RESULTS OF EXPERIMENTAL STUDIES OF THE DYNAMICS OF SODIUM LAYER PARAMETERS

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Regular sodium layer observations in Tuapse were performed to investigate the layer parameter dynamics. A transmitting system of a resonance lidar included a tunable lamp–pumped laser (589 nm, 8 pm, *and* 0.5 J). *The spatial resolution of the system was* 1 km.

There were 32 nights of measurements during a year and about 5–6 measurement sessions (30–50 min) *at each night. The average layer altitude was* 94 km *and its rms thickness was* 3.7–6.0 km.

Significant increase of sodium concentration was observed in August and was explained by the influx of particulate matter from meteor shower.

The study of layers of trace mesospheric impurities (sodium, lithium, potassium, calcium, and ferrum) by the lidar methods[1] is necessary for the construction of a dynamic model of natural background against which anomalies in the behavior of different anthropogenic pollutants are manifested.

It is impossible to explain the layer morphology based on a meteor shower alone without considering thermodynamics and photochemistry of sodium sink. Only season–latitude variations of sodium concentration in a vertical air column and the average altitude of the layer maximum correlated satisfactorily with the average altitude of ablation of meteors of mass 10^{-5}–10^{-7} g responsible for the main influx of particulate matter of cosmic origin.[2] The anomalies of impurity influx during large volcano eruptions as well as narrow layers 0.5–1 km thick which are occasionally observed in polar regions do not determine global behavior of the layer parameters.

The theoretical assumptions were repeatedly checked during long–standing observations of the sodium layer at the stations located near the oceans in England,[3] France,[4] Japan,[5] Brazil,[6] and the USA.[7] The studies of sodium in the Arctic regions[8] and Antarctica[9,10] indicated the peculiarities of its behavior caused by anomalies of aurora zones.

To regularly study the dynamics of the sodium layer above the continent, the Khar'kov Institute of Radioelectronics developed a network of lidar stations located in the Eurasian region in Ashkhabad, Tuapse, and Khar'kov.[11–13] Described in this paper are the instrument and the result of regular observations in Tuapse (44°N, 39°E).

The Tuapse station of resonance sounding of mesospheric impurities was equipped with a tunable organic–dye (Rhodamine–6G) lamp–pumped laser intended for sounding at resonance wavelength of sodium (the basic parameters of the instrument are given below).

Tuning of the lasing wavelength and narrowing of the radiation bandwidth were accomplished using two intracavity etalons. A rough tuning to a resonance line was accomplished using a spectroscope based on a diffraction grating, and a fine tuning relied on the current pulse amplitude of the lamp with a hollow cathode. Such a metrological support made it possible to estimate a resonance scattering cross section of sodium atoms with 10% error.[12]

TABLE I.

Transmitter	
Wavelength, nm	589
Divergence, mrad	0.6
Line width, pm	8
Pulse energy, J	0.5
Pulse duration, μs	8
Pulse repetition frequency, Hz	0.2
Efficiency of the optical train	0.6
Receiver	
Aperture area, m^2	0.4
Viewing angle, mrad	1.5
Bandwidth, nm	2
Number of channels	100
Channel duration, μs	6.7
Quantum efficiency, %	3.5
Efficiency of the optical train	0.3

The tuning to a resonance wavelength was controlled during the entire session of measurements. Passive stabilization of the laser–transmitter parameters was provided by thermostabilization of interferometers with an error of 0.2°C and of dye solution with an error of 1°C. In this case the tuning was kept for a long time without intervention of an operator.

A receiving telescope was assembled as Newtonian telescope based on a spherical mirror 0.7 m in diameter. A 1.5–mrad viewing angle was formed by a diaphragm placed in the focal plane of the mirror. The axes of the receiving and transmitting telescopes were aligned with an error of 0.5 mrad using a prismatic carriage with two perpendicular levels moved from the optical axis of the lidar transmitting telescope to that of the receiving telescope. The focused radiation from the receiving telescope was incident on a photocathode of a low–noise PMT FÉU–136.

During laser sounding of the upper atmosphere the scattered radiation intensity had a wide dynamic range. To reduce the level of afterpulsing noise of the PMT, a mechanical shutter of the objective (an obturator) was used which provided opening of the receiving telescope starting from 20–25 km for 50 μs that corresponded to an

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altitude range of 7.5 km. Thus complete opening of the objective occurred in the 28–33 km altitude range depending on the choice of its initial delay.

The scattered light radiation was recorded by the method of photon counting with amplitude discrimination. To this end, the signals from the PMT output were fed to an amplifier–shaper operating at the plateau of the photon–counting characteristic of the PMT (for maximum suppression of dynode noise). The pulses from the amplifier–shaper output were fed to the inputs of two fast gated counters which were alternately switched on for 6.67 μs for successive signal integration over one–kilometer intervals.

The lidar receiver allowed one to record a signal in 100 altitude intervals with discrete switching of the delay of record starting with respect to the instant of the sounding pulse transmission (0, 10, 20, ..., 70 km). To take into account the background level of the night sky and the level of the intrinsic noise of the PMT, the receiver recorded five additional 66.7 μs channels (10 km in altitude) following immediately after 100 km intervals.

The resonance scattering cross section of sodium atoms (with a spectral linewidth of 8 pm) is $8\cdot10^{15}$ m^2 which is approximately 12 times lower than its maximum value. With atmospheric transmittance being equal to 0.5 for a single passage of the sensing beam and atomic concentration of $5\cdot10^9$ m^{-3} in the layer maximum, the instrument enabled one to record about 3.5 photoelectrons in a 1–km interval of altitude averaging. In this case during a 10–min session of measurements about $4\cdot10^3$ photoelectrons were integrated from the entire layer.

When the transmittance of the atmosphere varies within wide limits, which is characteristic of the coastal region of the Black Sea with large variations of sodium concentration, the mean value of a really recorded signal varied between 1 and 8–10 photoelectrons in the layer maximum which corresponded to 10^3–10^4 photocounts from the layer integrated over a 10–min session.

Measurements of resonance scattering of atmospheric sodium are regularly carried out in Tuapse in order to study the dynamics of the layer and wave perturbations of the atmosphere in the 80–100 km altitude range.[13] The results given in this paper cover the period from April, 1989 to March, 1990 and include 32 nightime measurements with 5–6 measurement sessions for 30–50 min.

The analysis revealed frequent wavy perturbations of concentration profiles associated with propagation of internal gravitational waves through the mesosphere. In this case the shape of profiles was distorted and had sometimes 2–3 maxima. Comparatively rare the profiles had a smooth almost regular shape which resembled a Gaussian distribution. The increased disturbance of the layer was observed in the morning (before the dawn) and the maximum one – in the evening (after sunset).

Near $(1–3)\cdot10^4$ photoelectrons were integrated from the layer during a session depending on the transmittance of the atmosphere and total sodium content in the vertical air column. The level of the night–sky background and intrinsic noise of the PMT were measured between sensing steps and were subtracted before signal processing. The ratio of the valid signal to the background level and intrinsic noise of the PMT varied usually from 100 to 200 in the maximum of the sodium layer.

The parameters of the sodium layer which quantitatively characterized its properties were determined through spatial moments M_i of the concentration profile

$$M_i = \int_{z_l}^{z_u} z^i c_0(z)\, dz , \tag{1}$$

where $c_0(z)$ is the vertical profile of the sodium concentration in the layer and z_l and z_u are the altitudes of lower and upper boundaries of the sodium layer.

The impurity concentration in the vertical air column coincides with the zeroth spatial moment of the profile $c_s = M_0$, and the altitude and the rms thickness of the layer are equal to

$$z_s = \frac{M_1}{M_0} , \tag{2}$$

$$\sigma_s = \frac{M_2}{M_0} - \left[\frac{M_1}{M_0}\right]^2 , \tag{3}$$

respectively.

The sodium concentration measurement error in the vertical air column caused by stochastic nature of lidar returns did not exceed 1%. However, calibration of the absolute values of concentration against the signals of molecular scattering recorded between 36 and 40 km introduced an additional error. Therefore, the real error in the measurements of the absolute concentration was 15–20% due to variations in the model values of particle concentration in air and instability of the radiation bandwidth. The rms errors of estimating the altitude and thickness of the layer did not exceed 0.2 km.

Figure 1 depicts a seasonal profile of sodium concentration in the vertical air column near Tuapse. The dots stand for the night–averaged concentrations. The vertical lines in the plot show a range of concentration variation during the night.

The minimum midnight sodium concentration in the air column was observed on July 2–3, 1989 and was $1.2\cdot10^9$ cm^{-2}, while its maximum value – on December 27–28 ($1.1\cdot10^{10}$ cm^{-2}). As a whole, the character of seasonal dependence of sodium concentration in the air column was no different from that observed over Urbana[7] (USA, Illinois) in 1984–1986, though the absolute values of concentration in Tuapse were somewhat lower. The pronounced increase in the total sodium concentration on August 13–14 and 15–16, 1989 in Tuapse could be associated with the variation of matter influx from large particles of meteor showers of the Perseid epoch which were visually observed for bright meteors.

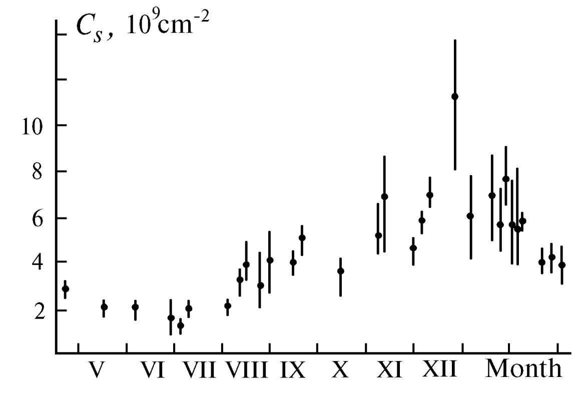
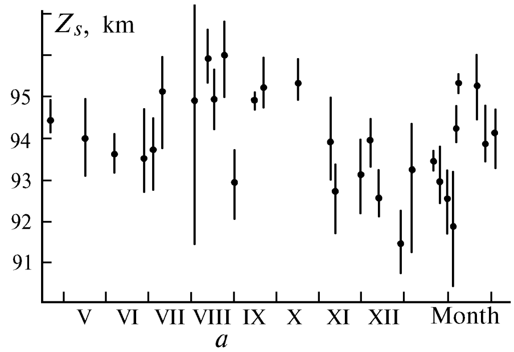


FIG. 1. Seasonal behavior of sodium concentration in the vertical air column.

Seasonal distributions of altitude and rms thickness of the sodium layer are shown in Figs. 2*a* and *b*. The vertical lines in the plots limit the ranges of nighttime variations of these parameters.



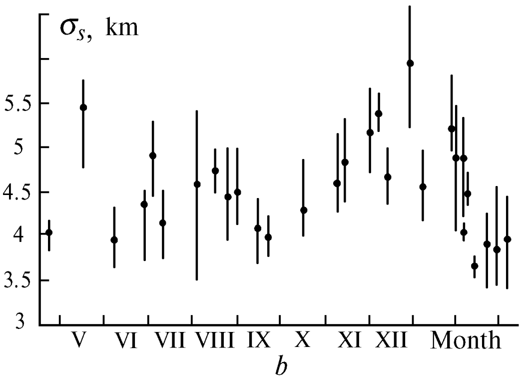


FIG. 2. Seasonal behavior of the altitude (a) and rms thickness (b) of the sodium layer.

The layer altitude averaged over the entire period of observations was equal to 94 km and varied from 91.4 to 96.0 km. The maximum altitude deviations during a night were usually ±(0.5–1.5) km. The rms thickness of the sodium layer in Tuapse varied between 3.7 and 6.0 km, and the nighttime variations of its thickness did not exceed, as a rule, ±(0.5–0.7) km.

A substantial increase of the sodium layer altitude to 95–96 km was observed in July–October, 1989. The layer thickness at that time was 4.0–4.7 km. The decrease of the layer altitude down to 92–93 km in midwinter was accompanied by the increase of its thickness up to 5.0–5.5 km and approximately coincided with seasonal enhancement of sodium concentration in the vertical air column which was observed at the coastal stations.

Relative changes in sodium concentration in the air column during three nights in August, 1989 shown as an example in Fig. 3 attained ±(25–35)%. This was caused by tidal effects and variations in the particle influx.

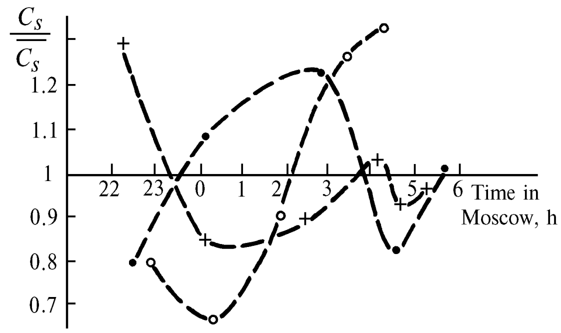


FIG. 3. Variations of sodium concentration in the air column.

CONCLUSIONS

1. Monitoring of the sodium layer for continental mesosphere has been pioneered.
2. The seasonal trends of concentration in the air column observed in autumn depend primarily on broadening of the lower part of the sodium layer and are explained by variation of photochemistry of sodium reduction as the mesosphere temperature rises at the beginning of winter. Similar results were observed at the stations located near the ocean.
3. The detected anomaly of sodium concentration in the air column in August caused by the influx of large particles of the Perseid shower was to a substantial extent masked by diurnal tidal variations in the atmospheric density.

REFERENCES

1. M.F. Lagutin, Astron. Vestnik **8**, No. 3, 145 (1974).
2. M.F. Lagutin, O.I. Andryushchenko, and O.A. Babenko, Izv. Akad. Nauk TSSR, No. 6, 61 (1976).
3. A.J. Gibson and M.C.W. Sanford, J. Atmosph. Terr. Phys. **33**, 1675 (1971).
4. G. Megie and J.E. Blamont, Planet Space Sci. **25**, 1093 (1977).
5. H. Kamijama and T. Fumihiko, Handbook for MAP **18**, 253 (1985).
6. V.M.J.H. Kirchoff and B.R. Clemesha, J. Atmosph. Terr. Phys. **35**, 1493 (1973).
7. C.S. Gardner, D.G. Voelz, C.F. Sechrist, et al., J. Geophys. Res. A **91**, No. A12 (1986).
8. G.F. Tulinov, Yu.P. Dudoladov, M.L. Shanen, et al., Ionosf. Issled., No. 32, 104 (1982).
9. M.F. Lagutin, Yu.E. Megel', A.A. Zarudnyi, et al., Dokl. Akad. Nauk SSSR **258**, No. 2, 334 (1981).
10. A. Nomura, et al., Geophys. Res. Lett. **14**, 700 (1978).
11. O. Ovezgeldyev, M.F. Lagutin, et al., Handbook for MAP **25**, 405 (1987).