FORTY YEARS OF ATMOSPHERIC OPTICS IN TOMSK

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Atmospheric optics originated in Tomsk practically simultaneously with the establishment of the Siberian Branch of the Academy of Sciences of the USSR (now the SB RAS). The Institute of Atmospheric Optics was founded on the basis of the Laboratory of Infrared Radiation of the Siberian Physical–Technical Institute at the Tomsk State University in September 1969. The laboratory itself was organized from zero. In accordance with the government decree, the Siberian Physical–Technical Institute was charged with the theme devoted to investigations of the operational efficiency of thermal direction finders under various atmospheric conditions. Professor N.A. Prilezhaeva, the Head of the Laboratory of Spectroscopy of the Physical Faculty of the Tomsk State University at that time, was appointed as theme manager and I, after graduation from the Physical Faculty of the Tomsk State University in 1951 and defense of Candidate's Dissertation in 1954, was appointed as Principal Investigator. Simultaneously and equally urgently, a scientific group should be organized.

In 1955, I was appointed to deliver a four–semester course of lectures on physics to the students of the Physical Faculty of the Tomsk State University. Based on the results of the first examination in January of 1956, I selected four gifted students, organized a scientific circle, and conducted its meetings once a weak while these students were studying at the University. After graduation from the University, I recommended three of them to enter the postgraduate course. The fourth student was assigned to Moscow. The first three students defended their Candidate Dissertations in time in 1962 and formed the scientific group on atmospheric optics. They became heads of the laboratories of the Institute of Atmospheric Optics and defended their Doctoral Theses in 1972–1973. One of them moved into Obninsk to work at the Institute of Experimental Meteorology. Now he is a well–known expert on laser sensing of the atmosphere. He is S.S. Khmelevtsov, Doctor of Physical–Mathematical Sciences. Two others – M.V. Kabanov and S.D. Tvorogov – continued to work at the Institute of Atmospheric Optics. Both were elected as Corresponding Members of the Russian Academy of Sciences.

An analysis of the government theme successfully completed in 1958 on the basis of measurements of the total transparency of the surface atmospheric layer for the radiation emitted by bodies heated to temperatures 100–500 °C showed that the obtained results had united application mainly to estimate the operational efficiency of the thermal direction finders. It became clear that it was right time to solve the integrated problem of optical wave propagation in the atmosphere in its general form, namely, to develop theory and experimental methods of investigations that in combination could provide quantitative data on the effect of the atmosphere on radiations of the parameters of an optical wave for arbitrary preset realistic physical models of the atmosphere, various geometry of radiation propagation, and different parameters of radiation, as well as various characteristic of receiving systems.

This problem formulation, immense by itself, called for the adequate integrated approach to a solution the problem on optical wave propagation in the atmosphere. This approach was coming into use already in the Laboratory of Infrared Radiation of the SPTI established by that time. Its first realizations were offered by M.V. Kabanov, S.S. Khmelevtsov, and S.D. Tvorogov in their Candidate Dissertations. The first two dissertations were mainly experimental, whereas the third dissertation was theoretical and its results were used in the first two dissertations. My Doctoral Thesis, defended in 1964, continued the development of this approach.

The unique opportunity of one–by–one selection of young specialists from the best students of the Tomsk State University founded in 1880 and of the Tomsk Polytechnic Institute founded in 1895 contributed to the successful development of the above–indicated infrared approach. These two educational institutions were unique in the vast territory of tsarist Russia behind the Ural. The method of one–by–one selection of specialists authored undoubtedly by M.A. Lavrent'ev, the founder of the Siberian Branch of the Academy of Sciences of the USSR, well–known mathematician, was of paramount importance for the entire development of atmospheric optics in Tomsk.

By the instant of establishment of the Institute of Atmospheric Optics, the group of scientists, engineers, and technicians was formed in the Laboratory of Infrared Radiation of the SPTI, who successively developed such main directions of the atmospheric optics as absorption of optical waves by atmospheric gases; scattering of optical waves by ensembles of aerosol particles, including haze, clouds, fogs, and precipitation; amplitude and phase fluctuations of waves caused by the atmospheric turbulence. All these directions may be integrated

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into one entitled "Investigation of the effect of the atmosphere on the optical wave propagation, or direct problems of atmospheric optics." Not only theoretical, but also experimental investigations were conducted concurrently in these directions, and in this connection, the development of the required equipment.

MAIN RESULTS OF ACTIVITY OF THE INSTITUTE OF ATMOSPHERIC OPTICS FOR 27 YEARS

The establishment of the Institute of Atmospheric Optics on the basis of the Laboratory of Infrared Radiation of the SPTI has opened principally new possibilities not only for the fast development of modern atmospheric optics whose fundamentals were laid in the last 13 years in the SPTI. Principally new directions of activity have appeared. Among them, solution of inverse problems of atmospheric optics and laser sensing of the atmosphere and subsurface oceanic layers should be mentioned first of all. Special attention was given to the creation of the unique modern material base of fundamental science, experimental shops, and design office.

In two years after the establishment of the Institute, the Special Design Office "Optika" was founded. Its main goal was the development of the most complicated experimental technology providing a means for fundamental researches in all directions of atmospheric optics. The powerful Computing Center of the Institute equipped with computers produced in our country was established. The main building of the Institute, the building of the model setup, the experimental shop, the polygon, and other objects of public utilities, whose total area exceeded 20,000 m^2, were built.

The establishment of the Special Design Office "Optika" (now, the Design and Engineering Technology Institute of the Siberian Branch of the Russian Academy of Sciences) provided realization of the chain of scientific–technological progress: from academic idea through fundamental and applied researches to design and development of high tech experimental models and in a number of cases to experimental units and their small–lot production. The activity of the DETI "Optika" entering the Joint Institute of Atmospheric Optics is discussed in more detail at the end of this paper.

Below we consider the main results of activity of the Institute in different directions including the last years of general crisis in Russian Science.

I. SPECTROSCOPY OF ATMOSPHERIC GASES

1. Theoretical studies

In the Laboratory of Molecular Spectroscopy, organized by Yu.S. Makushkin, the work was underway to create theory of fine structure of rotational–vibrational spectra. The method of effective Hamiltonian and the results of its application were the subject of his Doctoral Thesis. In connection with his appointment as a Rector of the Tomsk State University, this work was continued by V.G. Tyuterev, who defended his Candidate Dissertation and Doctoral Thesis at the Institute (at present, he has won international recognition as a leader of theoretical molecular spectroscopy), and the results of this work were updated using mathematical models so that vibrational–rotational spectra of various atmospheric gases can be synthesized theoretically with the highest accuracy, namely, with the accuracy of the best experimental data obtained using unique Fourier spectrometers (the accuracy of determining the position of line centers is about 10^{-4}–10^{-5} cm^{-1}). Tyuterev's theory was further developed by V.I. Starikov and V.I. Perevalov in their Doctoral Theses. It should be noted that Professor Yu.S. Makushkin had been the Rector of the Tomsk State University for 10 years and was elected as Academician of the Russian Academy of Higher School. His scholar O.N. Ulenikov developed original methods for identification of fine structure of vibrational–rotational spectra of molecules that provided a basis of his Doctoral Thesis.

S.D. Tvorogov developed original rigorous theory of continual absorption in the far wings of absorption lines of gases based on the first physical principles. This theory quantitatively explained the reason for contradictions between the experimental data obtained by different authors. Being the founder of the Laboratory of Statistical Optics of the Institute and its Head during all 27 years, he made decisive contribution to the development of theoretical programs of the Institute.

Applied problems of Tvorogov's theory were further developed by his scholar V.V. Fomin in his Doctoral Thesis.

Undoubtedly, the semiclassical representation of the quantum optics problems developed by Tvorogov with his scholar E.P. Gordov can be considered as his large contribution to science whose significance goes far beyond spectroscopic problems. This very problem was considered by E.P. Gordov in his Doctoral Thesis.

A.B. Bykov and V.P. Kochanov in their Doctoral Theses also considered urgent problems of theoretical molecular spectroscopy. The first thesis was devoted to the development and construction of the algorithms for quantitative interpretation of experimental data on rotational–vibrational absorption spectra of atmospheric gaseous molecules of different types. In the second thesis, a wide class of problems connected with nonlinear spectroscopy of spectral line profiles was solved.

2. Experimental investigations

V.P. Lopasov has been the Head of the Laboratory of Laser Spectroscopy from the establishment of the Institute. He developed the world's first laser spectrometer built around a ruby laser and a multipass cell with a 5–m baseline. Developing this new direction, he defended his

Candidate Dissertation and Doctoral Thesis and trained a group of specialists in this field of science.

The most extensive results on the study of absorption spectra of atmospheric gases using a large number of superhigh–sensitive intracavity and optoacoustic laser spectrometers were obtained by L.N. Sinitsa, who created these spectrometers capable of recording many thousands of absorption lines and several tens of vibrational–rotational bands of a large number of atmospheric gases and their isotopes for the first time. His Candidate Dissertation and Doctoral Thesis, defended at the Institute, were devoted to these problems.

Yu.N. Ponomarev defended his Candidate Dissertation and Doctoral Thesis devoted to the development of optoacoustic laser spectroscopy on the basis of two unique multipass cells (with 30–m and 110–m baselines) constructed in the building of the model setup. He succeeded in obtaining a record length of a laser beam under controllable laboratory conditions as great as 10–12 km and in investigating fine effects connected with the change of position of the absorption line centers of various gases caused by variations of the pressure and temperature. The results obtained provided a basis for the corresponding database.

II. OPTICS OF THE ATMOSPHERIC AEROSOL

1. Theoretical studies

A.G. Borovoi, a scholar of S.D. Tvorogov, developed original theory of multiple scattering of optical radiation in an aerosol medium that can be used to estimate quantitatively the fluctuations of the wave parameters due to spatial inhomogeneities of the atmospheric aerosol considering the fluctuations caused by the atmospheric turbulence. This work provided the basis of his Doctoral Thesis.

G.M. Krekov, after apprenticeship at the Computing Center of the Siberian Branch of the Academy of Sciences of the USSR in Novosibirsk at the Laboratory headed by G.A. Mikhailov, now a Corresponding Member of the RAS, a scholar of Academician G.I. Marchuk, developed the Monte Carlo algorithms adapted for a solution of problems on laser beam propagation in an aerosol medium and defended his Candidate Dissertation when he worked at the Laboratory of Infrared Radiation of the SPTI and then his Doctoral Thesis at the Institute of Atmospheric Optics. Many important problems were solved with the help of these algorithms, including the problem of determination of the applicability limits of Bouguer's law.

G.A. Titov in his Doctoral Thesis developed the theory that can be used to obtain quantitative data on a 4–D field of scattered solar radiation in the atmosphere under conditions of statistically inhomogeneous broken cloudiness. Participation of our Institute in the U.S. program on Atmospheric Radiative Measurements in the direction developed by G.A. Titov is the recognition of this original theory.

V.V. Belov developed the theory of optical signal transfer that can be used to estimate quantitatively the distorting effect of the atmospheric aerosols on the quality of images transferred through the real atmosphere, which provided the basis of his Doctoral Thesis. Based on this theory, methods for improvement of the quality of vision of objects through aerosol media were proposed.

2. Experimental investigations

After the small and large aerosol chambers were put into operation in the building of the model setup, investigations were continued of the contrast transfer by laser beams in different model aerosol media that originated in the Laboratory of Infrared Radiation of the SPTI. Dimensions of chambers (the small chamber has a diameter of 4 m and a length of 10 m and the large chamber–10 m and 27 m, respectively) and different methods of injection of aerosols into these chambers allowed us to carry out investigations in a wide range of optical thicknesses up to 100, that is, in the depth regime. Results of these investigations were considered by V.A. Krutikov, now a Chairman of the Presidium of the Tomsk Scientific Center of the SB RAS, in his Doctoral Thesis.

The second important direction of experimental investigations of the aerosols is connected with the AN–30 aircraft–laboratory "Optik–E" developed at the Institute and equipped with various instrumentation to investigate aerosols by way of their direct measurements with the use of photometers, nephelometers and lidars. Numerous flight missions performed by the researchers of the Institute in more than 100 cities and towns of the former USSR yielded very reach information generalized by two leaders of this direction B.D. Belan and M.V. Panchenko in their Doctoral Theses. The results obtained for the atmosphere above Baykal Lake and for the transparency of its waters should be specially emphasized. The case in point is the local circulation of air masses around the lake, which entrains the aerosols and is independent of the prevailing direction of air mass transport beyond the lake, as well as charting of the transparency of the Baykal waters for the entire lake basin.

III. PROPAGATION OF LASER BEAMS IN THE TURBULENT ATMOSPHERE

1. Theoretical studies

The main result of theoretical studies in this direction was the creation of the theory based on the Hyugens–Fresnel principle that can be used to estimate quantitatively the effect of the turbulent atmosphere on laser beam propagation along direct and ranging paths. V.L. Mironov and V.A. Banakh, who created this theory, successively defended their Doctoral Theses. V.L. Mironov has been a Rector of the Altai University since 1986. He was elected as a Corresponding Member of the RAS in 1991.

2. Experimental investigations

Experimental investigations performed at the Institute and aimed at comprehensive coverage of the conditions realized in the atmosphere and of the geometry of propagation of the optical radiation as well as high performance characteristics of the instrumentation developed at the Institute have made it possible to estimate the probability densities of strong and saturated intensity fluctuations, including patterns of their spatiotemporal structure, and phase of laser radiation on direct and ranging paths for a wide range of variations of the parameters of the turbulent atmosphere. The Doctoral Theses by V.A. Pokasov and G.Ya. Patrushev should be specially mentioned here.

IV. LASER SENSING OF THE ATMOSPHERE

This theme originated immediately after the establishment of the Institute. Now it became the central one. It objectively intensified the integrated approach to a study of modern problems in atmospheric optics, complementing it with a solution of inverse problems that yield quantitative information on the atmosphere.

1. Theoretical studies

Two directions of theoretical studies originated soon after the establishment of the Institute: 1) solution of inverse problems of laser sensing; 2) numerical modeling of the results of sensing for different lidars and atmospheric models. The leader of the first direction, I.E. Naats, developed algorithms for solving inverse problems for different schemes of sensing and various physical parameters of the atmosphere. These results were of fundamental importance and provided the basis for his Doctoral Thesis.

The second Doctoral Thesis in the first direction was successively defended by A.A. Mitsel'. In this Thesis, algorithms for reconstruction of humidity profiles and other atmospheric parameters from the data of laser sensing were developed.

The leader of the second direction, G.N. Glazov, performed numerical modeling of laser sensing taking into account all main effects of the interaction of laser sensing pulses with the atmosphere and of signal passage through a complicated train of a lidar receiving system. The obtained results provided the basis for his Doctoral Thesis.

2. Experimental investigations

Problems of laser sensing of aerosols, including development of lidars of several generations and obtaining, processing, and interpretation of the results of lidar sensing, were considered by I.V. Samokhvalov in his Doctoral Thesis. Basic principles of laser sensing of wind velocity with the use of correlation analysis of lidar return signals were developed and realized by G.O. Zadde and G.G. Matvienko. They also developed wind lidars. They successfully defended their Doctoral Theses based on the totality of their achievements.

The Doctoral Thesis by V.V. Zuev was devoted to an important problem of the interaction of the ozone molecules with aerosol particles. The unique multichannel lidar station was created, capable of simultaneous measuring of the ozone profiles in the stratosphere, where the ozone concentration reaches its maximum, and of the microphysical parameters of aerosols (their concentration and particle size spectra). As a result of investigations ozone holes were repeatedly recorded above Tomsk caused by the interaction of ozone with particles of volcanic aerosols emitted into the atmosphere after the eruption of the most powerful Pinatubo volcano in mid–June 1991 in Philippines.

V. NONLINEAR AND ADAPTIVE ATMOSPHERIC OPTICS

This new direction of atmospheric optics was stimulated by the advent and development of lasers with their unique properties resulting in nonlinear radiation interaction with the atmosphere as a medium in which the radiation propagates. Among these properties, very high power and energy densities and supershort durations of laser pulses that can be realized in lasers should be mentioned first of all. This direction originated in the Laboratory of Infrared Radiation some years before the establishment of the Institute of Atmospheric Optics.

1. Theoretical studies

Pioneer theoretical works on the aerosols upon expose to high–power laser radiation were continued by A.V. Kuzikovskii at the Institute in the Laboratory headed by S.S. Khmelevtsov. A.V. Kuzikovskii developed the theory of evaporation and exposure of a single particle and an ensemble of particles upon exposure to high–power laser radiation including continuous and pulsed radiation. These works were developed further by Yu.D. Kopytin and A.A. Zemlyanov in their Doctoral Theses considering also other nonlinear effects. Thresholds of these effects were determined together with the dynamics of their evolution.

Investigations on adaptive optics were initiated primarily by the necessity of elimination or reduction of the distorting effect of the atmosphere on the parameters of optical radiation that propagates through the atmosphere, including laser beam propagation. The leader of this direction and the Head of the Laboratory of Adaptive Optics is V.P. Lukin. He defended his Candidate Dissertation and Doctoral Thesis at our Institute.

2. Experimental investigations

Corresponding quantitative data on the dynamics were obtained for all examined nonlinear effects. In so doing, original techniques for measuring transient processes were developed and then used to study their mechanisms. Main results of these complicated original experimental investigations were generalized by V.A. Pogodaev, the leading experimenter, in his Doctoral Thesis.

VI. METAL VAPOR LASERS

This direction originated still in the Laboratory of Infrared Radiation of the SPTI. It was initiated by P.A. Bokhan who then became the first Head of the Laboratory of Coherent Radiation Sources of the Institute of Atmospheric Optics and did much work before he moved into Novosibirsk where he defended his Doctoral Thesis. The main part of his Thesis was written at the Institute. He published most of his papers when he worked at the Institute that also was on the title page of his Doctoral Thesis.

Soon after the establishment of the SDO "Optika", the special laboratory was organized in order to implement into practice the main achievements of the laboratory of our Institute in the form of corresponding laser units.

Fundamental researches in physics of metal vapor lasers and lasers on metal vapor compounds, conversion of laser radiation, and development of new methods for excitation of an active media were carried out over the entire period of existence of these laboratories. A large number of metal vapor lasers generating in a wide wavelength range including near–IR, visible, and UV regions, were also developed. The metal vapor lasers were produced in series of modifications, each differed first of all in the parameters of laser radiation such as the laser radiation power, which varied from several fractions to 83 W (the last was a record in due time), the pulse energy, and the pulse repetition frequency. Some modifications were produced by small batches, others were used in lidars and laser navigation systems developed at the Institute in collaboration with the SDO "Optika". Main results obtained in this direction were generalized by G.S. Evtushenko in his Doctoral Thesis. He is a Head of the Laboratory of the Institute now and headed the Laboratory of the SDO "Optika" before.

VII. INFORMATION SYSTEMS AND DATABASES

The integrated approach to a solution of current problems in atmospheric optics developed at the Institute automatically includes the development of corresponding information systems, databases, and software packages.

We have databases, mathematical algorithms and codes, as well as corresponding information systems to carry out numerical experiments practically in all directions of investigations and to acquire new knowledge on their basis.

Among information systems, the most developed geoinformation system should be mentioned first of all, whose foundations were laid by V.S. Komarov in his Doctoral Thesis.

VIII. ACTIVITY OF THE INSTITUTE IN RECENT YEARS

Up to perestroika announced by M.S. Gorbachev and especially up to the conversion company in early 1989 the Institute of Atmospheric Optics was the richest institution of the Academy of Sciences of the USSR that did huge volumes of Scientific researches by economic agreements with leading institutions of corresponding branches of our industry. All the time we worked with our constant customers that financed in full measure most of our investigations including fundamental ones. In the last year before the announced conversion the budget of the Institute was 4 million roubles and the budget of economic agreements was 21 million roubles and many rich customers stood in a queue. Since early 1989, all customers became instantly poor. The volume of agreements of the Institute decreased 6 times in the first week of 1989 and 4 times more during the year. Thus, the Institute, being the richest in our country, became literally poor. We faced with the problem of survival of the Institute and of the SDO "Optika". The staff of the Institute was 1000 and the staff of the SDO was 900 in late 1988. All 100% of researches in the SDO were financed from the agreements of the Institute with leading customers.

The main problem of survival of the Institute was to preserve its intellectual potential and unique material base of fundamental researches. From the very beginning, the problem was formulated to search effectively for principally new sources of finances with simultaneous gradual staff reduction. By late 1992, this problem was more or less successively solved at the expense of active resolute measures undertaken by the directorate, scientific divisions, and laboratories of the Institute. The staff was reduced by 40% for 4 years and remained unchanged since then. In so doing, the reduction was performed without the loss of elite personnel of all levels and material resources were completely preserved and started to increase in succeeding years.

Since late 1992 and up to now the main additional source of finances to the scanty budget have been the contracts with the Livermore National Laboratory of the U.S.A. (8 contracts on fundamental science), annual contracts on participation in the U.S. National Program on Atmospheric Radiative Measurements (pure fundamental programs), 8 contracts with the Korean Institute of High Technology (Taejŏn) on development and delivery of lidar systems, a number of small contracts with the institutes of the Chinese Academy of Sciences, grants of the State Department of the U.S.A. and of the International Soros Foundation (on fundamental science), and contracts with the Defense Research Agency of United Kingdom.

In parallel with the important contracts, our Institute enters into bipartite agreements on cooperation in fundamental researches with institutions of the U.S.A., France, Germany, China, Tunisia, and Slovenia, and receives the corresponding financial support from the Ministry of Science (now the State Committee on Science and Technology) of Russian Federation. The large number of grants of the Russian Foundation of Fundamental Researches received by the Institute by competition is also an important part of finances in excess of our basic budget.

The Institute has its own Publishing House, which publishes monthly the Journal *Atmospheric and Oceanic Optics* in Russian and in English performing all the operations beginning with subscription and ending with distribution of the journal to the subscribers. Monographs of the scientists of our Institute are also published by the Publishing House on a commercial basis.

Joint efforts of the Institute on additional financing allowed us to stabilize the general situation and to continue top–priority programs of fundamental researches, the most important results of which are considered below.

First we dwell on the most complicated and important problem of destruction of the ozone layer in the Earth's atmosphere. From the data of the World Meteorological Organization, the total ozone concentration decreases, on average, by 0.4% per year in the last decades. If this tendency preserves, our planet will suffer a global catastrophe because the biological ozone protective layer will not protect living organisms from the detrimental shortwave solar radiation anymore. It is clear that the problem of ozone layer depletion is of public concern. This most important integrated problem on a global scale must be investigated without delay also in Russia in spite of a serious crisis of its national economy now.

An ozone hole was first recorded from space above the Antarctic continent. In succeeding years the area of the hole in the southern hemisphere of the planet increased, and finally, in recent years ozone holes were also recorded in the northern hemisphere, in particular, above large territories of Western Europe and Western Siberia. Without reliable information on reasons of formation of the ozone holes above vast territories of the Earth, the qualitative reasoning suggests that the natural factors, rather than anthropogenic ones, play the main role. A study of joint and individual effects of these factors should be considered the central problem of ozone depletion. The significance of elucidation of mechanisms for ozone molecule destruction under various meteorological conditions and synoptic situations should be specially emphasized.

Integrated study of the ozone depletion problem calls for the development of methods and technical means of remote sensing of ozone concentration as well as the concentration of the main components of ozone cycle using airborne, shipboard, and ground–based stationary and mobile systems.

An analysis of the state of the art in the ozone depletion problem shows that satellite methods of retrieval of the ozone profiles are still unused for a number of important reasons. Airborne and especially shipboard measurements yield only fragmentary data. The existing aerological network cannot provide the ozone profiles with required spatial and temporal resolution. For example, ozonesondes are not sent aloft in the entire territory of Russia. The ground–based network for measuring the columnar ozone can be considered complementary to the above–mentioned method of spaceborne sensing. Lidar stations for ground–based sensing of ozone profiles are distributed nonuniformly and sensing is performed irregularly.

A study of physical and chemical mechanisms of ozone destruction calls primarily for obtaining simultaneously reliable quantitative data on ozone concentration profiles in the region of its maxima (that is, in the lower stratosphere), on the aerosols and many other components in the same altitude range, as well as for analogous data in the troposphere. Although the lower layers of the troposphere cannot contribute significantly to the formation of the ozone holes, nevertheless, repeatedly observed cases of the occasional essential increase of the ozone concentration detrimental to public health have attracted considerable attention to this problem.

An example of serious approach to a solution of the problem of investigating physical and chemical mechanisms of ozone layer destruction at altitudes from the Earth's surface up to about 50 km is the establishment, modernization, and use of the unique Siberian Lidar Station of the Institute of Atmospheric Optics of the SB RAS placed in a specially built three–storey building. Now this station is capable of simultaneous sensing of the profiles of the ozone concentration, ratios of the coefficients of aerosol and Rayleigh backscattering, aerosol concentration and aerosol particle size distribution, temperature and humidity with laser radiation at different wavelengths. Lidar signals are received through separate channels having telescopes with mirrors 2.2, 1.0, 0.5, and 0.3 m in diameter, respectively.

Simultaneously with lidar data, the NO_2 profiles are measured with a twilight spectrophotometer, and by late 1996 we planned spectrophotometry of NO_3. In addition, radiosonde and ozonesonde measurements are carried out. Mobile lidars for measuring the profiles of wind speed and direction can be also used if necessary. Of course, much work was done to solve the most complicated ill–posed inverse problems in addition to the above–described unique material resources that we had at the station.

Using this system, aerosol sensing (of the scattering ratio) has been carried out since 1986, ozone sensing – since 1989, sensing of the aerosol microphysical parameters – since 1991, temperature sensing – since 1994, and sensing of NO_2 profiles – since 1995. The profiles of aerosol characteristics and ozone were regularly measured from the instant of first recording of volcanic clouds, formed after the eruption of Pinatubo volcano, above Tomsk on 29 June 1991 to the instant of their complete dispersal in 1995.

The ozone program of the Institute envisages the use of the AN–30 aircraft–laboratory "Optik." Numerous flight missions performed practically in the entire territory of the former USSR repeatedly indicated the results of interaction of ozone with aerosols and gaseous components of the troposphere in various regions and at different altitudes. Thus, for example, the ozone concentration in the atmosphere above Khabarovsk and Komsomolsk–on–Amur in a number of cases decreased due to ozone interaction with aerosols, but also could increase. In flight missions devoted to investigation of the ecological situation in the atmosphere above Nizhnevartovsk, the best–known new town of oilmen in the Tyumen' Region, we recorded repeatedly zero values of the ozone concentration at altitudes of several hundreds of meters caused by the joint effect of NO and NO_2.

From this we may draw an ambiguous conclusion about indisputable effect of anthropogenic factor on the concentration of ozone molecules in the troposphere. This effect may be positive or negative. It should be noted that existing reliable quantitative data are insufficient to draw justified conclusions without additional systematic purposeful investigations.

It also should be noted that currency contacts allowed the Institute to purchase sufficient number of personal computers made in Western countries and to equip the Publishing House of the Institute with modern printing systems. Simultaneously, the Institute has great and continuously increasing achievements in the number of papers and abstracts of reports published in central Russian and international journals and in the number of reports presented at Russian and international conferences. Thus, in 1995 the number of papers and reports was 3.25 per a scientist. As a result, the Institute won the first place with a big advantage over 19 institutes of the Division of Oceanography, Atmospheric Physics, and Geography of the RAS including institutions of the central part of Russia and Siberian and Far–Eastern Branches of the RAS.

The anticrisis commission has been working effectively at the Institute all these years. It takes measures to ensure economy of energy resources, to improve organizational structure, and to increase efficiency of activity of all units of the Institute. A system of payment by contracts has already been successfully used for 4 years. The Director Fund also plays an important role. Since late 1992 till late 1996, 16 doctoral theses were defended at the Institute.

List of achievements in atmospheric optics in Tomsk for 40 years

Published papers	4500
Reports presented at the conferences	5300
Published monographs	120
including monographs published abroad	10
Conferences and symposia held in Tomsk	60
Doctoral theses	40
Candidate dissertations	170
Obtained authors' certificates and patents	475

From the scientists of the Institute, 1 Academician and 3 Corresponding Members of the RAS (Academy of Sciences of the USSR) were elected, 5 scientists became State prize winners of the USSR, 2 scientists became State–prize winners of the Russian Soviet Federative Socialist Republic, 2 scientists won the prize of the Council of Ministers of the USSR, and 1 scientist became a Hero of Socialist Labor of the Soviet Union.

Undoubtedly, most achievements belong to the Institute of Atmospheric Optics; nevertheless, the contribution of the Laboratory of Infrared Radiation of the Siberian Physical–Technical Institute at the Tomsk State University should be specially emphasized, as has been noted above. As for the main result on atmospheric optics obtained in Tomsk for 40 years, the formation of the largest scientific school, which has gained the world's recognition, should be primarily emphasized.

IMMEDIATE PROSPECTS OF THE INSTITUTE

In this section, we discuss fundamental researches planned for some years to come that will be financed mainly from new currency contracts; more particularly, they are our proposals to the Pacific Northwest National Laboratory or more precisely, to its division involved in the largest project on organization of the International Scientific Center for Better Quality of our Environment aimed at the increase of the economic efficiency of proposed technology along with its originality. In this case, the emphasis is on the environmental science and fundamental researches on a molecular level. In other words, the case in point is a study of processes in the atmosphere and global ocean, and on the solid Earth's surface to elucidate diverse mechanisms of these processes including the interaction of these three outer mantles of the Earth with each other.

Below, we briefly describe the proposals of our Institute.

1. Investigation of physical and chemical mechanisms of ozone depletion in the atmosphere. In spite of numerous and long–term investigations, a clear and commonly accepted concept of global change of the ozone layer has not yet been formulated and reasons for and mechanisms of the contemporary decrease of the atmospheric ozone content have not yet been understood. As known, nitrogen oxides are important for photochemistry of stratospheric ozone.

Joining very active chlorine compounds with the formation of chemical compounds–reservoirs that do not react with ozone, nitrogen oxides inhibit more active chlorine catalytic cycle of destruction of the stratospheric ozone molecules. However, to evaluate precisely the contributions from these processes in the real atmosphere and to establish quantitative relations among them, a very strong effect of dynamic factors in the lower and middle stratosphere should be eliminated.

One of the directions of this project is investigation of the stratospheric dynamic and photochemical mechanisms and processes that determine the content, distribution, and variability as well as interaction of the components belonging to the odd nitrogen family (NO_2 and NO_3) and ozone, which take part in catalytic ozone destruction, with each other. Investigations are based on the results of spectrophotometric measurements carried out at the Siberian Lidar Station (SLS) of the IAO of the SB RAS in Tomsk. The second direction of investigations in this project is a study of the dependence of the stratospheric ozone content on the variability of the stratospheric aerosol characteristics under conditions of the background stratospheric aerosol layer (SAL) and in the presence of aerosols in the form of polar stratospheric clouds or enhanced concentration of volcanic stratospheric aerosols. Investigations in these two directions are based on lidar and spectrophotometric measurements at the Siberian Lidar Station of the Institute.

2. Determination of air components of anthropogenic origin that generate ozone in the troposphere. The matter is that tropospheric ozone is a very toxic substance that poisons biological objects. In addition, it is a strong oxidizing agent and causes corrosion and destruction of many substances including resistant elements of the platinum group. Under natural conditions ozone is present in small amounts and plays a positive role because it oxidizes toxic pollutants. With the development of industry the tropospheric ozone concentration starts to increase. In many regions of the globe its concentration now exceeds maximum permissible values set up by the national standards. Investigations performed by now show a large number of photochemical cycles of ozone formation and several hundreds of substances that may produce ozone. Nevertheless, the tropospheric ozone problem has not yet been solved. Thus, for example, in most cases the change of the fuel for transport and electric power systems to natural gas, seemingly ecologically better fuel, results in ozone generation in this town (Tomsk is among these towns). It is likely that the main cycle, which triggers other mechanisms of ozone generation, has not yet been found. This is the objective of the above–indicated project.

3. Investigation of mechanisms of interaction between a turbulent wind field and a field of aerosol concentration in the atmospheric boundary layer. The project envisages experimental investigations of statistical correlation of the fundamental characteristics of turbulent flow specified by pulsations of the flow velocity and other characteristics of flow such as heat, humidity, and aerosol particles considered as pollutants as well as the development of a procedure for forecasting the diffusion of pollutants in the atmosphere considering the established correlation. Forecast of diffusion and transport of pollutants from points of their emission during ecologically dangerous industrial production processes call for knowledge of vertical profiles of the characteristics of the atmospheric turbulence and wind velocity that play important roles in the formation of aerosol fields in the atmospheric boundary layer and carry aerosol particles and condensation nuclei out of the Earth's (oceanic) surface. Statistical properties of atmospheric aerosol pollutant (aerosol content), in spite of its entrainment and conservative and passive nature, may differ essentially from the properties of the turbulent flow itself and of the heat content.

4. Lidar investigations of optical–physical properties, transformation, and transport of aerosols of anthropogenic origin. Salient features of anthropogenic aerosols forming a separate class are their specific chemical nature, multilayered structure, and presence of base metals. These atmospheric aerosols interact with the environment and are transformed. They are carried out by wind and turbulence and are settled down in large territories. Existing models that describe the behavior of anthropogenic aerosols in the atmosphere are very rough and need further improvement. In this case, we are interested in the transformation of aerosol properties (optical and physical) as well as in spatial aerosol diffusion. From this point of view, aerosol lidars having high spatial resolution (several meters) and sufficient range of operation (10 km and more) are promising for obtaining initial information about aerosol sources (their arrangement and intensity) and optical and physical properties of aerosols, their transport and diffusion. The project is aimed at:

– development of a method for lidar sensing of the parameters of anthropogenic aerosols and their discrimination against the background (natural) aerosols,

– lidar investigations of the transformation of the optical–physical properties of anthropogenic aerosols and their diffusion as well as the development of anthropogenic aerosol model,

– development of geoinformation system of the imitation modeling complex,

– regionalization of territory and preparation of recommendations for arrangement of aerosol sources considering the salient features of aerosols of this type and local topography.

5. Investigation of mechanisms for selective optical excitation of chemical molecular bonds to control chemical reactions in the process of utilization of wastes. The use of localized (frozen) vibrational clusters of highly excited molecules is very promising for control over the chemical reactions. High vibrational–rotational excitation leads to qualitative transformation of the molecular spectrum that cannot be explained in the context of commonly accepted theory. In the limiting case of local modes, the vibrational excitation is considered localized around a single bond. The lifetime of these states appears to be large in comparison with the molecular rotation period. This means that the rotational structure of vibrational states close to the limit of local modes should have salient features that reflect the local character of vibrations. So profound

interest to local vibrations in the molecule in the past few years is not surprising: they show real promise for search (and preparation) of long–living vibrational states required for selective excitation of bonds that can be used to control the chemical reactions.

The objective of the proposed project is investigation of vibrational–rotational energetic structure of molecules (H_2O, H_2S, and others of interest for the Pacific Northwest National Laboratory) in the limit of local modes possessing high angular momentum for search (and excitation) of long–living vibrational states required for selective laser excitation of bonds that can be used to control the chemical reactions.

6. Monitoring of ultrasmall values of atomic and molecular concentration by the methods of laser spectroscopy. Superhigh–sensitive laser spectrometers capable to analyze quantitatively the concentration of Na, Ba, Cs, K, Rb, Sr, Sm, Tm, Eu, V, and other atoms as low as $10^{-5} - 10^{-10}$ atm/cm^3 were developed at the Institute with the use of the method of intracavity spectroscopy for *in situ* measurements. Fluorescence laser spectroscopy can be used for *in situ* and remote measurements. In this case, spectral and temporal selection and cascade excitation eliminate effects of other substances thereby ensuring high sensitivity of measurements of the examined substance concentration. It is demonstrated that spectral range of lasers used for excitation of fluorescence allows the concentration of SO_2, NO_2, NO, benzene, xylene, OH, HCl, Cl_2, H_2S, Cl_2O, CH_3Cl, $ClONO_2$, and other molecules and radicals in the air of the order of $10^6 - 10^{10}$ mol/cm^3 to be measured.

7. Development of methods for measuring the rate constants of kinetic processes and chemical reactions in gaseous media and on the surface for selectively excited molecules. Reliable quantitative data on the above–mentioned constants of kinetic processes and rates of gas–phase chemical reactions in which selectively excited molecules take part are lacking or incomplete for many molecules that play leading roles in greenhouse effect in the atmosphere or in depletion of the ozone layer like O_3, C_xH_y, H_2O, photooxidants, freons, etc. as well as for molecular compounds used in modern technology of production of semiconducting layers, thin films, and catalysts.

The results of fundamental and applied researches on spectroscopy of molecules and interaction of laser radiation with molecular media and the atmosphere performed at the Institute of Atmospheric Optics of the SB RAS over a period of many years allow us to realize new methods for measuring the parameters of kinetic processes accompanying the interaction of selectively excited molecules in a gas with microparticles or solid bodies. These methods use signal waveforms measured in the cell of an optoacoustic detector in the process of competitive relaxation of molecules, excited selectively by laser radiation, by collisions in a gas and with the cell walls. Fundamental technical solutions are protected by patents (No. 711834, 10 April 1978; No. 818270, 26 November 1979; No. 1126078, 6 April 1983; No. 1485793, 19 October 1987).

8. Contribution of CO_2 fluxes produced by vegetation under natural conditions and technogenic stress actions to the greenhouse effect. This project envisages systematic measurements under dose actions of such stress factors as enhanced concentration of anthropogenic gases (carbon oxide, hydrocarbon compounds, nitrogen oxides, and sulfur) as well as variations of the pressure, temperature, and UV–radiation intensity. Based on these measurements, the contribution of additional fluxes of CO_2 produced by vegetative biosystems under conditions of technogenic stresses to radiative processes in the atmosphere and climatic models will be evaluated. Procedures for estimating the thresholds of technogenic stress actions on vegetative crops in industrial zones will be proposed based on investigated kinetics of CO_2 emission by various systems and a series of biotests.

ON THE ACTIVITY OF THE SDO (NOW DTI)"OPTIKA"

As mentioned above, the SDO "Optika" was established to develop and to produce any technology required for fundamental researches of the Institute. To realize this objective, all necessary elements of technological chain were formed. For example, special (including large) optics, turntables, automatics, detectors, filters, etc. are required in addition to lasers to manufacture lidars. As for any manufacturing, all test stands are required. This very approach was realized.

The unique experimental–manufacture resources of the SDO are noteworthy. First, we list the main buildings. They are the building in which the design office is situated, designers of corresponding systems including technologists, work and experimental shops are located, the first engineering building, the optical building, the administrative building, the special microelectronics building, and the second engineering building. Modern equipment was installed in all buildings, in particular, most technologic equipment of the microelectronics building was really unique, that is, it was not commercial. A technological line was developed at the electronics firm in Zelenograd and then was reproduced only twice in the USSR, including our SDO "Optika." It was ready to be set to work when perestroika broke out. If we mastered this technology, we would produce any reliable systems on the basis of our national element base, including systems placed on space platforms. Technology of optics manufacture by the time of perestroika incorporated more than 250 units, including mirrors with diameters up to 1 m, prisms, lenses, objectives, interference filters, etc. Thus, the DTI "Optika" was capable of designing and developing any modern optoelectronic devices including the most complicated ones – ground–based, airborne, shipboard, and spaceborne lidars.

All buildings of the SDO (with a total area of 30,000 m^2) were built and equipped as a result of heroic efforts of the staff.

In conclusion, we list the lidars developed at the Institute and produced at the SDO. They were used or will be used to obtain unique results of laser sensing of the atmosphere.

1. Three multifrequency stationary lidar complexes.
2. Airborne lidars for sensing of atmospheric aerosols including their elemental composition as well as for measuring of the transparency of upper water layers.
3. Fluorescent shipboard lidars for sensing of the subsurface layers of oceans and seas.
4. Multipurpose mobile lidars (for sensing of aerosols, slant visibility ranges in airports, altitudes of the lower cloud boundary, etc.).
5. Mobile spectrochemical lidar for determining the elemental composition of aerosols including salts of base metals and sensing of water and minerals.
6. Mobile Raman lidar for sensing of the temperature, humidity, and aerosol concentration profiles as well as for remote detection of gaseous pollutants and emissions from stacks of industrial objects and determination of rates of emissions near mouths of the stacks.
7. Mobile lidar system for determining the values of concentration of 20 gaseous pollutants of the atmosphere.
8. Lidar for sensing the profiles of water vapor concentration (humidity).
9. Wind lidar.
10. The first Balkan–1 spaceborne lidar delivered for mounting on the Spektr module of the Mir space station in December 1990 and launched into the orbit on 20 May 1995, although its launch was first planned in late 1992 or early 1993.

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