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ADVANCES OF ATMOSPHERIC ACOUSTICS IN TOMSK

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Advances of the 30-year research in atmospheric acoustics in Tomsk and the results obtained are considered. Sodars, ultrasonic meteorological stations, and other instrumental complexes developed in Tomsk are described. Results of theoretical and experimental research on atmospheric sounding are presented. Results of investigations of near-ground sound propagation in the atmosphere and high-power laser beam acoustics are described.

In Tomsk, work in the direction of atmospheric acoustics was started in 1974 when the problem of mastering **acoustic sounding of the atmosphere** was formulated and a group of specialists in atmospheric acoustics was organized at the Institute of Atmospheric Optics of the SB RAS. This scientific direction arose at the Institute engaged in research on atmospheric-optical problems under the auspices of its former director, Zuev Vladimir Evseevich. After his business trip to Australia where the first meteorological acoustic radar developed at the Scientific Research Armament Institute was demonstrated to him, V. E. Zuev initiated analogous investigations at the Institute. Taking part at the International Symposium on Tropospheric Profiling held in Australia in 2000, I pointed out in my report and discussions with Australian colleagues the oustanding contribution of L. G. McAllister who developed this acoustic radar and as a matter of fact, laid the foundation for further rapid development of the given scientific direction in the world. The subject of research was not alien for the Institute, as might appear at first sight, since remote optical sensing of the atmosphere and optical wave propagation in the atmosphere as a random inhomogeneous medium were successfully developed at the Institute. Within the framework of the integrated approach to problem solutions developed at the Institute, the new scientific direction supplemented already existed ones. At the same time, it should be noted that at that time there were no experts in acoustics in Tomsk, and students were not trained for acoustics at high schools.

As always at the Institute, theoretical and experimental work was simultaneously planned. At that time, I took up work at the IAO SB RAS and had been engaged in the formulation and development of the theoretical principles of acoustic sounding of the atmosphere since 1974. In the next 20 years since 1979, I was engaged in all investigations on atmospheric acoustics as a head of the corresponding Laboratory of the Institute. At the end of 1979, new scientific problems of sound wave propagation in the atmosphere and acoustic effects accompanying the propagation of high-power laser radiation in the atmosphere were formulated. In 1999, I took up for work at the Institute of Optical Monitoring of the SB RAS (former Special Gesign Bureau of Scientific Instrumentation "Optika" and Design and Technology Institute "Optika"; at present Institute of Monitoring of Climatic and Ecological Systems of the SB RAS) and organized again a scientific group, created an experimental base, and carried out scientific research in the given direction at the IMCES SB RAS.

It is impossible to describe briefly all the results obtained by the staff over the 30-year period, but the main advances are described in monographs and reviews [1-12].

To develop **acoustic sounding of the atmosphere**, as always at the beginning of work from nothing, in addition to the study of the formulated problem and interaction of acoustic radiation with the atmosphere as a propagation medium, an experimental base must be created for scientific research, including acoustic radars. Life experience demonstrated that creation of acoustic radars for atmospheric sounding is not only a science but also to a certain degree an art. During more than 30-year period, a number of prototypes and working acoustic radars have been created, including MAL-1, MAL-2, Zvuk-1, Zvuk-2 (renamed Volna-3), mS-1, and Zvuk-3 acoustic radars for sounding of the atmospheric boundary layer and measuring the characteristics of temperature stratification, wind velocity profile, structure constant of temperature fluctuations, etc. The Zvuk-1 acoustic radar was delivered to the Kemerovo Regional Center on Hydrometeorology (1990) and to the Russian Federal Nuclear Center (Chelyabinsk-70) together with an ultrasonic meteorological station (1996).

In theoretical investigatios, much attention was given to a study of mechanisms of acoustic radiation interaction with the atmosphere, theoretical calculations and optimal choice of the sounding system parameters, elaboration of new methods of sounding, study of the influence of refraction on acoustic radar performance, search for new information opportunities of acoustic sounding, etc. [1, 2].

The foregoing provided the basis for a design of shielded parabolic reflector antennas used in the above-listed acoustic radars. These antennas are one of the main part of an acoustic radar and determin its capabilities. The equipment was developed and a small-lot production of antennas for Zvuk-1 (Zvuk-2), mS-1, and Zvuk-3 acoustic radar modifications was organized.

The developed acoustic radars were used in numerous experiments and expeditions in our country and in Atlantic onboard the *Mstislav Keldysh* research vessel, where they demonstrated their high efficiency and importance for the study of the atmospheric boundary layer. Thus, for example, interdepartmental tests on measuring the wind shear conducted in the Alma-Ata airport in 1987 demonstrated that in such categorized airport as this, the MAL-2 monostatic acoustic radar could stably operate near a runway to measure the meteorological parameters during time intervals between takeoffs and landings of airplanes.

In connection with the severe problem of pollution of the atmosphere of industrial centers, acoustic radars can be very useful for systems of air basin monitoring; they provide information on the meteorological state of the atmospheric boundary layer in real time. The work performed for some years in critical (from the ecological viewpoint) regions of the country allowed us to collect initial data to estimate the ecological state of the atmosphere in these regions. Some experiments were carried out using a sodar, an aerosol lidar, base laser and *in situ* gas analyzers, and ground-based ultrasonic meteorological stations.

The characteristics of temperature stratification (especially of temperature inversions) obtained with acoustic radars are important for climatic prediction of situation hazardous from the viewpoint of atmospheric pollution. It was demonstrated that the statistics of characteristics of temperature stratification is different for different regions and depends on local features (orography of the locality), which results in different conditions for pollutant accumulation. In particular, the general analysis of the conditions of atmospheric stability for Kemerovo allowed us to conclude that the percentage of temperature inversions for this city is high, heights of their boundaries are low, and their spatial localization is relatively stable. All this alongside with low heights of stack mouths (50–120 m) explains unfavorable ecological conditions in industrial regions of the city when smoke plumes are cupped by temperature inversions, thereby increasing the pollutant concentration in the surface layer of the atmosphere. This was also confirmed by the result of laser sensing of aerosol fields of industrial origin.

It was demonstrated that laser and acoustic means of remote sensing of the atmosphere are rather efficient for air pollution monitoring in the city. In this case, a laser radar was used to monitor directly the distribution of aerosol impurities in the atmosphere of large territories, and an acoustic radar, used to monitor the atmospheric state, allowed the atmospheric stability to be monitored in real time and boundaries of temperature inversions to be determined, thereby facilitating the prediction of meteorological conditions hazardous from the viewpoint of air pollution.

Experimental works devoted to simultaneous sensing of the atmospheric boundary layer with acoustic radars and aerosol lidars demonstrated that the main obstacles for vertical aerosol propagation in the atmosphere are barrier layers of temperature inversions where aerosols are accumulated. Moreover, the height of the upper boundary of an aerosol cloud virtually coincided with the barrier layer height. Investigations also revealed a correlation between the atmospheric stratification parameters and concentrations of some gases, in particular, ozone and carbon dioxide.

Now two acoustic radars – Volna-3 at the IAO SB RAS and Zvuk-3 at the IMCEC SB RAS that has been operating continuously in the monitoring mode since December, 2004 – are in use.

Ultrasonic systems. The operating principle of ultrasonic meteorological systems is based on the dependence of the sound velocity in air on the absolute air temperature and wind velocity. The sound velocity is determined from the measured time of ultrasonic signal propagation from the source to the receiver spaced at a fixed distance. Solving the corresponding system of equations for the required number of the meteorological parameters by choosing the proper number of measuring paths, we retrieve the sought-after meteorological parameters (the temperature and wind velocity components).

The final result of two R&D performed under my supervision was the development of the BMK-01 onboard system, 1B65 portable system, and various modifications of stationary automated meteorological complexes (AMC) for *in situ* measurements of the meteorological parameters (pressure, humidity, three wind velocity components, and temperature) and turbulent characteristics of the atmosphere. These systems have successfully passed the State tests, certification, and can be used to measure the friction velocity, turbulent heat flux, Monin–Obukhov length, structure constants of the temperature (C_T^2) and wind velocity fields (C_V^2), and many other characteristics with reconstruction of vertical profiles of meteorological characteristics in the atmospheric surface layer.

The absence of moving parts, rather small time constant, selective sensitivity to the wind velocity component, and capability of measuring temperature fluctuations make this system convenient and reliable means for investigation of optical and sound wave propagation in the atmosphere.

Sound wave propagation in the atmosphere. The main attention here was given to investigations of near-ground sound propagation, that is, to the propagation of sound above the Earth's surface. This problem has its own special features in comparison with sound propagation in free space. Alongside with numerous meteorological parameters (temperature, pressure, humidity, wind speed and direction, and turbulence), the near-ground sound propagation is also influenced by the geometrical factors, for example, by mutual arrangement of the source and receiver and underlying surface as well as by their characteristics [6–9].

The most important for practice here are problems of prediction of sound propagation conditions and audibility and intelligibility of speech. Noise pollution monitoring in the atmosphere, development of acoustically noise-proof systems, broadcasting, and active and passive acoustic sounding are in the list (far from being completed) of scientific and technical areas where the results of prediction of sound propagation conditions can be used.

On the basis of our investigations, a model of near-ground sound propagation was constructed, a "Prognoz" program complex was developed, and a prognostic system for calculations of the average sound pressure field in the audible frequency range in the near-ground atmosphere in real time with allowance for the characteristics of sources of noise, underlying surface, and meteorological conditions at distances up to 10 km was manufactured. The complex has successively passed field tests. The average prediction error was 2–3 dB.

As for broadcasting [10], the result of our investigations allowed us to develop a new-generation mobile broadcasting station (BS) equipped with a system for predicting the maximum broadcasting range. The station can be used for broadcasting at rest and in motion with different acoustic signal sources. The prediction system provides the insonification characteristics (audibility and intelligibility of speech) of the BS for the given territory under specific application conditions in real time and provides recommendations for optimal application of the station (choice of the location and broadcasting direction) to the BS operator. During field tests, a high efficiency of station operation and prediction was demonstrated.

Acoustic diagnostics of HLR. Intensive studies of transportation of high-power laser radiation (HLR) at large distances called for the development of radically new methods of diagnostics (sounding) of HLR propagation in the atmosphere. The methods traditionally used for this purpose did not meet all the requirements for HLR source operation on extended atmospheric paths. The property of high-power laser radiation to generate acoustic signals can be used for the development of methods of acoustic diagnostics of HLR propagation in the atmosphere. As a result of our investigations started in 1980, it was demonstrated that sound waves have sufficient amplitude and can be measured with acoustic receivers. On the basis of careful experimental investigations, methods of acoustic diagnostics of geometrical and energy HLR characteristics and propagation channel as well as of the atmospheric parameters were developed. They are partly described in reviews [11, 12].

Summary. As a result of purposeful 30-year work of two Tomsk institutes of the Russian Academy of Sciences and universities, the scientific community in the field of atmospheric acoustics obtained significant results on the State level. Five Candidate's Dissertations were defended by Shamanaeva L. G. (1984), Bochkarev N. N. (1986), Odintsov S. L. (1987), Bogushevich A. Ya. (2000), Mananko E. E. (2004) and two Doctoral Theses were defended by Krasnenko N. P. (entitled

“Acoustic sounding of the atmospheric boundary layer”) in 1998 and Bochkarev N. N. (entitled “Atmospheric optoacoustics of high-power laser beams”) in 2005. A Lenin Komsomol Premium was awarded to Bochkarev N. N. in 1987, Premiums of the Siberian Branch of the USSR Academy of Sciences were awarded to Krasnenko N. P., Galkin V. I., Molchanov B. N., Fedorov V. A., and Fursov M. G. in 1985 and to Krasnenko N. P., Bochkarev N. N., Root A. G., and Fursov M. G. in 1989; Premium of the Tomsk Region was awarded to Krasnenko N. P. in 2005; a Grant of the President of the Russian Federation for 2006–2008 was awarded to Krasnenko N. P, etc.

REFERENCES

1. Krasnenko N. P. Acoustic sounding of the atmosphere. Novosibirsk: Nauka. 1986. 167 P. (in Russian)
2. Krasnenko N. P. Acoustic sounding of the atmospheric boundary layer. Tomsk. 2001. 278 P. (in Russian)
3. Krasnenko N. P. Development of atmospheric acoustic research at the IAO SB RAS // Opt. Atm. Okeana. 1997. V. 10. Nos. 4–5. P. 542-552. (in Russian)
4. Krasnenko N. P. Technical means and technologies of remote sounding of the atmosphere and underlying surface // Opt. Atm. Okeana. 2002. V. 15. No. 1. P. 51-61. (in Russian)
5. Krasnenko N. P., Mananko E. E. Parabolic reflector acoustic antennas for atmospheric sounding // Methods and means for information transfer and processing: Intercollege collection of scientific works. No. 5. Romashev V. V., Bulkin V. V., eds. Saint Petersburg: Gidrometeoizdat. 2004. P. 83-98. (in Russian)
6. Bochkarev N. N., Krasnenko N. P. Special features of near-ground propagation of sound waves // Deposited at VINITI. 1986. No. 501-V86. 82 P. (in Russian)
7. Krasnenko N. P., Shamanaeva L. G. Influence of the underlying surface on near-ground propagation of a sound wave // Opt. Atm. 1995. V. 8. No. 10. P. 1517-1526. (in Russian)
8. Krasnenko N. P. Sound propagation in the atmosphere above the ground surface at long distances // Proc. SPIE. 2005. V. 6160. Part 2. P. 1-12.
9. Krasnenko N. P. Near-ground propagation of sound waves in the atmosphere // Proc. XV Session of the Russian Acoustic Society. 2004. V. II. Moscow: GEOS. P. 97-102. (in Russian)
10. Krasnenko N. P., Abramochkin V. N., Bukhlova G. V., *et al*. Broadcasting in the near-ground atmosphere and its prediction // Proc. XV Session of the Russian Acoustic Society. 2004. V. II. Moscow: GEOS. P. 110-113. (in Russian)
11. Botchkarev N. N., Krasnenko N. P., Sorokin Yu. M. Optoacoustic effects in aerosols // Opt. Atm. 1990. V. 3. No. 6. P. 563-578. (in Russian)
12. Bochkarev N. N. Kabanov A. M., Pogodaev V. A. Optoacoustics of the channel of high-power laser radiation propagation in the atmosphere // Opt. Atmos. Okeana. 2003. V. 16, No. 9. P. 816-821. (in Russian)