkaline atom backscatter coefficient, are functions of the wavelength λ.

The greatest difficulties in lidar upper atmosphere studies arise when the accuracy of concentration measurements require achieving a certain signal level.

On the assumption of the Poisson distribution of photons, the measurement precision will be $1/\sqrt{S}$ where S is the total number of photons detected from a given height interval Δz.

As measurements data is accumulated gradually after each probe, N_e represents a total number of photons transmitted for the period t. Thus, the mean power of a laser N_e/t constitutes an important parameter. On the other hand, N_e should be sufficient to meet the condition $S \gg N_n$, where N_n is the number of noise photons.

Fig. 1 presents a block-diagram of the lidar system functioning in Ashkhabad. The transmitter uses a flashlamp pump dye laser with the output energy of about 1 j and pulse duration of 4µs. Two Fabry-Perot etalons are used to filter it to 589 0 nm and maintain the 0.01 nm bandwidth.

As is seen from Fig. 1, the laser output beam is collimated by M_1 and M_2 to produce a final angular beamwidth of about 2 mR. A small fraction of the laser output is sampled by a partially reflecting mirror M_3 and is focused through a sodium vapour cell (3) maintained at 120°C. The light scattered by the sodium vapour (21) and measured by a photomultiplier (21) provides a means of keeping the laser energy within the D_2 line width. Changes in the laser output spectrum during observations occur due to changes in the quality of the dye, flashlamps, pumping, etc.
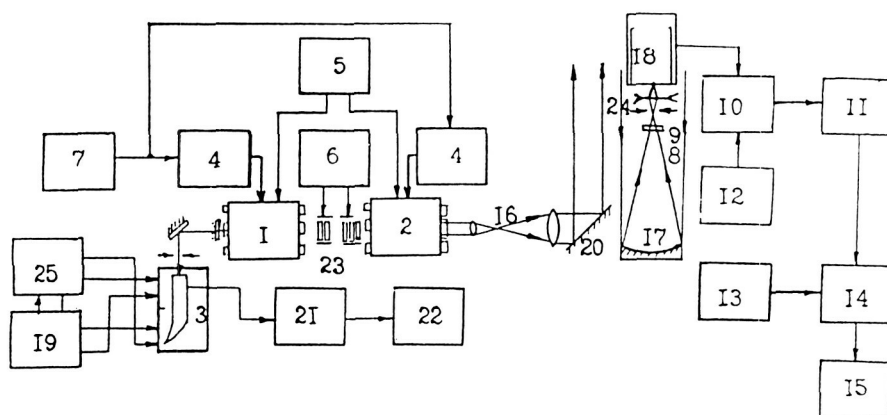
Fig. 1. Block-diagram lidar: 1-laser generator; 2-laser amplifier; 3-system wavelength control; 4-energy system (supply); 5-system pumping dye; 6-system F.P. thermostability resonators (23); 7-modulator and system trigger; 8-interference filter; 9-diaphragm; 10-preamplifier of PM I photoreceiver; 11-signal shaping circuitry; 12-V.H. supply PM I; 13-strobimpulse block; 14-multichannel recorder; 15-the monitoring documentation block; 16-collimator telescope; 17-zenith receiver telescope; 18-PM I; 19-the thermochamber resonance camera; 20-rotating mirror; 21-PM I of probing wave system; 22-probing wave indicator and output energy; 23-multiplex tuning Fabry-Perot (F.P.) interferometer; 24-focusing lens before PM I; 25-thermochamber resonance camera.

The receiver has a spherical mirror M_4 47 cm in diameter and 2,65 m focal length.

After passing through an adjustable diaphragm which determines the receiver angular beamwidth, the signals pass through a 2 nm bandwidth interference filter before being focused by (25) onto the PM-I photocathode (18).

The photon counts, usually accumulated for 200 laser shots, are transferred to a micro-computer which carries out its partial analysis and, in turn, transfers it to a display to be observed and recorded (Fig. 2). The data are also recorded on digital data cassettes and processed on an ES-computer.

References

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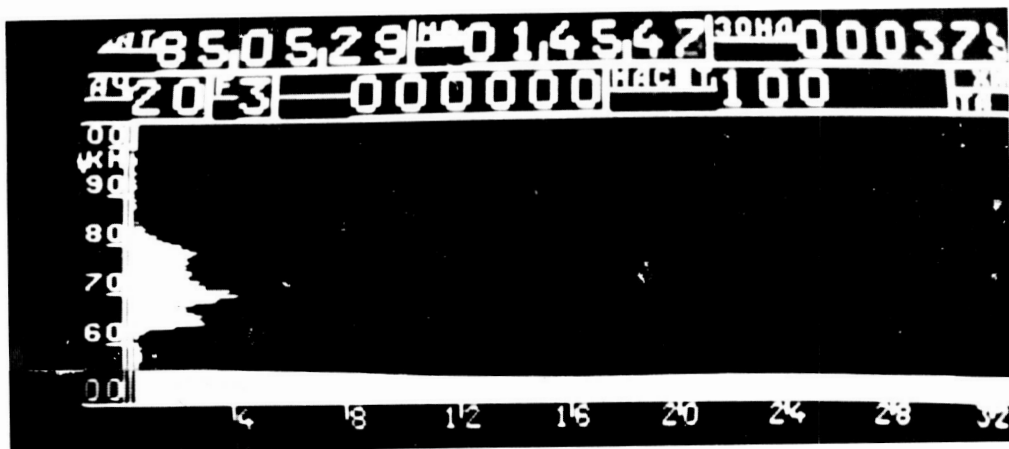8. Lagutin, M.F., 1977 (abstr.), 8th International Laser Radar Conference, Philadelphia, p. 59.

Fig. 2.   A photograph from monitoring system TV.