# DEVELOPMENT OF INVESTIGATIONS ON ATMOSPHERIC ACOUSTICS AT THE IAO SB RAS

**N.P. Krasnenko**

*Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk*
*Received January 21, 1997*

*The history of the atmospheric acoustic investigations at the Institute of Atmospheric Optics of the SB RAS is traced and main results of investigations in problems of acoustic sounding of the atmosphere, development of ultrasonic meteorological systems, propagation of acoustic waves in the atmosphere, and acoustic diagnostics of the parameters of propagation of high-power laser radiation are considered.*

## 1. INTRODUCTION

Atmospheric acoustics as a whole has a rather long history because sound (speach) and the atmosphere surround a human being from birth. Class of problems solved in atmospheric acoustics is rather wide and versatile.

This scientific direction was initiated at the Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences of the USSR, engaged in atmospheric-optical investigations, by the permanent Director of the Institute, Academician V.E. Zuev, Doctor of Physical and Mathematical Sciences at that time, in 1974. After his visit to Australia, where the first meteorological sodar was demonstrated to him, V.E. Zuev started analogous investigations at our Institute. The subject of these investigations, seemingly foreign for the Institute, was in fact associated and complementary in the context of an integrated approach to a solution of problems of remote optical sensing of the atmosphere and propagation of optical waves in the atmosphere as a random inhomogeneous medium.

The experimental scientific group, headed by V.Ya. S'edin, Candidate of Physical-Mathematical Sciences, was organized in the Laboratory of Optical Sensing of the Atmosphere and the theoretical group, headed by me, was organized in the Laboratory of Theory of Remote Sensing of the Atmosphere. These two groups joined in February 1977 and formed the group (having the rights of laboratory) of the acoustic sounding of the atmosphere headed by V.Ya. S'edin.

In May 1986, this group was reorganized into the Laboratory of Atmospheric Acoustics. Since July 1979, I have been a Head of this Laboratory.

The main directions of the Laboratory are shown in Fig. 1.

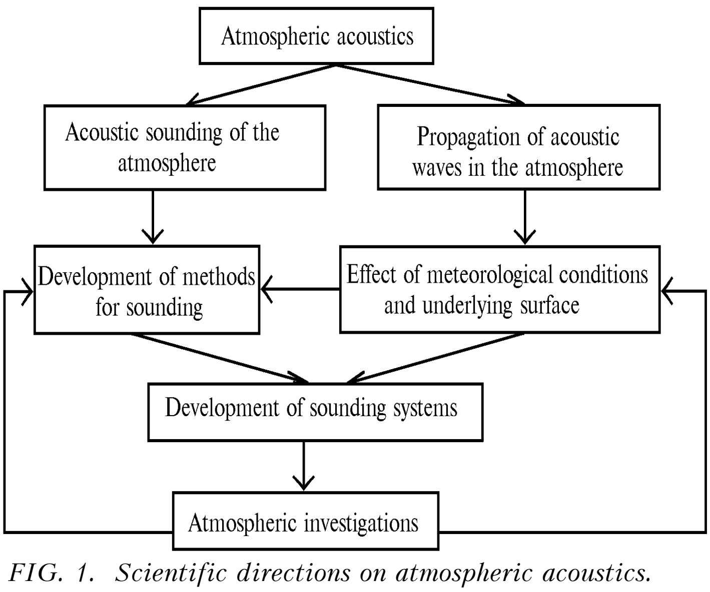


*FIG. 1. Scientific directions on atmospheric acoustics.*

0235-6880/97/04–05 337-06 $02.00 

## 2. ACOUSTIC SOUNDING OF THE ATMOSPHERE

The essence of the method for acoustic sounding is as follows. An acoustic signal is transmitted into the atmosphere in a given direction. During its propagation through the atmosphere, the signal interacts with the atmosphere. The radiation scattered by atmospheric inhomogeneities or the directly transmitted radiation is received by a receiving antenna. The atmospheric parameters are determined from the parameters of received acoustic signal. The problem itself and the main results of its solution obtained up to 1986 are described in my monograph.[1]

Investigations started at the IAO SB AS USSR in 1974 on the problem of acoustic sounding of the atmosphere brought a monostatic (one-channel) acoustic sounder with facsimile recording of signals into being in 1977. Its further modernization brought a sodar for measuring the profile of the radial wind velocity component, built around the M - 6000 minicomputer, into being in 1978. New sodar modification, controlled by the 15 VSM-5 computer, was developed in 1979. The MAL-1 sodar controlled by the Elektronika-60 computer was developed in 1980. The MAL-2 three-channel meteorological sodar (Doppler) for measuring the temperature stratification and vertical profile of the wind velocity vector in the lower 1-km layer of the atmosphere was developed in 1982. Group of designers headed by me including V.I. Galkin, B.N. Molchanov, V.A. Fedorov, and M.G. Fursov won encouraging prize in competition of applied researches of the Siberian Branch of the Academy of Sciences of the USSR in 1985.

The above-indicated meteorological sodars were used to investigate atmospheric processes only by their designers. Practical application of sodars in the meteorological network of our country was impeded by many reasons, among them by the fact that the use of sodar data called for certain experience, whereas accumulation of this experience by practical meteorologists was difficult not only due to the lack of sufficient number of sodars and also due to the complexity and unreliability of existing sodar units unacceptable for their practical application.

Based on our experience accumulated in the process of operation of the first sodars, in 1989 we developed a new concept of designing commercial sodar of a new generation.[2] By that time, IBM PC became available which essentially helped to solve the above-formulated problem due to their high performance characteristics. They could be used as control and processing (service) computers. It should be noted that in our society an urgent demand arose for monitoring of the quality of life including the quality of the atmospheric air, by virtue of its industrial development. Even when industrial enterprises meet standards on maximum permissible amounts of pollutants emitted into the atmosphere, enhanced concentration of pollutants in the lower atmospheric layers may be observed under unfavorable meteorological conditions without significant vertical air flows and air mixing. Therefore, to estimate the atmospheric stability, that is, the ability of the atmosphere to disperse pollutants, the real-time information on the vertical temperature and wind stratification of the atmosphere must be obtained. This information can be obtained using sodars.

The Zvuk-1 sodar developed in 1990 is intended to monitor the temperature stratification of the atmospheric boundary layer. It determines the type of stratification (class of the atmospheric stability), mixing layer height, thickness of temperature inversion layers, and structure characteristic of the temperature field.

The sodar is compact and highly automated; it can operate without operator. High degree of noise protection allows the sodar to operate under conditions of noisy environment. Its antenna is automatically heated in winter and so can operate without servicing. Echo - signal recording, data processing, and control of the sodar operation are performed by a personal computer.

The sodar can be used in routine regime of operation by meteorologists, weather forecasters, and specialists in ecology and atmospheric optics without any special qualification in hydrometeorological service, departments of monitoring of air basin, etc. One sodar unite was delivered to the Kemerovo Regional Center on Hydrometeorology in 1990 to monitor the atmospheric state and one more sodar unit was delivered to the Russian Federative Nuclear Center (Snezhinsk of the Chelyabinsk Region) to solve analogous problems.

Based on the Zvuk-1 sodar, the Zvuk-2 three-channel meteorological Doppler sodar[3] was developed in 1996 for measuring the temperature stratification, the vertical profile of the wind velocity vector, and the structure constant of the temperature fluctuations.

This sodar, as compared with previous units, has minimum analogous devices for transmission, reception, and preliminary filtration of acoustic signals. It is controlled by a PC/AT 486 DX4, including generation of transmitted acoustic pulses. Its second peculiarity is the low-frequency complex representation of a received high-frequency signal. Then the signal-to-noise ratio is determined for each strobe pulse, and the instantaneous radial wind velocity is calculated for this strobe if the signal-to-noise ratio exceeds a preset threshold. After completion of a measurement cycle, the obtained array of wind velocities is statistically processed to obtain a stable average profile of the wind velocity. The algorithms employed allow the vertical profiles of the wind velocity and echo-signal amplitudes to be measured in real time without application of any additional special - purpose computing devices. In 1996, we carried out continuous seasonal cycle of atmospheric sensing using the Zvuk-2 sodar as part of the ARM (Atmospheric Radiative Measurements) program and conducted comparative tests with a wind lidar.

The development of sounding systems calls for the theoretical study of sounding problems including patterns of interaction of the acoustic radiation with the atmosphere, theoretical calculations of the parameters of sounding systems, optimization of these parameters, estimation of the accuracy characteristics, and development of new methods for sounding. These results are partially considered in Ref. 1.

In 1984, S.L. Odintsov, V.A. Fedorov, and M.G. Fursov from our Laboratory were rewarded with encouraging diploma in competition of young scientists of the SB AS USSR for their work entitled "Development of Methods and Means for Remote Sounding of the Atmosphere." In 1987, S.L. Odintsov defended his Candidate Dissertation based on the results of theoretical studies.

In resent years, the primary emphasis of our theoretical studies[4-8] was on the investigation of the effect of refraction on sodar operation and the search for new informational capabilities of acoustic sounding by recording in addition to the conventional parameters of echo signals – amplitudes and Doppler frequencies – the time and the angle of arrival of acoustic signals. We usually considered this problem in the linear approximation of geometric acoustics of inhomogeneous moving media. The effect of wind stratification on the accuracy of wind velocity measurements by the Doppler sodar was analyzed in Ref. 4. A system of equations was derived and analytical solutions were obtained that can be used to analyze and to evaluate numerically the effect of refraction on the geometry of acoustic sensing of the atmosphere.[7]

In addition, systems with scanning antenna directivity patterns were investigated.[8] It was demonstrated that fast scanning in bistatic sensing in case of signal transmission or reception causes noticeable changes of the waveform and peak power of pulsed scattered signals, which can be used to control the duration and the amplitude of scattered signal when the parameters of the transmitted signal remain unchanged.

Results of experimental investigations performed with sodars in recent years were given in Refs. 9-18.

In 1987, in collaboration with the Kazakh Republican Administration on Hydrometeorology and Environmental Monitoring and the Kazakh Scientific-Research Institute of the State Committee on Hydrometeorology, we tested the MAL–2 sodar in the Alma-Ata airport as part of the program of the State Committee on Hydrometeorology of the USSR on the development of a wind shift measuring device for airports.

Our test showed that the MAL–2 sodar can operate reliably in monostatic regime near a runway in the intervals between takeoff and landing events of aircrafts in such a categorized airport as Alma-Ata.

In connection with a serious problem of air pollution in industrial centers, sodars may be used as part of systems for monitoring of the air basin, providing information on meteorological state of the atmospheric boundary layer in real time.

Investigations carried out by the researches of the IAO SB RAS in critical (from ecological viewpoint) regions provided some initial material to estimate the ecological situation in the atmosphere of these regions. A number of investigations were carried out with the joint use of the sodar, an aerosol lidar, path and local gas analyzers, and ground – based meteorological stations.

To determine the typical altitudes of temperature inversions used to estimate climatic premises for atmospheric pollution, results of acoustic sounding were statistically processed for some regions of the former USSR where we took part in scientific missions. Among these regions are Tomsk, Kemerovo, Alma-Ata, Leningrad, Semipalatinsk, and Nizhnii Novgorod.

The statistics of temperature stratification differed in different regions and was a function of local orography,[12] which created different conditions for accumulation of pollutants.

In particular, general analysis of classes of the stability of the atmosphere allows a conclusion about his percentage of temperature inversion to be drawn as well as about low altitudes of inversions and their relatively stable location. All this together with low heights of stacks (50-120 m) mostly explains unfavorable ecological situation in the industrial regions of the town, when smoke plumes are blocked by the temperature inversions thereby increasing the concentration of pollutants in the surface layer of the atmosphere. This is also confirmed by the results of laser sensing of aerosol fields of industrial origin. The use of laser and acoustic means for remote sensing of the atmosphere is very promising for monitoring of pollution of the urban air basin.

In this case, laser radar is used to monitor the distribution of aerosol pollutants in the atmosphere over large territories and sodar is capable of monitoring the atmospheric stability in real time and determining the altitude of temperature inversions, thereby making easier the forecast of unfavorable meteorological conditions resulting in air pollution. Simultaneous sensing of the atmospheric boundary layer with the MAL-1 and MAL-2 sodars and the LOZA-3 and LOZA-4 aerosol lidars showed that the main barrier to vertical spreading of aerosols in the atmosphere were barrier layers in the form of temperature inversions under which aerosols accumulated. The altitude of the upper boundary of aerosol cloud practically coincides with the altitude of the barrier layer (the coefficient of correlation is 0.9 and higher). Further investigations established a definite correlation between the parameters determining the atmospheric stratification and concentration of some gases, in particular, ozone and carbon dioxide.[15-18]

The ZVUK-1 sodar was also used to investigate the marine atmosphere from aboard of the scientific – research vessel Mstislav Keldysh that sailed the Atlantic (mission No. 35, January – April 1995).

## 3. ULTRASONIC SYSTEMS

The principle of operation of ultrasonic meteorological systems is based on the dependence of the sound speed in air on the absolute air temperature and wind velocity.[1] The speed of sound is determined from the measured propagation time of ultrasonic signal from a transmitter to a receiver spaced at a fixed distance. Performing measurements for corresponding paths and solving the corresponding systems of equations, we obtain the sought – after values of the meteorological parameters (temperature and wind velocity components).

The first acoustic (ultrasonic) meteorological stations were developed at the Institute under the supervision of V.P. Lukin.[20, 21] The acoustic part of the system measured two orthogonal components of the wind velocity (their mean values and variances).

Then these systems were modernized by V.I. Galkin,[22] G.Ya. Patrushev, and A.P. Rostov.[23,24]

The acoustic meteorological station for measuring the meteorological parameters[24] (pressure, humidity, three components of the wind velocity, and temperature) and turbulent characteristics of the atmosphere is the best among the analogous stations. It is capable of measuring the coefficient of friction, the turbulent heat flux, the Monin-Obukhov length, and the structure characteristics of the temperature $C_T^2$ and wind velocity $C_V^2$.

The absence of moving parts, relatively small time constant, selective sensitivity to the wind velocity component to be measured, and capability of measuring of the temperature fluctuations make this system suitable and reliable for investigation of optical and acoustic wave propagation in the atmosphere.

Since 1993, the BMK-1 basic meteorological complex has been developed on the basis of the ultrasonic meteorological station at the Design and Technology Institute "Optika" under my supervision. The BMK-1 complex is capable of measuring the average values of the meteorological parameters (temperature, three components of the wind velocity, pressure, and humidity) with preset time averaging and instantaneous values of the temperature and wind velocity components with subsequent estimation of the parameters of the atmospheric turbulence.

The operating model[25] of the BMK-1 was developed in 1995. It has high performance characteristics. In particular, it can operate at ambient air temperatures in the range from –50 to +50 °C and is capable of measuring the wind velocity as great as 30 m/s. It can operate under conditions of precipitation (rain or snow). The program package "Statistika Meteo" is used to calculate the mean values and the statistical characteristics of the temperature, three components of the wind velocity, and standard parameters of the atmospheric turbulence in the ground layer of the atmosphere (the totality of 67 parameters) and to forecast their values in the context of the Monin – Obukhov theory, as well as to display the profiles of a number of meteorological and turbulent characteristics of the ground layer of the atmosphere.[26]

## 4. PROPAGATION OF SOUND WAVES IN THE ATMOSPHERE

This problem originated at the Institute in 1979 to solve defense research problems. The emphasis was on near-ground propagation[1, 27-48] in contrast with the sound propagation in the free atmosphere. The near-ground propagation of sound waves is affected by the experimental geometry, for example, relative position of a source, a receiver, and underlying surface and their parameters in addition to the meteorological parameters (temperature, pressure, humidity, wind speed and direction, and atmospheric turbulence). Forecast of the parameters of sound propagation is the most important practical problem of near-ground sound propagation.

First of all, this is the prediction of sound attenuation, variance of the sound pressure level, and its correlation functions and fluctuation spectra at the point of reception. Control over the atmospheric noise, development of noise-proof constructions, broadcasting, and active and passive acoustic sounding are among the branches of science and technology where the results of forecasting of sound propagation parameters are used.

Because a unified theory of near-ground sound propagation considering the joint effect of the above-enumerated factors is lacking, the primary attention is given to outdoor experiments under controllable conditions. Based on the results of these investigations, N.N. Bochkarev defended his Candidate Dissertation in 1986. The group of researchers including K.N. Bochkarev, A.G. Root, and M.G. Fursov headed by me was awarded by a second class diploma in the competition of applied researches of the SB RAS USSR in 1989.

The model for atmospheric sound propagation channel and program package "Outdoor Acoustics" intended to calculate in real time the average sound pressure level in audible frequency range at distances up to 10 km with allowance for the parameters of sources of noise, underlying surface, and meteorological conditions are main achievements in this direction.[31,32]

This program package is used in the system of real-time forecasting of sound propagation in the ground atmosphere including an IBM PC and a system for measuring the meteorological parameters as hardware. The flow chart of the algorithm of this complex is shown in Fig. 2. Four groups of meteorological parameters are the input data for solving the forecasting problem. They are: meteorological parameters, parameters of the underlying surface, parameters of the source of noise, and parameters of the propagation path. The complex was tested and approbated under natural conditions. The average error of forecasting was 2–3 dB.

The Doppler effect was considered in the approximation of the acoustics of an inhomogeneous moving medium.[34,35] It was demonstrated that the transverse Doppler effect affects the operation of sodars.[4,6,7] The exact expression was derived for the curvature radius of a sound ray in a 2–D medium.[36,37]

A plasma sound generator[38] and a high-power acoustic antenna array[39,40] were used to investigate the sound propagation on long paths and nonlinear effects.[41,42]

A new method for determining the structure constant of the acoustic refractive index fluctuations $C_n^2$ in the atmospheric boundary layer from the measured sound pressure level in the refractive shadow zone was proposed based on the developed model and program package.[43]

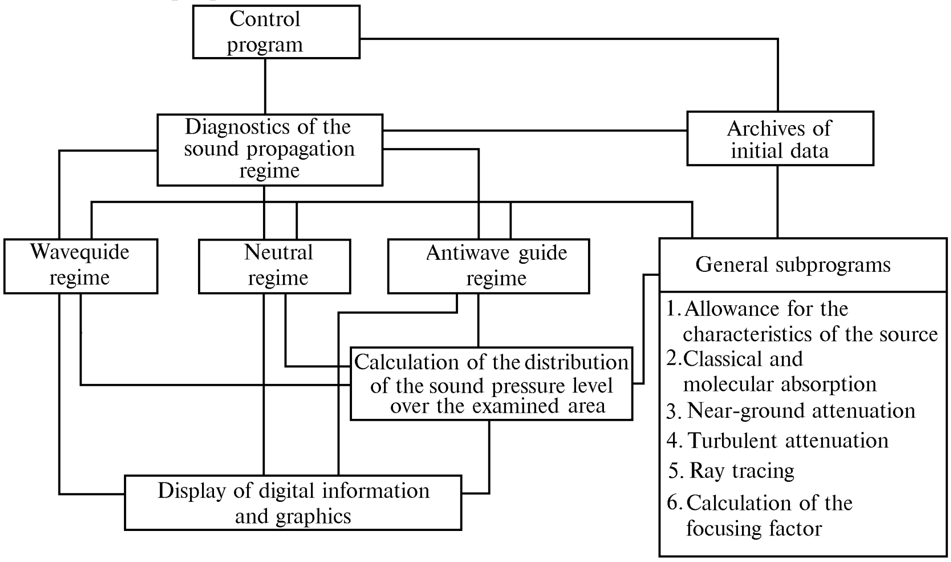


*FIG. 2. Flow chart of the program package "Outdoor Acoustics."*

The further refinement of the model and program package is based on investigations of sound wave fluctuations that were reported in Refs. 44–48.

## 5. ACOUSTIC DIAGNOSTICS OF THE PARAMETERS OF PROPAGATION OF HIGH-POWER LASER RADIATION (HPLR)

Intense study of the problem on transportation of the high-power laser radiation energy at long distances calls for the development of principally new methods for diagnostics (sensing) of the parameters of HPLR in the atmosphere. Conventional methods are unsuitable for long atmospheric paths. The property of the HPLR to generate acoustic signals in the region occupied by the beam was used to develop a method of acoustic diagnostics of the parameters of propagation of the HPLR in the atmosphere. Our investigations[49-52] showed that acoustic waves have sufficiently high amplitudes and can be reliably recorded with acoustic detectors. Based on thorough experimental investigations the methods were developed for acoustic diagnostics of the geometric and energetic parameters of the HPLR, channel of radiation propagation, and atmospheric parameters.[50–54] L.G. Shamanaeva and N.N. Bochkarev made the main Contribution to these investigations that provided the basis for their Candidate Dissertations defended in 1984 and 1986, respectively. The group of researchers including N.N. Bochkarev won the prize of the Leninist Young Communist League of the Soviet Union cycle of investigations in this direction in 1987.

## REFERENCES

1. N.P. Krasnenko, *Acoustic Sounding of the Atmosphere* (Nauka, Novosibirsk, 1986), 167 pp.
2. V.A. Glagkikh, V.I. Karpov, N.P. Krasnenko, et al., Atmos. Oceanic Opt. **5**, No. 7, 473–477 (1992).
3. V.A. Glagkikh, V.I. Karpov, N.P. Krasnenko, and V.A. Fedorov, in: *Abstracts of Reports at the Third Interrepublic Symposium on Optics of the Atmosphere and Ocean*, Tomsk (1996), p. 143.
4. A.Ya. Bogushevich and N.P. Krasnenko, Izv. Akad. Nauk SSSR **23**, No. 7, 716–723 (1987).
5. A.Ya. Bogushevich and N.P. Krasnenko, *Phase methods of acoustic sounding of the atmosphere,* Dep. VINITI, Reg. No. 8546-V88, Moscow, 1988.
6. A.Ya. Bogushevich and N.P. Krasnenko, Atm. Opt. **2**, No. 4, 323–377 (1989).
7. A.Ya. Bogushevich and N.P. Krasnenko, Atmos. Oceanic Opt. **7**, No. 9, 680–689 (1994).
8. A.Ya. Bogushevich and N.P. Krasnenko, Atmos. Oceanic Opt. **6**, No. 1, 53–58 (1993).
9. N.P. Krasnenko and M.G. Fursov, in: *Optical-Meteorological Investigations of the Earth's Atmosphere* (Nauka, Novosibirsk, 1987), pp. 244–252.
10. Yu.F. Arshinov, B.D. Belan, S.M. Bobrovnikov, et al., Atm. Opt. **2**, No. 9, 812–816 (1989).
11. N.P. Krasnenko, I.V. Kuznetsov, I.A. Razenkov, and M.G. Fedorov, in: *Results of Integrated Experiments "Vertical'–86" and "Vertical'–87"* (Tomsk Scientific Center of the Siberian Branch of the Academy of Sciences of the USSR, Tomsk, 1989), pp. 70–76.
12. N.P. Krasnenko and M.G. Fursov, in: *Investigation of the Atmospheric Boundary Layer above Land and Ocean by Acoustic Methods,* Preprint No. 7, Institute of Atmospheric Physics of the Academy of Sciences of the USSR, Moscow (1990), Vol. 1, pp. 30–33.
13. Yu.S. Balin, T.V. Vil'de, V.E. Zuev, et al., Atm. Opt. **3**, No. 7, 669–676 (1990).
14. E.V. Klimova, N.P. Krasnenko, and M.G. Fursov, in: *Investigations of Atmospheric Pollution in Alma-Ata Vol. 1. ANZAG–87 Experiment* (Gylym, Alma-Ata, 1990), pp. 49–57.

15. N.P. Krasnenko and M.G. Fursov, Atmos. Oceanic Opt. **5**, No. 6, 412–414 (1992).
16. V.V. Zuev, N.P. Krasnenko, O.A. Pelymskii, and M.G. Fursov, in*: Abstracts of Reports at the Eleventh International Symposium on Laser and Acoustic Sensing of the Atmosphere*, Tomsk (1993), pp. 43–46.
17. B.D. Belan, V.V. Zuev, V.E. Zuev, and N.P.Krasnenko, EUROTRAC Annual Report 1992, ISS, Garmisch-Partenkirchen (1993), Part 9, pp. 188–195.
18. N.P. Krasnenko and M.G. Fursov, Atmos. Oceanic Opt. **7**, No. 11, 874–875 (1994).
19. N.P. Krasnenko and B.N. Molchanov, in*: Abstracts of Reports at the Third Interrepublic Symposium on Atmospheric and Oceanic Optics*, Tomsk (1996), p. 154.
20. L.V. Antoshkin, O.N. Emaleev, V.P. Lukin, et al., Prib. Tekhn. Eksp., No. 3, 240–241 (1986).
21. L.V. Antoshkin and V.P. Lukin, in: *Abstracts of Reports at the Third Bulgar-Soviet Seminar on Laser and Radar Methods of Environmental Monitoring,* Sofia (1990), pp. 383–388.
22. V.I. Galkin and V.G. Ushakov, in: *Abstracts of Reports at the First International Symposium on Optics of the Atmosphere and Ocean,* Tomsk (1994), Vol. 2, pp. 186–187.
23. E.A. Monastyrnyi, G.Ya. Patrushev, and A.P. Rostov, Prib. Tekh. Eksp., No. 4, 196–199 (1988).
24. A.P. Ivanov, G.Ya. Patrushev, and A.P. Rostov, Atmos. Oceanic Opt. **7**, Nos. 11–12, 890–891 (1994).
25. A. Ya. Bogushevich and N.P. Krasnenko, in: *Abstracts of Reports at the Third Interrepublic Symposium on Optics of the Atmosphere and Ocean*, Tomsk (1996), p. 167.
26. A. Ya. Bogushevich and N.P. Krasnenko, *ibid*., p. 143.
27. L.G. Shamanaeva, J. Acoust. Soc. Amer. **73**, No. 3, 780–784 (1983).
28. N.N. Bochkarev, N.P. Krasnenko, and V.P. Muravskii, Akust. Zh. **30**, No. 2, 171–176 (1984).
29. N.N. Bochkarev, N.P. Krasnenko, "*Salient features of near-ground propagation of acoustic waves*," Dep. VINITI,. Reg. No. 501–B86, Moscow, 1986, 82 pp.
30. R.A. Baikalova, N.P. Krasnenko, and L.G. Shamanaeva, Atmos. Oceanic Opt. **5**, No. 7, 494–495 (1992).
31. N.P. Krasnenko and A. Ya. Bogushevich, in: *Abstracts of Reports at the International Congress on Noise Control Engineering "Inter-noise – 93,"* Leuven (1993), Vol. 3, pp. 1751–1754.
32. N.G. Abramov, A. Ya. Bogushevich, V.I. Karpov, et al., Atmos. Oceanic Opt. **7**, No. 3, 215–220 (1994).
33. N.P. Krasnenko, and L.G. Shamanaeva, Atmos. Oceanic Opt. **8**, No. 10, 827–832 (1995).
34. A. Ya. Bogushevich and N.P. Krasnenko, Akust. Zh. **34**, No. 4, 398–402 (1988).
35. A.Ya. Bogushevich, Akust. Zh. **40**, No. 6, 899–902 (1994).
36. N.G. Abramov, in: *Abstracts of Reports at the First Interrepublic Symposium on Optics of the Atmosphere and Ocean,* Tomsk (1994), Vol. 1, pp. 156–159.
37. N.G. Abramov, Atmos. Oceanic Opt. **7**, No. 7, 499–502 (1994).
38. N.N. Bochkarev, N.P. Krasnenko, P.I. Netreba, and A.S. Tobolkin, in: *Propagation of Acoustic and Optical Waves in the Atmosphere* (Tomsk Affiliate of the Siberian Branch of the Academy of Sciences of the USSR, Tomsk, 1988), pp. 93–96.
39. N.N. Bochkarev, V.A. Klochkov, N.P. Krasnenko, and A.A. Fomichev, *ibid*., pp. 101–104.
40. N.N. Bochkarev, Atmos. Oceanic Opt. **9**, No. 8, 725–726 (1996).
41. N.N. Bochkarev and P.A. Konyaev, Atmos. Opt. **3**, No. 6, 611–613 (1990).
42. N.N. Bochkarev, Akust. Zh. **42**, No. 5, 706–707 (1996).
43. A.Ya. Bogushevich and N.P. Krasnenko, Akust. Zh. **42**, No. 3, 339–346 (1996).
44. N.N. Bochkarev and N.P. Krasnenko, in: *Abstracts of Reports at the Eighth All-Union Symposium on Propagation of the Laser Radiation in the Atmosphere,* Tomsk (1986), Vol. 2, pp. 304–308.
45. N.G. Abramov, in: *Propagation of Acoustic and Optical Waves in the Atmosphere* (Tomsk Affiliate of the Siberian Branch of the Academy of Sciences of the USSR, Tomsk, 1988), pp. 97–100.
46. N.N. Bochkarev and N.P. Krasnenko, in: *Abstracts of Reports at the Second Interdepartmental Acoustic Seminar on Models, Algorithms, and Making Decisions,* Moscow (1988), p. 22.
47. N.N. Bochkarev, N.P. Krasnenko, G.Ya. Patrushev, and A.P. Rostov, in: *Abstracts of Reports at the Eleventh All-Union Symposium on Propagation of Laser Radiation in the Atmosphere and Water Media,* Tomsk (1991), p. 20.
48. G.Ya. Patrushev and A.P. Rostov, Akust. Zh. **42**, No. 1, 88–90 (1996).
49. E.B. Belyaev, A.P. Godlevskii, Yu.D. Kopytin, et al., in: *Abstracts of Reports at the Second All-Union Conference on Atmospheric Optics,* Tomsk (1980), Vol. 3, pp. 156–159.
50. N.N. Bochkarev, N.P. Krasnenko, and Yu.M. Sorokin, Atm. Opt. **3**, No. 6, 513–527 (1990).
51. L.G. Shamanaeva, in: *Proceedings of the Eighth International Symposium on Remote Sensing and Associated Techniques of the Atmosphere and Oceans*, Moscow (1996), pp. 135–140.
52. Yu.D. Kopytin, E.T. Protasevich, L.K. Chistyakova, and V.I. Shishkovskii, *Air Medium upon Exposure to Laser and HF Radiation* (Nauka, Novosibirsk, 1992), 190 pp.
53. Yu.D. Kopytin, N.P. Krasnenko, L.G. Shamanaeva, in: *Abstracts of Reports at the Seventh All-Union Symposium on Laser and Acoustic Sensing of the Atmosphere,* Tomsk (1982), Vol. 2, pp. 126–130.
54. L.G. Shamanaeva, Atmos. Oceanic Opt. **10**, No. 1, 65–70 (1997).