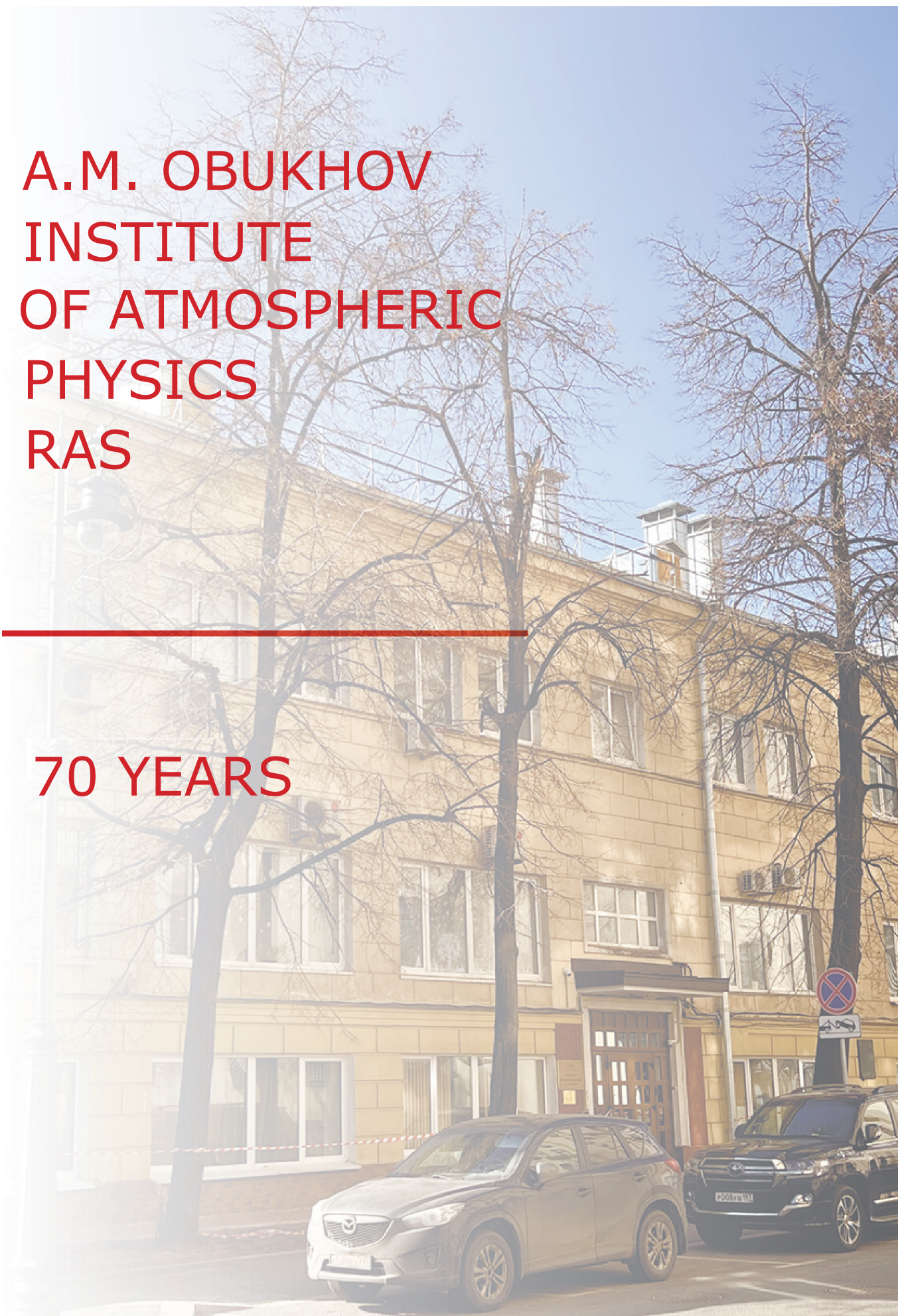


A.M. OBUKHOV INSTITUTE OF ATMOSPHERIC PHYSICS RAS

70 YEARS







FOUNDER OF THE INSTITUTE –
ACADEMICIAN A.M. OBUKHOV

FEDERAL STATE BUDGETARY
INSTITUTION OF SCIENCE:
A.M. OBUKHOV INSTITUTE OF
ATMOSPHERIC PHYSICS OF THE
RUSSIAN ACADEMY OF SCIENCES
(A.M. OBUKHOV IAP RAS)

History

On January 6, 1956, Resolution No. 5 of the Presidium of the USSR Academy of Sciences was issued, approving the organizational structure of the Institute of Atmospheric Physics of the USSR Academy of Sciences and incorporating it into the Division of Physical and Mathematical Sciences of the Academy. That day marked the beginning of the Institute's history. On March 30, 1956, Alexander Mikhailovich Obukhov, a corresponding member of the USSR Academy of Sciences, was appointed director of the Institute, and on July 6 of that same year, Resolution No. 114 of the Presidium approved the composition of the Academic Council. However, the institute was not created from scratch — its establishment was preceded by nearly 30 years of development in Soviet geophysics. The first geophysical institute in the young Soviet Republic — the Seismological Institute of the USSR Academy of Sciences (SIAS) — was founded in Leningrad in 1928. Its founder and first director, Pavel Mikhailovich Nikiforov, was a student and successor to the outstanding Russian seismologist Boris Borisovich Golitsyn. In 1935, the institute moved to Moscow, into a three-story building in the Zamoskvorechye district at 3 Pyzhevsky Lane. To this day, the "Moscow" Seismological Station — established under the SIA on January 1, 1936 — continues to operate successfully in the building of the Institute of Atmospheric Physics, maintaining the longest continuous series of seismological observations in Central Russia.

In 1937, on the initiative and under the leadership of the outstanding mathematician, geophysicist, and polar explorer Otto Schmidt, the Institute of Theoretical Geophysics was established in Moscow. One of its fundamental organizational principles was the comprehensive study of processes in all geospheres of our planet and a multifaceted scientific approach to the objects under study. O.Yu. Schmidt brought together leading mathematicians, mechanical engineers, physicists, geophysicists, and geologists. It was there that the first atmospheric studies began, focusing primarily on wave propagation in the atmosphere and the magnetosphere.

Shortly after the war, in 1946, the Seismological Institute and the Institute of Theoretical Geophysics in Moscow were merged to form the unified Geophysical Institute (GEOFIAN), with Academician O.Yu. Schmidt serving as its director. In 1946, the Comprehensive Geophysical Expedition — established shortly before that by G.A. Gamburtsev to conduct scientific research and pilot production work at enterprises engaged in the exploration and mining of uranium ores — was incorporated into GEOFIAN. In 1948, G.A. Gamburtsev became director of the unified geophysical institute.

GEOFIAN developed and expanded rapidly; prominent scientific leaders emerged, and at some point, all of its areas of activity outgrew the single



A commemorative plaque honoring the Institute's founder, Alexander Mikhailovich Obukhov, on the building of the A.M. Obukhov Institute of Plant Physiology of the Russian Academy of Sciences (unveiled on May 5, 2018)



The photo that served as the model for the memorial plaque: A.M. Obukhov on a board of scientific vessel during expedition in the North Atlantic

building. At the initiative of Academician G.A. Gamburtsev, the question of dividing the institute along its main areas of research was raised in 1955. The director's sudden death accelerated the planned reorganization, and in November 1955, the Academy of Sciences issued a decision to divide GEOFIAN into three independent scientific institutions: the Institute of Earth Physics, the Institute of Atmospheric Physics, and the Institute of Applied Geophysics.

The Institute of Atmospheric Physics of the USSR Academy of Sciences was established to study the fundamental processes in the atmosphere, drawing on advances in physics, mechanics, and applied mathematics. The institute's structure, its main research areas, and its disciplined yet creative and free atmosphere of scientific activity were shaped by its first director, Alexander Obukhov, who held this position for 33 years. In building the team, he attracted a large number of promising young scientists, many of whom later became recognized leaders in key fields of atmospheric physics. Today, the Institute is a leading scientific school in Russia and worldwide, and a leader in our country in the field of atmospheric and climate sciences.

In 1994, the Institute of Atmospheric Physics of the Russian Academy of Sciences was named after Academician Alexander Obukhov, the founder and long-standing director of the Institute from 1956 to 1989 (Resolution No. 226 of the Presidium of the Russian Academy of Sciences dated December 13, 1994). And on May 4, 2018, in honor of the centenary of the founder's birth, a commemorative bronze plaque dedicated to Academician A.M. Obukhov was unveiled on the facade of the Institute of Atmospheric Physics RAS.

Subsequent directors successfully continued the traditions established by Alexander Mikhailovich, maintaining continuity and developing new, relevant areas of scientific research. From 1990 to 2008, the director of the Institute was Georgy Golitsyn, a member of the Russian Academy of Sciences; from 2009 to 2018, it was Igor Mokhov, a member of the Russian Academy of Sciences; from 2018 to 2023, Sergey Kulichkov, Doctor of Physical and Mathematical Sciences, and in 2024, Vladimir Semenov, a member of the Russian Academy of Sciences, became director of the A.M. Obukhov IAP RAS.

Scientific Achievements

Outstanding scientists contributed to the development of the Institute's main areas of activity, the formation of its core staff, and the organization of scientific research: A.M. Obukhov, G.S. Golitsyn, V.M. Bovsheverov, A.S. Gurvich, V.I. Dianov-Klokov, L.A. Dikiy,

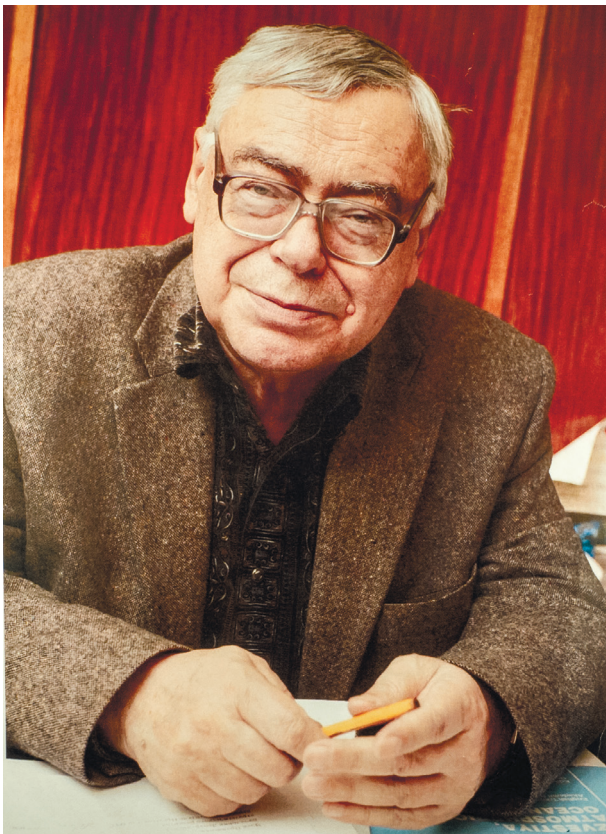
E.M. Dobryshman, F.V. Dolzhansky, V.I. Krasovsky, M.S. Malkevich, A.S. Monin, I.I. Mokhov, G.V. Rosenberg, A.I. Semenov, V.I. Klyatskin, V.I. Tatarsky, N.N. Shefov, E.M. Feigelson, L.R. Tsvang, A.M. Yaglom, and many others.

The Institute's work on atmospheric turbulence is widely recognized. The science of atmospheric turbulence, which has become the foundation of modern atmospheric and climate physics, was developed by A.N. Kolmogorov, a student of A.M. Obukhov, as early as the 1930s. Together, they developed a theory of local homogeneous and isotropic turbulence, which describes random variations in airflow velocity. Later, Obukhov developed a theory to describe pressure fluctuations as well as the behavior of passive constituents in the air (such as temperature or gas concentrations). In particular, he derived the famous "two-thirds law" for the structural function of temperature or impurity concentration. In addition, A.M. Obukhov determined a universal scale for heat and momentum exchange processes in the surface layer of the atmosphere. This discovery later formed the basis of the world-renowned Monin-Obukhov similarity theory, which is used to describe atmospheric processes.

The theory of similarity for a thermally stratified turbulent atmospheric boundary layer, developed by A.S. Monin and A.M. Obukhov, was a truly revolutionary development, making it possible to describe complex exchange processes in the atmospheric boundary layer using a set of relatively simple-to-measure variables. To this day, parameterizations based on its findings remain an essential component of all existing weather and climate forecast models, and the 1954 Russian-language publication outlining its fundamental principles is one of the most cited works in global geophysics. Current developments in the Monin-Obukhov similarity theory are aimed at overcoming the limitations of its classical formulation, which assumes horizontal homogeneity and stationarity of conditions. The main challenge lies in extending the theory to heterogeneous underlying surfaces (e.g., urban areas, forested areas, and "land-water" transitions), where the hypothesis of constant fluxes with height is violated. Recent research at the Institute of Atmospheric Physics has focused on modifying the theory by introducing additional parameters that account for horizontal gradients, as well as on using ensemble averaging and spectral analysis methods to separate the contributions of different turbulence scales in order to accurately describe exchange processes in real, complex landscapes.



Alexander M. Obukhov



George S. Golitsyn

Based on the statistical laws of turbulence, A.M. Obukhov was the first to theoretically substantiate the phenomenon of sound scattering due to atmospheric turbulence. On this basis, in 1958, M.A. Kallistratova, under the supervision of V.M. Bovsheverov, developed prototypes of devices capable of measuring the vertical distribution of turbulence characteristics in the atmospheric boundary layer. Subsequently, these studies were used to create acoustic detectors of atmospheric turbulence — sodars. The institute has developed a multi-frequency Doppler radar — the LATAN-3 sodar — designed to monitor the profile of wind speed and direction, as well as the heights of surface and elevated inversion layers in the lower troposphere (in the layer from 30 m to 300–600 m), as well as a series of mini-sodars that enable the study of the fine structure of the atmosphere.

Under the leadership of V.M. Bovsheverov, the foundations were also laid for methods of acoustic anemometry and thermometry, upon which the operating principle of acoustic anemometers is based — devices that are still widely used today to measure heat, moisture, momentum, aerosols, and gaseous impurities. The development of high-frequency equipment for measuring the structure of atmospheric turbulence contributed not only to the advancement of theoretical models but also to the development of methods for determining turbulent flows in the atmosphere-surface system. The theoretical justification and initial experimental validation of the turbulent pulsation method for determining energy and mass fluxes (including climatically active gases), widely known worldwide as the eddy covariance method, were also carried out at IAP experimental sites — and first and foremost at the Tsimlyansk Scientific Station, established specifically for the experimental study of atmospheric turbulence and atmospheric acoustics.

The development of experimental research in boundary layer physics was facilitated by the establishment — on the initiative of A. M. Obukhov — and the continuous improvement of the instrumentation workshop, which made it possible to develop the researchers' ideas for instruments and devices into functional prototypes. In the 1960s and 1970s, the custom-built instruments created at the institute — a thermoanemometer, an AC resistance thermometer, acoustic anemometers, a circulumeter, an optical hygrometer, as well as devices for data recording and processing — successfully competed with foreign brand-name instruments.

Under the leadership of L.G. Elagina, the first pulsed infrared and optical hygrometers for measuring turbulent moisture fluxes were developed, as well as some of the world's first

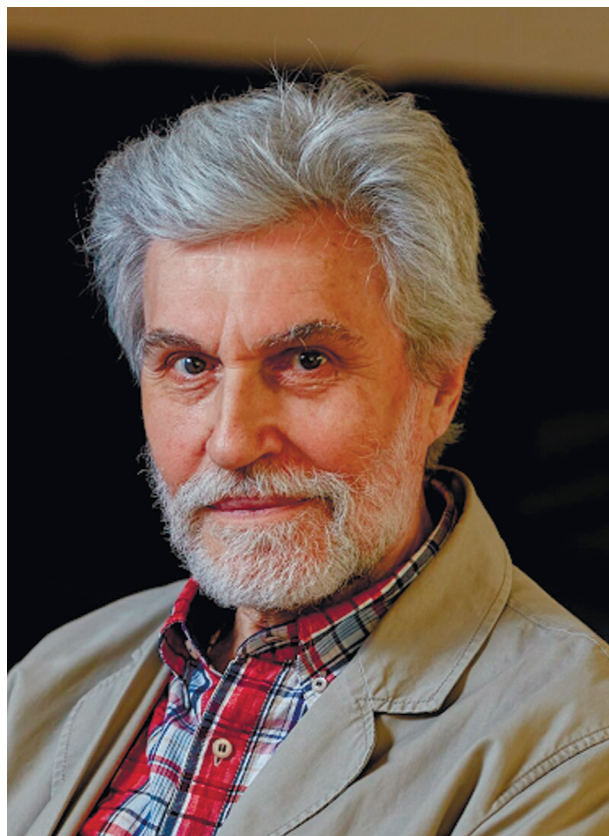
pulsed sensors for measuring carbon dioxide fluxes. The experimental sites of the IAP RAS (the Tsimlyansk and Zvenigorod scientific stations) were actively used for international experiments on the study of turbulence, processes in various layers of the atmosphere, and instrument comparisons.

Research on the theory of atmospheric turbulence has been conducted continuously at the Institute of Atmospheric Physics throughout its history. Scientists not only developed theoretical models but also conducted numerous experiments — on land, using tall masts and aircraft, and during marine expeditions. One of the key areas of research was the study of a fundamental property of vortices: vorticity (a measure of the “twist” in an air current). Researchers developed a theory linking vorticity to atmospheric dynamics, which made it possible to analyze vortices of various scales. Under the leadership of B.M. Koprov, scientists at the institute were the first in the world to measure turbulent helicity under real-world conditions. They also developed methods for estimating helicity both in the overall turbulence field and throughout the entire boundary layer.

A new scientific field originated at the IAP and gained worldwide recognition: the study of how waves (light, sound, radio waves) propagate in a turbulent atmosphere. The foundations of this field were laid by A.M. Obukhov and further developed by V.I. Tatarsky. By combining theoretical work with experiments, the scientists succeeded in discovering an important phenomenon—the effect of increased backscattering of waves. For these achievements, the institute’s staff — A.S. Gurvich, V.I. Klyatskin, A.M. Obukhov, and V.I. Tatarsky—were awarded the USSR State Prize in 1990.

In the early 1970s, the institute began work on the development of hydrodynamic-type systems for describing global geophysical motions, studying their stability and energy transformations within them using laboratory, theoretical, and numerical models. The works of A.M. Obukhov, E.B. Gledzer, and E.A. Novikov on the development of hydrodynamic-type systems to describe developed turbulence using cascade models — which simulate the energy conversion scheme in turbulent flows in accordance with Kolmogorov’s theory — date from this period.

In the 1980s and 1990s, the Institute conducted large-scale experimental studies of convection in rotating fluids. These experiments and the theory developed based on them have found applications in various fields — ranging from ocean dynamics and the motion of the Earth’s liquid core to understanding the mechanisms behind the formation of hurricanes.



Igor I. Mokhov



Sergey N. Kulichkov

With the active participation of F.V. Dolzhansky, a theory of quasi-two-dimensional vortex fluid flows was developed based on laboratory experiments, and this theory was applied to describe large-scale geophysical flows. Low-parameter models of the general circulation of the Earth's atmosphere have been developed, allowing for the reproduction of the main features of circulation, its energy cycle, and various mechanisms of circulation instability, including those dependent on the type of conditions at the underlying surface. Laboratory studies of vortex motion, initiated by A.M. Obukhov, are currently ongoing on a rotating ring apparatus that simulates conditions in the Earth's atmosphere. The motion of a weakly conductive fluid in the apparatus is excited by a magnetohydrodynamic method. Particular attention is currently being paid to modeling so-called blocking processes — when areas of high or low pressure persist for long periods in the atmosphere, determining the weather over large territories.

Among the Institute's most significant achievements of the 1960s were the advancement of understanding regarding the dynamics of the atmosphere and the development of a theory of Earth's atmospheric oscillations (L.A. Dikiy, 1969), as well as the formulation (A.M. Obukhov, 1968) of the concept of "hydrodynamic-type systems" — discrete approximations of the equations of hydrodynamics. Based on this, it became possible to develop effective low-parameter approaches that allow for the study of complex processes (such as large-scale atmospheric circulation or turbulence) using relatively simple models. These methods have not lost their relevance and are still successfully applied today.

The institute made a significant contribution to the development of the country's space program, particularly to the discovery and study of Earth's radiation belts. IAP equipment was installed on the third Soviet Earth satellite (1958) and on the "Kosmos-3," "Kosmos-5," and "Kosmos-149" satellites. Under the leadership of the IAP's scientific team, the "Kosmos-243" and "Kosmos-384" satellites were used to conduct the first-ever studies of the Earth's thermal radio emission spectrum, marking the beginning of a new direction in the development of methods for probing the atmosphere and the underlying surface from space. On the "Salyut" and "Mir" manned space stations, with the direct participation of G.M. Grechko — a twice Hero of the Soviet Union, Soviet cosmonaut, and later head of the IAP laboratory — research into the Earth's atmosphere based on optical refraction phenomena was initiated. The Institute has also

developed methods for probing the Earth's atmosphere from space based on measurements of radio wave refraction.

Research on the upper atmosphere began at the Zvenigorod Scientific Station immediately after the institute was founded in 1957 as part of the International Polar Year program, and since then, continuous observations of the nighttime atmospheric glow have been conducted there. As a result, the institute has accumulated the world's longest time series of temperature data at the mesopause (an altitude of about 90 km), which has led to a number of fundamentally important discoveries. Analysis of the data revealed wave-like temperature oscillations in the mesopause region, and V.I. Krasovsky provided a theoretical explanation for them, linking them to the propagation of internal gravitational waves from the lower layers of the atmosphere. In doing so, he discovered the phenomenon of modulation of the intensity of hydroxyl radiation in the upper atmosphere by these waves. N.N. Shefov and A.I. Semenov developed empirical models of variations in the radiation of hydroxyl, atomic oxygen, and sodium, taking into account solar activity and the processes of long-term changes in the thermal regime of the middle atmosphere; for the first time in the world, significant long-term seasonal temperature variations at mesopause altitudes were established, which is of key importance for understanding the dynamics of the upper atmosphere and the mechanisms of climate change.

The fundamentals of remote sensing using infrasonic waves have been developed, and the effect of acoustic signal scattering on the thin layered structure of the atmosphere has been detected for the first time (at altitudes of 0–1,000 m and 20–130 km) based on the results of a series of unique experiments using ground-based explosions with a TNT equivalent of 20–70 metric tons and pulses from a detonation generator as sources. Methods have been developed for the theoretical description of the long-range propagation of infrasonic waves, which are used in the international system for monitoring atmospheric nuclear explosions. Using lidar and rocket sounding, it was discovered that the upper atmosphere contains long-lived thin layers with sharp temperature and wind speed gradients — the vertical gradients in these layers significantly exceed average values. Based on these data, a theory was developed that allows for the reconstruction of the detailed vertical structure of wind speed. This is necessary to refine the reference atmospheric model used for scientific and applied purposes.

In the 1950s, G.V. Rosenberg set out to conduct a detailed study of the optical and microphysical properties of atmospheric aerosols, including measurements of the light

scattering matrix in the surface layer of the atmosphere. The institute began to develop research on the aerosol components of the atmosphere and formulated a theory of optical phenomena and light propagation in an aerosol-laden atmosphere. An important step in this direction was the concept, developed by G.I. Gorchakov, of atmospheric aerosol as a system of fractions. Research continuing to this day has made a significant contribution to the assessment of urban pollution, the theory of near- and far-field propagation of pollutants, the development of methods for remote sensing of the Earth from space, and atmospheric modeling. A fundamentally new approach to assessing aerosol emission intensity has been proposed, one that takes into account convection and turbulent structures.

Since the middle of the last century, the institute has been actively advancing research on the propagation of solar and thermal radiation in the atmosphere, a field pioneered by E.M. Feigelson and L.M. Romanova. Scientists are studying how clouds, gases, aerosols, and the interaction between the atmosphere and the Earth's surface affect the passage of radiation. An important step forward was moving away from the simplified view of clouds as a continuous, homogeneous medium. They began to be regarded as complex systems consisting of a multitude of individual particles: water droplets and ice crystals. Models were developed that account for the actual heterogeneity of clouds: droplet sizes, crystal shapes, the ratio of water to ice, and how all these particles are distributed in space. The institute also launched research into how clouds influence the climate through radiative processes. The results of this research provided the physical basis for so-called parameterizations — that is, simplified descriptions of radiative processes in clouds, which are used today in Earth system models for weather and climate forecasting. These developments have also found direct application in methods of remote sensing of the atmosphere (for example, in the interpretation of satellite data).

In the 1970s, under the leadership of V.I. Dianov-Klokov, IAP established a regular monitoring program for the concentrations of trace atmospheric gases: carbon monoxide (since 1970), methane (since 1974), ozone (since 1979), and nitrogen dioxide (since 1981) near Moscow and in the Caucasus region around Kislovodsk. For four decades now, a network of four observation stations in various Russian regions (in the North Caucasus, Central Siberia (Zotino Station), the Moscow Region, and the city of Moscow) has been conducting regular measurements of the gaseous and aerosol composition of the atmosphere. Research on variations in the concentration of gaseous impurities at the Zvenigorod Research Station is the longest-running in the world,

and it is the only station in the world where the vertical profile of nitrogen dioxide in the stratosphere is determined. Measurements of ozone concentrations at the Vysokogornaya Research Station are part of the World Ozonometric Network and the Global Atmospheric Composition Monitoring Network and also constitute one of the world's longest continuous observation series. These observations, unique in their duration and comprehensiveness, make it possible to identify long-term trends in the concentrations of greenhouse gases and trace gases, assessing the impact of anthropogenic and natural factors on atmospheric composition under various geographical conditions. Data obtained at IAP stations serve as the basis for verifying satellite measurements and global climate models.

In the 1990s, under the leadership of N.F. Elansky, for the first time in global practice, a mobile observatory was developed in collaboration with the All-Russian Scientific Research Institute of Railway Transport to conduct comprehensive observations of the chemical composition of the atmosphere, its thermodynamic and radiative characteristics, as well as to monitor pollution of soil, water, and vegetation. From 1995 to 2010, with the participation of Russian and foreign research centers, a series of 15 international experiments was conducted to observe atmospheric conditions across a vast territory of the country: from Moscow to Vladivostok and from Murmansk to Kislovodsk and Sochi. Circumventing Moscow via the Ring Railway provided unique insights into the impact of megacities on the environment.

Growing interest in the ocean's role in weather and climate formation led to the establishment in 1978 of a research program focused on exchange processes in the boundary layers of the atmosphere and the ocean. Institute staff have repeatedly participated in coastal, marine, and oceanic expeditions, including comprehensive international experiments (the "Sections" program, HEXOS, ASTEX, CAPMOS, NABOS, the International Polar Year 2007–2008 research, and others), as well as in Antarctic and Arctic expeditions. Research was conducted on the dynamics of sea waves, processes of turbulent energy and gas exchange, and convective transport. For the first time, the relationship between the sea surface roughness parameter and sea wave characteristics was determined, as well as the dependence of exchange coefficients on atmospheric stratification and the structure of the ice-covered surface in polar regions.

In the late 1960s, on the initiative of G.S. Golitsyn, the Institute of Atmospheric Physics began studying the atmospheres of other planets. He developed a similarity theory for planetary atmospheric circulation.

The results obtained regarding wind characteristics in the atmospheres of Venus and Mars were used by the S.A. Lavochkin Design Bureau in the design of the landing modules for the Soviet "Venera" and "Mars" series of unmanned interplanetary probes and were later confirmed by measurements from space probes. The institute continues to conduct research on dust storms on Mars, vortex circulations on Jupiter and Saturn, and the composition of planetary atmospheres.

In the 1980s, G.S. Golitsyn and A.S. Ginzburg, together with staff from the Computing Center of the USSR Academy of Sciences and scientists from other countries, carried out pioneering work to assess the possible long-term climatic and ecological consequences of a large-scale nuclear conflict—"nuclear winter." Calculations of global cooling resulting from the blocking of sunlight by smoke from massive fires caused by nuclear explosions were performed using a simple analytical model developed by A.S. Ginzburg to describe the anti-greenhouse effect of Martian dust storms. Natural analogues of "nuclear winter," such as asteroid impacts, volcanic eruptions, and massive wildfires, were also described. This work played an important role in negotiations on the ban on nuclear testing.

Since the 1970s, one of the key areas of activity at the IAP has been climate research, initiated by G.S. Golitsyn and further developed under the leadership of I.I. Mokhov, who trained three generations of students, almost all of whom work at the Institute, including Director V.A. Semenov, a member of the Russian Academy of Sciences (RAS); Deputy Director for Science A.V. Chernokulsky; and Head of the Climate Theory Laboratory, RAS Professor A.V. Eliseev.

V.K. Petukhov developed the IAP RAS global climate model (KM). The model is actively being developed and currently accounts for the interactions between the atmosphere, the ocean, the active layer of the land surface, cryospheric and biospheric processes, the carbon and methane cycles, and the effects of atmospheric electricity — all of which are necessary to describe climate variations and changes ranging from intra-annual scales to many millennia. Ensemble numerical experiments are conducted using the KM IAP RAS model to describe climate changes over tens and even hundreds of thousands of years. The model is used to assess the impact of natural factors (solar and volcanic activity) and anthropogenic factors (greenhouse gases, aerosols, etc.) on climate change.

In the 2000s, P.F. Demchenko developed a research direction in stochastic climate modeling at the Institute of Atmospheric Physics (IAP), in which climate is viewed as the result of the interaction between fast chaotic processes (atmospheric vortices acting as noise)

and slow processes (changes in ocean dynamics and soil moisture), which are mathematically described using Brownian motion equations. This work made it possible to develop methods for distinguishing anthropogenic climate change from natural fluctuations, to calculate statistics on variations in soil moisture and river flow, and to derive generalized equations for the evolution of climatic variables that account for memory effects. This research provides a powerful analytical tool that complements complex computer models and helps to gain a deeper understanding of the nature of long-term climate fluctuations.

I.I. Mokhov proposed new methods for diagnosing the structure of the climate system and the characteristics of its stability, which have been used to estimate the contributions of natural climate fluctuations and anthropogenic impacts to historical climate changes on various time scales.

Studies of weather and climate anomalies and their connection to contemporary climate change have revealed significant trends toward an increase in the amount of convective precipitation across Russia in recent decades. The mechanisms underlying a number of significant extreme events have been explained, including the extreme precipitation in Krymsk in 2012, the increase in the number of abnormally cold winters in the early 21st century, and the flooding of the Amur River in 2013.

V.A. Semenov obtained important results regarding the significant contribution of natural variability to temperature trends in the 20th century and proposed new mechanisms explaining accelerated climate change in the Arctic and its nonlinear impact on weather anomalies in Northern Eurasia. An analysis of the relationship between climate change and sea ice concentration in the Arctic Ocean made it possible to reconstruct sea ice concentration data for the first half of the 20th century — a period for which direct measurements of sufficient quality were lacking — and to identify a strong negative anomaly in sea ice extent in the middle of the last century.

The Institute conducts field studies of natural ecosystems in Eurasia and develops methods for mathematical modeling of ecosystems. Unique data have been obtained on greenhouse gas emissions from wetlands and lakes in Western Siberia, as well as from hydroelectric power plant reservoirs. A new type of Markov model has been created to describe and predict changes in vegetation cover under the influence of climate change, a theory of the stability of biological communities and the dynamics of interacting biological species has been developed, and models have been constructed to assess carbon flux in natural terrestrial ecosystems and the coupled cycling of organic matter and nitrogen in wetland ecosystems.

Research on the ecology and energy sector of large cities is advancing: a statistical model of the dynamics of average daily concentrations of atmospheric pollutants in Moscow has been developed; studies are underway on the direct and inverse relationships between climatic processes and energy consumption in megacities in Russia and around the world, as well as on the variability of oxygen and methane levels in the urban atmosphere, and trends in the thermal comfort period under conditions of global warming. Assessments have been conducted of the impact of reduced economic activity during the COVID-19 pandemic on air quality in Moscow compared to other major cities around the world.

The achievements of the Institute's staff have been recognized with departmental, state, and Academy of Sciences awards. Members of the Institute's staff are recipients of USSR State Prizes and Russian Federation Government Prizes.

The Institute's scientific director, Academician G.S. Golitsyn, has been awarded the Order "For Merit to the Fatherland," 4th class, the Order of Honor, and a Letter of Appreciation from the President of the Russian Federation. He is a recipient of the A.A. Friedman Prize of the USSR Academy of Sciences and the B.B. Golitsyn Prize of the Russian Academy of Sciences. In 2019, he was awarded the highest honor of the RAS — the M.V. Lomonosov Grand Gold Medal of the RAS.

Academician V. A. Semenov, Director of the Institute, was awarded the Medal of the Order "For Merit to the Fatherland," 2nd class, and the O. Yu. Schmidt Prize of the Russian Academy of Sciences (jointly with I. I. Mokhov).

A.A. Makosko, Head of the Laboratory for Atmospheric Transport Modeling and Corresponding Member of the Russian Academy of Sciences, was awarded the Order of Friendship, the Medal of the Order "For Merit to the Fatherland," Second Class, and a Letter of Appreciation from the President of the Russian Federation.

N.F. Elansky, Head of the Department of Atmospheric Composition and Corresponding Member of the Russian Academy of Sciences, was awarded the honorary title of "Honored Scientist of the Russian Federation."

In 2016, to honor the memory of A.M. Obukhov, an academician of the USSR Academy of Sciences, the Russian Academy of Sciences established the A.M. Obukhov Gold Medal, which is awarded by the Department of Earth Sciences of the Russian Academy of Sciences for outstanding scientific work in the field of atmospheric sciences. The first recipient of the medal in 2018 was G.S. Golitsyn for his work, which made an outstanding contribution to research in magnetic hydrodynamics and the development of a number of theories in the fields of planetary science, climate theory, atmospheric physics, and geophysics.



*The Academician
A.M. Obukhov Medal*



The Present and the Future

Currently, the A.M. Obukhov Institute of Atmospheric Physics of the RAS is a leading scientific center in Russia and worldwide in the field of atmospheric sciences. The institute conducts fundamental research on climate, atmospheric dynamics from the surface to the upper atmosphere, the interaction between atmospheric and oceanic processes, atmospheric composition and the transport of pollutants, as well as wave processes on all scales.



V.A. Semenov

The Institute plays a key role in providing expert and analytical support to government agencies. Its responsibilities include the scientific assessment of issues, the preparation of recommendations for decision-making in the fields of environmental protection and climate policy, as well as support for intergovernmental agreements on global climate change and the development of the Arctic and Antarctic.

The present (since 2023) director of the Institute is Academician Vladimir A. Semenov, the leading Russian researcher in the area of atmosphere and climate dynamics with focus on the Arctic climate, extreme events, weather and climate predictability. V.A. Semenov is a Co-Chairman of the Scientific Council of the Russian Academy of Sciences on Earth's Climate Problems and Deputy Academician-Secretary of the Earth Sciences Department of RAS.

The Institute's staff are recognized by the international community for their exceptional expertise: they are regularly invited to serve as lead authors and reviewers in the preparation of reports by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Commission on Sustainable Development.

According to its current Charter, the Institute's primary areas of scientific activity are fundamental, exploratory, and applied research in the following fields:

- climate diagnostics and modeling, parameterization of climate-forming processes, investigation of the interaction between clouds, aerosols, and radiation, interaction between the atmosphere and the underlying surface, and study of regional manifestations of global climate change;
- Research and monitoring of the atmospheric gas composition and atmospheric pollutants; forecasting the potential consequences of their changes for the environment and Earth's climate;
- Study of the dynamic and statistical characteristics of vortex and wave motions in the atmosphere, as well as acoustic and internal gravitational waves;
- satellite sounding of the atmosphere;
- monitoring and forecasting temporal and spatial changes in the state of the upper atmosphere.

The Institute not only maintains its traditional areas of scientific research but also actively engages in addressing new, pressing fundamental and applied challenges. These include the development of the physical foundations of climate theory to study the role of natural and anthropogenic factors in climate change; the diagnosis and modeling of climate and climate change; the identification of mechanisms underlying extreme weather and climate events and the study of their predictability; parameterization of climate-forming processes; research and monitoring of the composition and structure of the atmosphere, assessment of their impact on ecosystems and atmospheric pollution; and assessment of the consequences of climate change for the population and economic sectors with the aim of developing effective adaptation measures.

The Institute comprises 13 research laboratories and one sector, organized into three departments: Climate Processes, Atmospheric Dynamics, and Atmospheric Composition. The Institute's experimental facilities include a network of geophysical stations located in various climatic zones: the Zvenigorod Scientific Station (Moscow region, Odintsovo District), the Tsimlyansk Scientific Station (Rostov region,

Tsimlyansk), the High-Altitude Scientific Station (Republic of Karachay-Cherkessia, Malokarachaevsky District) with its base in Kislovodsk (Stavropol Krai).

As of 2026, the Institute employs 300 people, including 187 researchers, among whom are two members of the Russian Academy of Sciences (RAS), two corresponding members of the RAS, 40 Doctors of Science, and 83 Candidates of Science. Nearly half (88 people) of the research staff are young scientists. The Institute has a Scientific Council, which includes two full members of the Russian Academy of Sciences (RAS), two corresponding members of the RAS, 12 Doctors of Science, and 7 Candidates of Science.

The A.M. Obukhov of the Russian Academy of Sciences serves as the host institution for the Department of Ocean Thermohydraulics at the Moscow Institute of Physics and Technology (MIPT) and the Department of Atmospheric Physics at the Faculty of Physics of Lomonosov Moscow State University (MSU), and also collaborates closely with the Faculty of Geography at MSU and a number of relevant departments at universities across the country.

The Institute regularly organizes Russian and international schools and conferences for young scientists and actively conducts joint research with foreign scientific organizations. The Institute also organizes two periodic conferences: "Turbulence, Atmospheric and Climate Dynamics — In Memory of Academician A.M. Obukhov" and "Climate Change: Causes, Risks, Consequences, and Issues of Adaptation and Regulation." The A.M. Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences actively participates in fundamental research programs and carries out applied research projects under contracts with Russian clients, including major commercial and state-owned corporations (Roscosmos, RusHydro, ALROSA, Norilsk Nickel, and others). The institute's staff are engaged in research supported by grant programs: in 2026, the Institute is carrying out 14 grants from the Russian Science Foundation, three of which are international.

There is a long history of bi-lateral cooperation between two Institutes of Atmospheric Physics of the Chinese and Russian Academy of Sciences (IAP CAS and IAP RAS) that began in 1991 with a visit of, at that time, the Director of IAP RAS, Academician G.S. Golitsyn to Beijing. Intense research collaboration has been established in the area of atmospheric pollution based on spectrometric measurements of atmospheric constituents and models of pollution transport. This cooperation resulted in the establishment of a joint Chinese-Russian Laboratory in 2007. Since then, scientific delegations from IAP CAS and IAP RAS have been exchanging annual visits to Russia and China and organizing bi-lateral conferences.

Nowadays, the problem of the ongoing climate change has urged stronger cooperation between China and Russia in the area of climate prediction and climate change impacts. In the recent years, several joint bi-lateral scientific projects have been successfully conducted. In 2025, so-called megagrant project started in the IAP RAS supported by the Russian Science Foundation. Such a projects aim to attract prominent foreign scientists to lead research on prioritized technological areas in the Russian institutes and universities. The project "Climate and weather extremes, impacts, and risks under the rapid Arctic climate change" involves more than 30 IAP RAS researches and is led by Prof. Lin Wang from IAP CAS.

IAP and the Russian Academy of Sciences are the founding institutions of the journal "Izvestiya RAN. Physics of the Atmosphere and Ocean," whose editors-in-chief over the years have included Academicians A. M. Obukhov, G. S. Golitsyn, and I. I. Mokhov, and who is currently Academician V. A. Semenov. The first issue of the journal (then titled "Proceedings of the Academy of Sciences of the USSR. Physics of the Atmosphere and Ocean") was published in 1965; since then, 61 volumes have been published, and the journal has become the country's leading and internationally recognized publication in the field of atmospheric and climate physics. In 2025, a special issue of the journal was published, dedicated to the sixtieth anniversary of the publication of its first issue and the ninetieth birthday of its long-time editor-in-chief, G.S. Golitsyn.

The institute's staff are actively involved in expert work, serving as members of expert councils and as experts for the Russian Academy of Sciences and the Russian Science Foundation, as well as members of international commissions on climate, dynamic meteorology, atmospheric ozone, polar meteorology, Antarctic research, and other fields; they also participate in Russian and international projects and symposia.

Today, the A.M. Obukhov Institute is a unique scientific center where fundamental science is inextricably linked to solving practical problems of national importance. By preserving and building upon the traditions established by its founders, the institute continues to remain at the forefront of global atmospheric and climate science. Its high standing in the international scientific community, active involvement in training young specialists, and close collaboration with academic and educational institutions serve as the foundation for new discoveries and developments necessary for understanding and predicting changes in the environment. With its many years of experience and a new generation of researchers, the institute looks confidently to the future, continuing to make an invaluable contribution to the study of our planet.



DEPARTMENT OF CLIMATE PROCESSES RESEARCH

- LABORATORY OF CLIMATE THEORY
- LABORATORY OF UPPER ATMOSPHERE PHYSICS
- LABORATORY OF MATHEMATICAL ECOLOGY
- LABORATORY OF ATMOSPHERIC TRANSPORT MODELING
- GREENHOUSE GASES LABORATORY
- CLIMATE PREDICTABILITY LABORATORY

LABORATORY OF CLIMATE THEORY (LCT)

Head of Laboratory:
Doctor of Sciences A.V. Eliseev

History of the laboratory

The history of the laboratory dates back to 1975, when the Laboratory of Planetary Atmospheric Energy (LPAE) was established as part of the Theoretical Department. Its founder was the distinguished Soviet and Russian geophysicist, Academician G.S. Golitsyn. Already in its early years, the team began studying the fundamental laws governing atmospheric circulation not only on Earth but also on other planets in the Solar System, which laid the foundation for a systematic approach to analyzing climate as a unified mechanism. In 1981, due to the expansion of its research scope and a shift in focus toward Earth's climate, the laboratory was renamed the Laboratory of Climate Theory (LCT). In 1997, I.I. Mokhov, a corresponding member of the Russian Academy of Sciences, took over as head of the laboratory, and the research reached a new level, encompassing issues of global and regional climatology, monitoring of natural hazards, and climate predictability. Since 2002, the CLT has been part of the Department of Climate Processes Research (DCPR). Since 2025, the laboratory has been headed by A.V. Eliseev, Doctor of Physical and Mathematical Sciences and Professor of the Russian Academy of Sciences.

Main areas of activity

- Research in Climate Theory.
- Диагностика и моделирование глобальных и региональных климатических процессов и изменений.
- Research on climate predictability.
- Assessments of the impacts of climate change.
- Research related to climate change adaptation and mitigation.

Key results

Over the years, the Climate Theory Laboratory (formerly LEPA) has made a fundamental contribution to our understanding of how the Earth's climate system is structured and functions. It conducts detailed analyses of the causes of observed climate change. In particular, using Granger's statistical causality method, it has been convincingly demonstrated that over the past 150 years, variations in global near-surface temperature have been determined by a complex set of factors. These include fluctuations in atmospheric carbon dioxide (CO₂) concentrations, changes in the solar constant, and volcanic activity.

However, the key finding was the demonstration that the long-term trend of rising global temperatures observed in recent decades can be explained only by taking into account the anthropogenic factor—namely, the increase in the concentration of greenhouse gases, primarily CO₂.

The laboratory's flagship project is the Earth Climate System Model of Intermediate Complexity—MZS IAP RAS—which it has developed and continues to refine. This model is unique in its architecture: it includes all the main components of the climate system—the atmosphere, the ocean, the active land surface layer, as well as biogeochemical cycles (carbon, methane), and components describing atmospheric electricity and atmospheric chemistry. The main feature of the MZS is the parameterization of synoptic variability (vortices) in the atmosphere and ocean. This approach allows calculations to be accelerated by two orders of magnitude compared to traditional general circulation models, while maintaining realistic climate reproduction. The model has been successfully verified using instrumental measurements and paleoclimate reconstructions, making it a powerful tool for analyzing the system's response to external forcings on timescales ranging from decades to millennia and beyond.

Key results obtained using the MZS model developed by the IAP RAS:

A Comparison of Modern and Ancient Climates: Model experiments have shown that, although the modern global climate is warmer than that of the mid-Holocene (the so-called climatic optimum, about 6,000 years ago), regional characteristics can vary significantly. In some regions, current temperatures have not yet reached the peak warming levels characteristic of that period. This underscores the importance of taking regional specifics into account when analyzing climate change.

Cryolithozone Hysteresis: For the first time, a model was used to study in detail the hysteresis (lag) effect in the response of near-surface permafrost extent to global temperature change. It was found that restoring permafrost extent during climate cooling requires a much more significant temperature reduction than that at which it degraded during warming. This indicates the irreversibility of permafrost loss under the current warming scenario.

Changing the terrestrial carbon balance: Modeling has revealed the risk of terrestrial ecosystems (soils and vegetation) losing their ability to absorb CO₂ from the atmosphere as current warming continues.

The transition of ecosystems from a carbon sink to a carbon source could significantly enhance the greenhouse effect and create a positive feedback loop, further accelerating warming.

Dynamics of wetland ecosystems and methane: It has been shown that climate warming leads to increased methane (CH₄) emissions from wetland ecosystems. This leads to a significant increase in methane accumulation in the atmosphere. Calculations show that the effect of this additional methane on subsequent temperature changes (feedback) is weak. In other words, the feedback between climate and the methane cycle becomes virtually one-sided: climate influences methane emissions, but rising methane concentrations weakly modify climate itself against the backdrop of the powerful influence of CO₂.

Paleodata analysis and anthropogenic factors: The model was used to explain the phase lag between global temperature and CO₂ concentration, as observed in paleoreconstructions (for example, in ice age cycles, temperature changes first, followed by a delay in CO₂ concentration). It was demonstrated that this paleoclimatic mechanism is consistent with modern understanding of climate change. On the contrary, it highlights the uniqueness of the current situation: the rapid and abrupt change in CO₂ observed during the industrial period is the cause, not the consequence, of temperature change, confirming the decisive anthropogenic influence. A separate area of the laboratory's work is the analysis of hazardous convective weather phenomena. The laboratory's staff has created unique, unparalleled databases:

- Tornadoes in Northern Eurasia.
- Heavy rainfall and large hail in Russia.
- Squalls and windthrows in forested areas of Russia.

An analysis of these data revealed a general intensification of hazardous convective phenomena: the number of moderate events is decreasing, while the number and intensity of particularly strong events (destructive tornadoes, extreme downpours) is increasing. A statistically significant increase in the height of convective clouds and an increase in the proportion of convective clouds in total cloud cover were recorded. Furthermore, a change in precipitation structure was detected over Northern Eurasia: the contribution of intense convective precipitation (downpours) is increasing, while the proportion of light and moderate continuous precipitation, conversely, is decreasing.

This has serious implications for water balance, agriculture, and infrastructure, increasing the risk of floods and droughts.

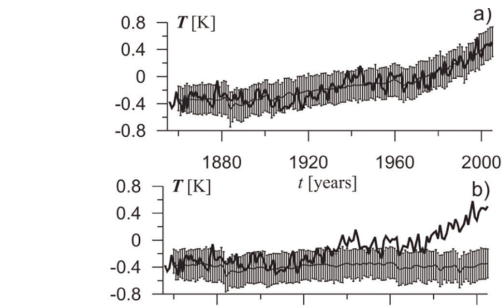


Fig. 1. Changes in global temperature in 100 realizations of a statistical model based on Granger causality, taking into account all factors of climate variability (shaded area) in comparison with HadCRUT3 data (black line) (top) and without taking into account the effect of changes in the concentration of CO₂ in the atmosphere (bottom).

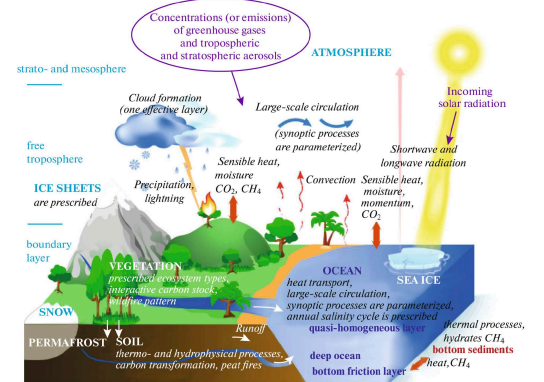


Fig. 2. Scheme of the IAP RAS MZS model.

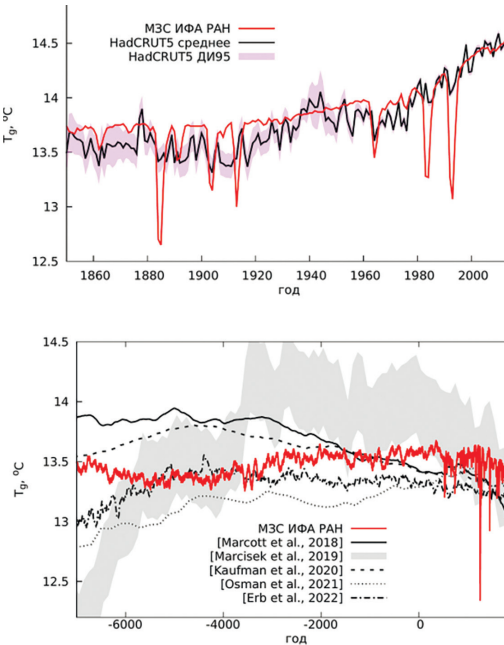


Fig. 3. Average global surface temperature based on calculations with the IAP RAS MZS in comparison with HadCRUT5 data (top) and paleoreconstructions for the Holocene (bottom).

LABORATORY OF MATHEMATICAL ECOLOGY (LME)

Head of the Laboratory:
Doctor of Sciences A.S. Ginzburg

History of the laboratory

The Laboratory of Mathematical Ecology (LME) was established in 1976 at the Computing Center of the USSR Academy of Sciences on the initiative of Academician N.N. Moiseev. Its founder and first director was Yu.M. Svirezhev, under whose leadership the foundations of mathematical modeling in ecology were laid, general equations of population dynamics and the theory of community stability were developed. In 1990, by decision of Academicians A.A. Dorodnitsyn and G.S. Golitsyn, the laboratory became part of the Institute of Atmospheric Physics. In 1992, Yu.M. Svirezhev headed the Department of Systems Analysis at the Potsdam Institute for Climate Change Research (Germany), and K.V. Chevelev became the head of the LME. From 1994 to 2002, L.L. Golubyatnikov, and since 2002 the Laboratory has been headed by A.S. Ginzburg.

Main areas of activity

The LME's primary objectives are to develop mathematical methods for describing and predicting the dynamics of natural ecosystems and studying the climate of megacities. Work is conducted in two key areas: "Natural Ecosystems: Observations and Modeling" and "Climate and Ecology of Megacities." The first area emphasizes modeling biological cycles, population dynamics, and greenhouse gas fluxes, while the second focuses on analyzing urban pollution, heat balance, and adaptation to climate change. The laboratory combines theoretical developments with experimental measurements and actively participates in the preparation of scientific and methodological materials for government agencies and the general public.

Key results

In the 1980s, the Laboratory's staff assessed the long-term climatic and ecological consequences of a hypothetical nuclear conflict, and in the first quarter of the 21st century, they developed statistical models of gas and aerosol pollution in urban air and studied the climate and ecology of large cities.

General equations for the dynamics of evolving populations and a theory of the stability of biological communities were developed. A key result was the "matrix flower" diagram, which summarizes the logical relationships between

various stability concepts (Lyapunov, dichotomous, sign stability, etc.) taking into account the signs of the diagonal elements of the species interaction matrix. This approach is fundamental for analyzing the stability of multispecies communities and allows for the classification of types of ecosystem dynamic behavior.

A new type of Markov model has been created to describe vegetation succession under the influence of climate change. A model for estimating carbon flux in natural ecosystems has been developed, allowing for the prediction of changes in annual carbon sequestration. Specifically, using the LME bioclimatic productivity model and the MPI-ESM1 climate model, it was shown that by the end of the 21st century, carbon dioxide uptake by vegetation in northern Russian ecosystems could increase by 6–45% compared to the end of the 20th century. A nonlinear model of the coupled turnover of organic matter and nitrogen in a wetland ecosystem (COM-BOLA) was constructed and calibrated. The model is based on the extremal principle of maximizing work to bring the system into thermodynamic equilibrium with the environment. This model was used to estimate the current carbon stocks in northern-latitude bogs (547 ± 74 billion tons) and their potential capacity (875 ± 125 billion tons), indicating the potential for further atmospheric removal of up to 1200 ± 730 billion tons of CO_2 . These estimates are important for understanding the role of bogs in the global carbon budget and for climate forecasts. Measurements of methane fluxes in tundra ecosystem microlandscapes in the southern tundra region of Western Siberia and at taiga lakes in Paanajärvi National Park (Karelia) showed that dry tundra valleys act as a sink for atmospheric methane during the warm season. This discovery corrects our understanding of the methane balance at high latitudes.

A practical approach to constructing matrix models based on the life cycle stages of organisms has been developed. Calibrated models allow us to obtain objective quantitative characteristics of populations, including measures of their viability under random variations in key environmental factors. These methods have been successfully applied to the analysis of alpine plant dynamics in the Northwest Caucasus and are reflected in the textbook "Matrix Models of Biological Populations: A Practical Course" (2024).

A detailed analysis of the abnormally hot summer of 2010 in Moscow was conducted. The average daily temperature exceeded 25°C , and smoke from wildfires led to a 1.5-fold increase in mortality.

The LME estimate of the maximum possible temperature under a stable anticyclone was close to the observed values, confirming the adequacy of the developed models and providing a better understanding of the mechanisms underlying heatwave formation.

The oxygen content in Moscow's surface air was studied using data from three automatic stations for 2017–2021. Clear seasonal and diurnal variations were identified, with the minimum concentration occurring in the early morning hours of summer. These data are important for understanding the self-purifying capacity of the urban atmosphere, the influence of green spaces, and anthropogenic sources. Maps of anthropogenic heat fluxes have been constructed for the world's largest cities (Moscow, New York, London, Beijing, St. Petersburg, and Novosibirsk), demonstrating that urban agglomerations shape their own climates through heat emission from industry, transport, and buildings. An analysis of trends in surface and physiologically effective temperatures revealed that the combination of positive temperature and wind speed trends in the southern regions of European Russia leads to a decrease in the number of days with thermal comfort.

Based on this research, the laboratory is participating in the development of criteria for preventive adaptation to climate change, including assessing the impact of heat waves on the stability of energy systems. Scientific and methodological materials have been prepared: A.S. Ginzburg edited the manual "How to Talk About Climate? Recommendations and Guidelines for Science Journalists and Communicators" (GEOS, 2021), as well as the Russian Ecological Society's report "Adaptation to Climate Change: Risks and Opportunities" (2025). These publications contribute to the dissemination of scientific knowledge and the formation of evidence-based climate policy.

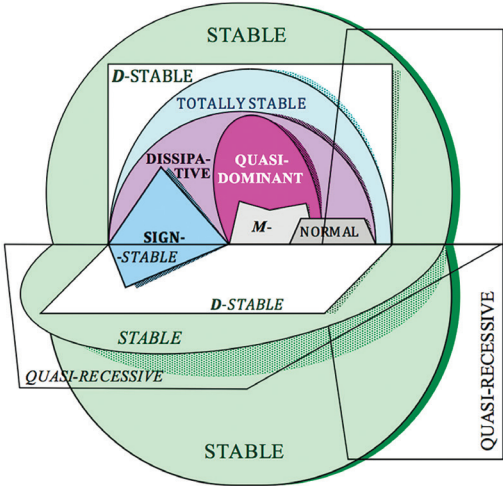


Fig. 1. The "matrix flower" diagram reflects theoretical achievements in the analysis of the stability of ecological communities and is the hallmark of the laboratory.

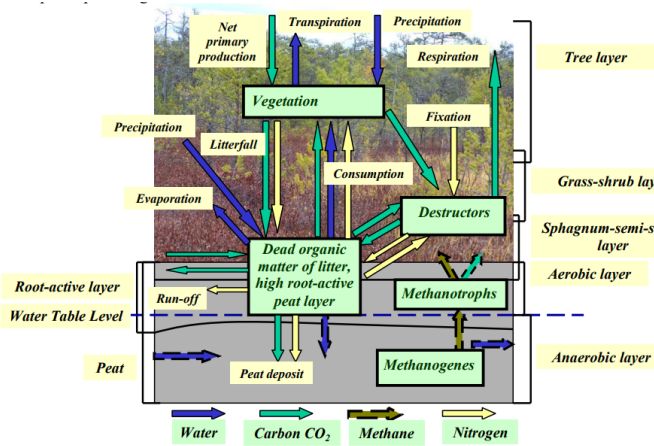


Fig. 2. Schematic diagram of the COMBOLA model (or graph of carbon stock assessment in wetlands). Contribution to the modeling of biogeochemical cycles and climate-forming processes.

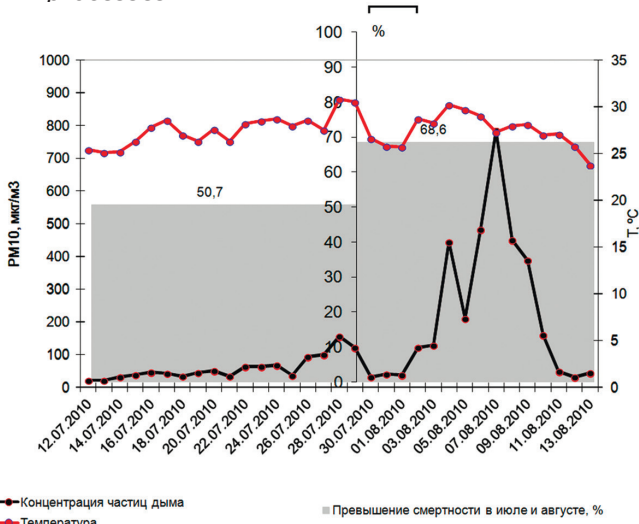


Fig. 3. The impact of temperature and fires in 2010 on mortality.

LABORATORY OF UPPER ATMOSPHERIC PHYSICS (LUAP)

Head of the laboratory:
Doctor of Sciences N.N. Pertsev

History of the laboratory

The Department (later Laboratory) of Upper Atmosphere Physics was established jointly with the Institute of Atmospheric Physics in 1956. From the very beginning, the Department's work focused on research in the field of aeronomy — a branch of atmospheric physics that studies photochemical and dynamic processes in the neutral and ionized layers of the atmosphere using various methods. Throughout the years of the Department's (Laboratory's) existence, the main research method was spectrophotometric measurements of the upper atmosphere's own nighttime radiation using high-aperture spectrographic equipment developed at the S.I. Vavilov State Optical Institute in the 1950s on the initiative of the first head of the Department, V.I. Krasovsky. Since the International Geophysical Year (1957–1958), the Department has gained worldwide recognition. During this period and subsequent years, new types of radiation (hydrogen, helium, continuum) were discovered for the first time in the world, their theoretical interpretation was given, and emissions of hydroxyl, molecular oxygen, sodium, and oxygen atoms were studied in detail. Based on the systematization of the accumulated data, models of variations in these emissions were developed, reflecting a wide range of variations, including those due to solar activity and long-term trends. The systematization of the accumulated data was embodied in the fundamental monograph by N.N. Shefov, A.I. Semenov, and V.Yu. Khomich, "Radiation of the Upper Atmosphere – an Indicator of Its Structure and Dynamics," published in Russian and English and receiving international recognition.

Main areas of activity

- Experimental and modeling studies of aeronomy.
- Atmospheric waves and related effects in the upper atmosphere.
- Climate of the middle and upper atmosphere. Solar-terrestrial and intra-atmospheric relationships.

Key results

Research into internal gravity waves (IGWs) and their influence on the upper atmosphere has played a key role in the laboratory's history. Under the direction of V.I. Krasovsky,

it was first established in the 1960s and 1970s that IGWs are generated not only by large-scale meteorological processes in the troposphere but also by the interaction of wind currents with irregularities in the Earth's topography. Propagating upward, these waves transfer energy and momentum, causing significant variations in temperature, density, and composition at altitudes in the mesosphere and lower thermosphere. It was shown that IGWs modulate the intensity of emissions of hydroxyl, atomic oxygen, and other components, enabling the use of ground-based spectrophotometry for diagnosing wave processes. This work not only created a new scientific field — the physics of internal gravity waves in the upper atmosphere — but was also recognized as Discovery No. 209 on December 21, 1978, with a priority date of January 10, 1972.

At the Zvenigorod Scientific Station of the Institute of Atmospheric Physics, a unique—the longest in the world—series of temperature observations in the meso-pause region (at an altitude of approximately 87 km) has been accumulated, obtained from the emission of hydroxyl (OH*). Systematic measurements, begun in the 1950s and continuing to the present, span more than 70 years. This allowed the first detection of long-term trends in upper atmospheric temperature and their relationship to anthropogenic changes. The analysis showed that until the mid-1970s, the cooling was -0.53 ± 0.09 K/yr, and then, from the mid-1980s, slowed to -0.11 ± 0.02 K/yr. This trend reversal coincides with a period of increasing greenhouse gas concentrations and ozone layer changes, confirming the high sensitivity of the upper atmosphere to climate impacts. These data became the basis for verifying global middle-atmosphere models and are in demand by international climate change assessment projects.

Further analysis of hydroxyl emitting temperature variations for 2000–2024 revealed a statistically significant positive trend in wave activity in various frequency ranges. Periods from 0.7 to 8.2 hours, corresponding to internal gravity waves of different wavelengths, were studied. The increase in the standard deviations (SD) of temperature indicates an increase in the transfer of energy from the troposphere to the upper layers. This effect can lead to intensified turbulent diffusion, changes in the vertical and horizontal transport of gas components (including ozone and water vapor), and modifications of the wind regime in the mesosphere. Of particular significance is the fact that the obtained trends

differ for different wave periods, indicating a complex structure of sources and propagation conditions.

In recent years, a fundamentally new result has been obtained: an inverse dependence of the response of IGW activity to solar activity on wave period has been discovered. For a quantitative assessment, the Lyman-alpha flux was used as an indicator of solar ultraviolet variations. It turned out that the greatest sensitivity is characteristic of short-period waves (less than 2 hours), while long-period waves demonstrate a weak or statistically insignificant relationship. This discovery clarifies existing concepts, in which the analysis was conducted for integrated intensity and yielded ambiguous results. It is now becoming clear that solar activity influences not only the thermal regime but also wave dynamics, and selectively in scale. This is important for predicting the state of the upper atmosphere under conditions of changing solar activity and for understanding the mechanisms of solar-terrestrial relationships.

Since 2000, systematic observations of noctilucent (mesospheric) clouds — the highest cloud layer on Earth, forming at altitudes of approximately 82–85 km — have been conducted in the Moscow region. These clouds serve as a natural indicator of water vapor content and temperature in the mesopause, as well as wave processes at these altitudes. Long-term statistics collected by the laboratory have revealed a clear relationship between the frequency of cloud occurrence and brightness with the 11-year cycle of solar activity and even with the 27-day rotational variations of the Sun. Furthermore, stationary longitudinal variations in cloud cover along the Arctic and subarctic parallels were detected, indicating the influence of planetary waves and orography. Observations of noctilucent clouds, including those conducted using automatic cameras in Krasnogorsk and other locations, are integrated into the international SAFSO network.

Currently, the laboratory's experimental facilities include the Zvenigorod and Kislovodsk research stations, equipped with modern spectrographs. In particular, the SP-50 spectrograph for the near-infrared range (up to 1.5 μm) enables the recording of high-quality hydroxyl band spectra with a time resolution sufficient for studying wave variations. An example of a record from August 1, 2018, demonstrates a clear separation of rotational lines, from which the temperature of the emitting layer is reconstructed with an accuracy of approximately 1–2 K. These data are regularly submitted to the international NDMC (Network for the Detection of Mesospheric Change) database, where they are used

for global mesopause temperature monitoring and satellite measurement validation. Participation in the NDMC and SAFSO confirms the laboratory's high international status and facilitates the integration of Russian results into global science.

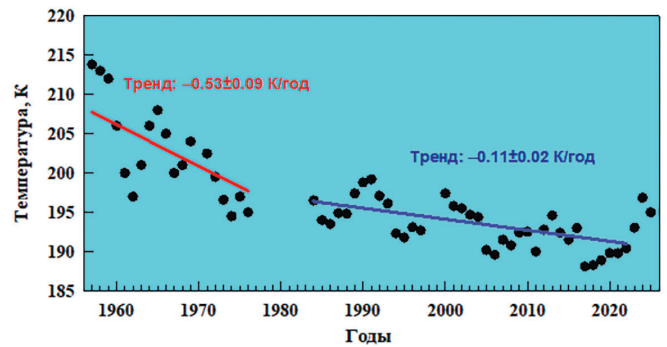


Fig. 1. Long-term behavior of the average annual temperature near the mesopause (about 87 km) based on observations of hydroxyl radiation at the Zvenigorod scientific station.

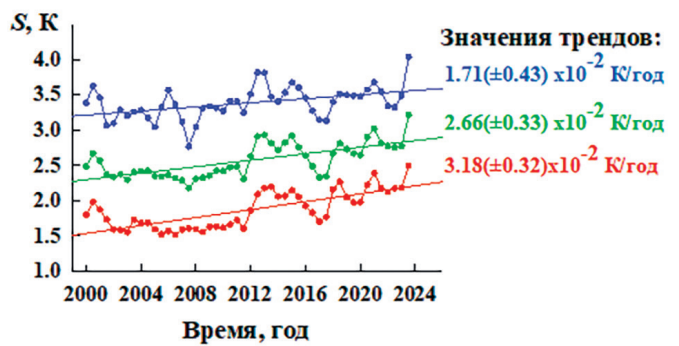


Fig. 2. Long-term variations in the annual mean standard deviation (S) of the OH^* temperature, corresponding to three ranges of wave periods: 0.7–2.0 h (red), 1.4–4.1 h (green), 2.7–8.2 h (blue). On the right are the trend values.



Fig. 3. A field of noctilucent clouds (lighter) recorded by a camera in Krasnogorsk (Moscow region) on July 9, 2023 at 02:04 Moscow time.

LABORATORY OF ATMOSPHERIC TRANSPORT MODELING (LATM)

Head of the Laboratory:
Corresponding Member of the RAS
A.A. Makosko

History of the laboratory

In November 1996, the Laboratory of Modeling of Orographic Transport Processes and Effects was established at the IAP, which was renamed the Laboratory of Atmospheric Transport Modeling in April 2002. The founder and first head of the laboratory was Doctor I.G. Granberg; since 2010, the head of the laboratory has been Corresponding Member of the RAS A.A. Makosko.

Main areas of activity

- Study of aerosol emission and transport processes
- Impact of aerosols on the environment and humans
- Study of atmospheric currents under the influence of gravity field inhomogeneities
- Study of certain vortex flows

Key results

Long-term comprehensive studies of the microphysical parameters and chemical composition of aerosols have been continued:

- semi-arid zones in the semi-desert regions of Kalmykia and the study of various processes of aerosol formation and removal into the atmosphere (jointly with staff of the Laboratory of Geophysical Hydrodynamics and the Radioacoustic Laboratory);
- the steppe zone at the Tsimlyansk scientific station of the IAP RAS (jointly with the Laboratory of Geophysical Hydrodynamics and the Radioacoustic Laboratory);
- at the High-Mountain Scientific Station (Shadzhattmaz) and at the station in Kislovodsk (jointly with staff of the Sector of Remote Sensing of Atmospheric Composition).

In September 2018, together with staff from the Laboratory of Geophysical Hydrodynamics, regular aerosol studies were initiated and continue at the background environmental monitoring station of the T.I. Vyazemsky Karadag Scientific Station. In 2020 and 2021, similar aerosol measurements were simultaneously conducted at the Black Sea Hydrophysical Test Site of the Moscow Hydrophysical Institute of the Russian Academy of Sciences in the village of Katsiveli. Atmospheric pollution trends in the Caucasian Mineral Waters region due to long-range transport from 1980 to 2050 were investigated.

Taking into account the SSP2-4.5 and SSP5-8.5 scenarios, the region's health potential is expected to be maintained until 2050. Concentrations of CO, NO₂, and NH₃ in the air of Moscow in 2024 due to vehicle emissions were determined using the WRF-Chem model. The concentrations of these substances did not exceed the MAC.

The dynamics of long-range air pollution in the regions up to 2050 were studied, taking into account climate change.

The dynamics of the risk to plants (lichens, conifers, deciduous trees, and herbaceous plants) in the continental Arctic zone of the Russian Federation from SO₂ atmospheric pollution by potential sources from 1980 to 2050 was studied, taking into account the RCP4.5 and RCP8.5 climate scenarios. The results are relevant for strategic planning for the development of the Arctic zone of the Russian Federation. In collaboration with the Hydrometeorological Center of Russia, a method for estimating the onset of birch pollen in the European part of the Russian Federation was developed and tested. This method is based on a phenological model for calculating plant development stages, using air temperature forecasts based on the model of the Institute of Computational Mathematics of the RAS. The method has been recommended for implementation by the Central Methodological Commission of Roshydromet.

A series of studies was conducted on trends in human health risks caused by long-range air pollution and changes in weather and climate comfort. The need for additional attention when planning adaptation measures to climate change in the southern and central regions of the European part of the RF, in most of Western Siberia, the Magadan Region, and Kamchatka was demonstrated.

In collaboration with the NPO Typhoon, a number of key results were obtained in the study of atmospheric currents under the influence of gravity field inhomogeneities (GFRI). Two physical mechanisms have been identified for the influence of the NST on atmospheric dynamics, resulting in horizontal velocity deviations of approximately 1 m/s:

(a) the non-ideality of the real atmosphere (the presence of significant heat exchange), which can lead to noticeable violations of the conditions of N.E. Kochin's well-known theorem: the emergence of uncompensated forces and currents in a density-stratified medium, the velocity of which is proportional to the product of the geoid deviation and the buoyancy frequency;

b) the presence of background currents in the atmosphere, which are also not provided for by the conditions of this theorem and can lead to disturbances in their velocity.

The possibility of generating internal gravity waves caused by the NSST is demonstrated and a mechanism for their generation is discovered, and the most important characteristics of these processes are calculated.

The presence of a mechanism for slow snow mass transport caused by the NSST in polar regions is demonstrated. The velocity of the resulting horizontal currents is low (on the order of 4–10⁻³ m/s). However, these effects can accumulate over years and become significant.

An analogy is demonstrated between disturbances caused by the NSST and thermal inhomogeneities of the underlying surface.

The curvature of isopycnals and isotherms caused by the NSST leads to disturbances in vertical heat fluxes in the near-surface layer of the atmosphere, reaching 1 W/m².

Relationships are established between the kinematic characteristics of the wind (maximum speed and acceleration) in a tropical cyclone and the vertical and horizontal components of the NSST along its trajectory.

The characteristics of certain vortex flows were investigated. The predictive properties of the helicity of the atmospheric velocity field were established. It was shown that the trend in the height of the 1000 hPa isobaric surface is proportional to the integral helicity of the geostrophic flow.

In collaboration with Lomonosov Moscow State University, Moscow Institute of Physics and Technology, and the Eastern Mediterranean University, a modeling of the observed phenomenon of a sharp change in the direction of tropical cyclones was conducted based on exact solutions of the hydrodynamic equations on a rotating sphere, describing the Hamiltonian dynamics of point eddy currents.

It was shown that the long-range interaction of a tropical cyclone (TC) with the continent can lead to its attraction by the continent, similar to the well-known observed phenomenon of attraction of a tornado vortex to a solid boundary. The Fujiwara effect, the convergence and merging of two shopping centers, was simulated.



Fig. 1. Dynamics of the unit standardized risk (in percent for the period under review) from SO2 atmospheric pollution for vegetation in the continental part of the Russian Arctic in 1980–2050, taking into account climate scenarios..

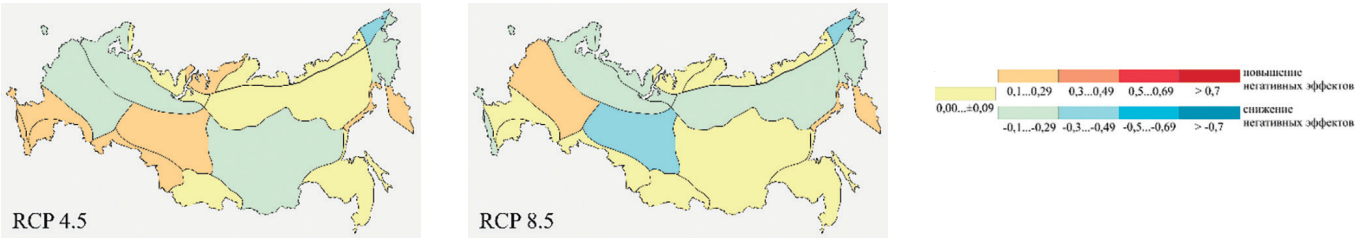


Fig. 2. Integrated assessments of trends in average annual health risks by climatic regions for the period 2020–2050, taking into account climate change scenarios RCP4.5, RCP8.5.

GREENHOUSE GASES LABORATORY (GGL)

Head of the laboratory:
PhD in Biology V.S. Kazantsev

History of the laboratory

The Greenhouse Gas Laboratory was established in 2022 as a youth laboratory within the framework of the national project "Science and Universities." Its team was formed from the research group of the Laboratory of Mathematical Ecology at the IAP.

Main areas of activity

- Monitoring greenhouse gas emissions from Russian Arctic ecosystems (mineral soils, bogs, thermokarst lakes, and khasyreys) and studying fundamental aspects of the carbon cycle in these ecosystems;
- Studying greenhouse gas emissions from the surface of hydroelectric power station reservoirs;
- Providing methodological assistance to research groups in studying greenhouse gas emissions from various natural ecosystems in the Russian Federation;
- Training specialists in studying greenhouse gas sources.

The laboratory combines field expeditions, instrumental measurements, and laboratory experiments to quantify methane and carbon dioxide fluxes, identify key factors controlling emissions, and develop recommendations for reducing anthropogenic impacts on the climate system.

Key results

In its short existence, the Greenhouse Gas Laboratory has completed a wide range of studies covering key regions of the permafrost zone and inland waters of Russia. Seasonal field campaigns were conducted at eight sites: the Yamal Peninsula (near the village of Tazovsky), the Norilsk industrial region, the Lena Delta (Samoilovsky Island, right bank of the Lena), the Krasnoyarsk and Tsimlyansk reservoirs, the Tarmansky bog in Western Siberia, and the peatlands of the Moscow region (the Zhuravlinaya Rodina Nature Reserve). The geographic scope of the work allows for comparison of the emission characteristics of various ecosystem types — from tundra to man-made and aquatic ecosystems.

Methane emission factors from 48 thermokarst lakes near the village of Tazovsky in Yamal were studied in detail. Contrary to popular belief,

ultra-small lakes (less than 0.1 km²) are not more powerful sources of CH₄ than small lakes (0.1–1.0 km²). The key factor was water surface area. The data are important for refining regional methane budgets in the thermokarst zone.

At the same sites, statistical correlations were established between specific methane fluxes (SMF) and environmental factors. During daylight hours, emissions are most strongly dependent on the thickness of the seasonally thawed layer ($r = 0.82$), the presence of marsh waters ($r = 0.75$), and fluctuations in their level ($r = 0.56$). In wetted microrelief elements (hollows, interpolygonal cracks), soil temperature dependence is added. Analysis of diurnal dynamics in a hollow revealed a high correlation between the SPM and air temperature ($r = 0.90$) and soil temperature at a depth of 5 cm ($r = 0.79$). This allows for the parameterization of emission models for tundra landscapes.

In the Norilsk industrial region, CH₄ and CO₂ fluxes were measured from tundra-bog complexes, communities on mineral soils, and lakes. A negative correlation was found between moisture content and methane emission, and a positive correlation with CO₂ emission. For ecosystems on mineral soils, a link was found between methane absorption and air temperature, which is important for understanding the response of permafrost landscapes to climate change. As part of a research project commissioned by En+ GROUP, measurements were conducted at the Krasnoyarsk Reservoir. In collaboration with the Institute of Hydrological Problems of the RAS and Moscow State University, the spatiotemporal variability of CH₄ content and its fluxes in the Tsimlyansk Reservoir was studied for the first time. Methane emissions depend significantly on the hydrological regime, water temperature, and organic matter content.

It was shown for the first time that areas of inter- and suprapermfrost water discharge in the permafrost zone (the Sullar, Ulakhan-Taryn, and Buluus springs on the right bank of the Lena River) emit significant quantities of greenhouse gases. In collaboration with the Permafrost Institute of the SB RAS and NEFU, it was established that the share of methane in emissions depends on the contribution of suprapermfrost waters. In springs with a predominance of these, CH₄ concentrations are higher due to the activity of methanogens in the active layer. This opens a new direction: the study of emissions from geological sources in the Arctic.

On Samoylovsky Island, anaerobic methane formation pathways were studied in incubation experiments with peat samples from the seasonally thawed layer. Using the inhibitor methyl fluoride, the contributions of acetoclastic and hydrogenotrophic methanogenesis were separated, and the temperature sensitivity of the process was determined in the range of 5–10°C (peak vegetation). In collaboration with the Russian Society for the Conservation and Study of Birds, observations are being conducted at abandoned peat extraction sites in the Zhuravlinaya Rodina Nature Reserve (Moscow Region). The goal is to assess current emissions and develop restoration technologies for disturbed peatlands. Preliminary results show that drained peatlands continue to emit CO₂ and CH₄, with emissions from residual streams comparable to those of natural bogs. A dataset of over 850 methane flux values from taiga and tundra bogs in Western Siberia, including 670 measurements in 2023–2024, was analyzed. Using 3D visualization, multivariate relationships between emissions and temperature, bog water level, seasonally thawed layer thickness, and organic carbon content were identified. This provides the basis for regional-scale empirical models and territorial extrapolation using satellite data. The data obtained are used in the preparation of national greenhouse gas reports and in international projects assessing the carbon cycle in northern regions.



Fig. 1. Expedition areas with the participation of LPG employees on the map of the Russian Federation: 1 - peat extraction in the "Crane Homeland" nature reserve in the vicinity of the town of Taldom; 2 - southern tundra in the vicinity of the village of Tazovsky; 3 - Krasnoyarsk Reservoir; 4 - Tsimlyansk Reservoir; 5 - Tarmansky marshland; 6 - Norilsk industrial region; 7 - Samoylovsky Island; 8 - springs on the right bank of the Lena.

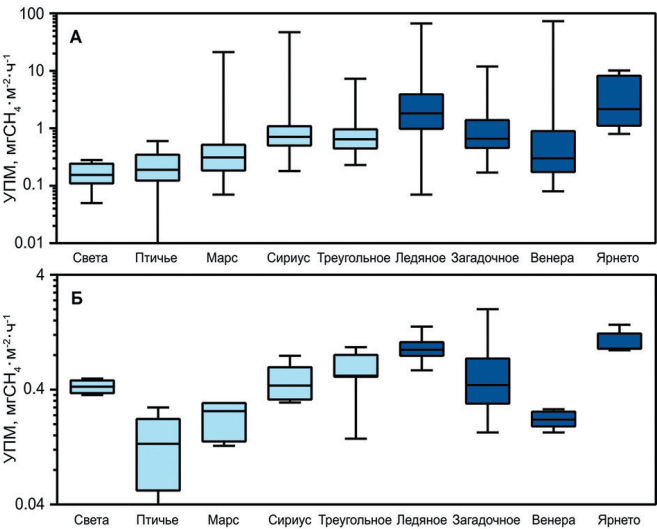


Fig. 2. Semi-logarithmic boxplots for the UMPs: (A) measured using the floating chamber method (bubble and diffusion emission components); (B) calculated using the two-layer model (diffusion emission component). The lakes are arranged in order of increasing area. Small (>0.1 km²) and ultra-small (<0.1 km²) lakes are shown in blue and light blue, respectively.

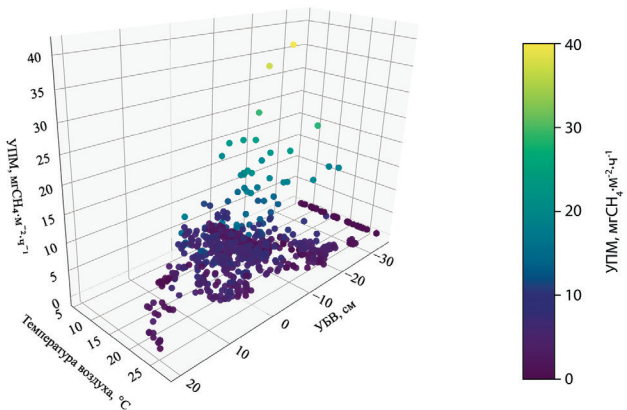


Fig. 3. Graphic 3D visualization of the dependence of the values of the Specific methane flow on key environmental factors.

CLIMATE PREDICTABILITY LABORATORY (CPL)

Head of the laboratory:
PhD A.V. Chernokulsky

History of the laboratory

The Climate Predictability Laboratory was established at the IAP as part of the Megagrant program in 2021 in collaboration with the P.P. Shirshov Institute of Oceanology of the RAS, the G.I. Marchuk Institute of Numerical Mathematics of the RAS, Lomonosov Moscow State University, and the Hydrometeorological Center of Russia. From 2021 to 2023, the laboratory was headed by visiting scientist Dr. N. Keenlyside. From 2023 to 2025, the laboratory was headed by RAS Academician I.I. Mokhov. Since 2025, the duties of the laboratory have been performed by PhD A.V. Chernokulsky..

Main areas of activity

- Quantitative assessment of the contribution of different climate system components to climate variability on time scales from weeks to centuries;
- Identification of sources of climate predictability in Northern Eurasia on different time scales based on observational data and models;
- Improving the quality and reliability of climate forecasts for Northern Eurasia on different time scales (from weeks to centuries);
- Improving the ability to forecast extreme hydrometeorological events and associated risks in Northern Eurasia on subseasonal time scales and creating more accurate scenarios for changes in the frequency and intensity of such events and risks in the coming decades;
- Quantitative assessment of climate risks in Russian regions.

Key results

A new reconstruction of gridded Arctic sea ice concentration (SIC) data for the period 1901–2019 was created. This reconstruction is based on relationships between the spatiotemporal structure of SIC variations and surface air temperature, sea surface temperature, and sea level pressure using empirical orthogonal function decomposition and a multiple principal component regression model. The new reconstruction shows a significant decrease in SIC from 1920 to 1940 in both summer and winter, coinciding with the early 20th-century warming in the Arctic.

Ice concentration data from the new reconstruction are available on the IAP website. The mechanisms of early 20th-century warming in the Arctic are examined. This warming was comparable in magnitude to modern warming, but occurred during a period when the increase in greenhouse gases in the atmosphere was significantly smaller than over the past 40 years. It was most likely caused by the combined effects of long-term natural climate variations, including the contribution of natural radiative forcing associated with decreased volcanic activity and solar fluctuations, as well as increased greenhouse gas concentrations in the atmosphere due to anthropogenic emissions. The possibility of increasing the predictability of temperature anomalies in Northern Eurasia by considering their relationship with large-scale climate variability is explored. It was found that the highest frequency of extremely high temperatures and drought conditions in the spring-summer months over European Russia occurred in years beginning in the El Niño phase and transitioning to the La Niña phase at the end of the year.

Using the clustering method, stable weather patterns for winter and summer were identified over Northern Eurasia. Statistically significant long-term changes in the frequency of these patterns were revealed. Closed sequences of significantly frequent transitions between regimes were discovered, indicating the presence of preferred paths of system evolution rather than a completely random nature of regime changes. A link between the frequency of weather regimes and large-scale climate variability was revealed.

Various approaches to climate risk assessment and existing open questions in this area are explored. A heuristic approach to the relative assessment of climate risks and ranking of the constituent entities of the Russian Federation by risk level is proposed. Russian regions are prioritized based on the need to adapt to the risks considered.

In collaboration with staff from the Institute of Numerical Mathematics of the Russian Academy of Sciences and the Hydrometeorological Center of Russia, a version of the Earth system model for seasonal weather and climate forecasting was developed and implemented in the practical activities of Roshydromet. Assessments of the use of seasonal hydrodynamic forecasts for various target variables were obtained.

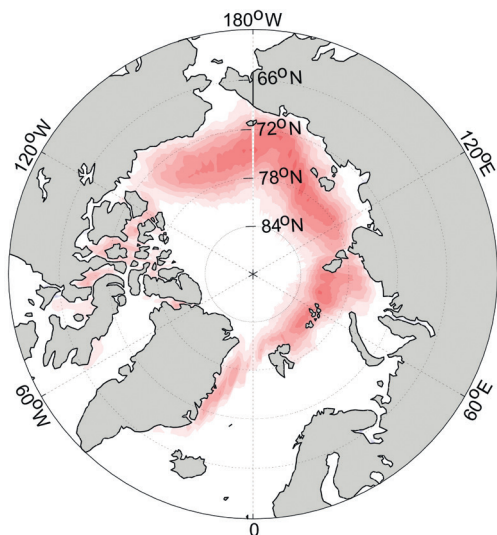
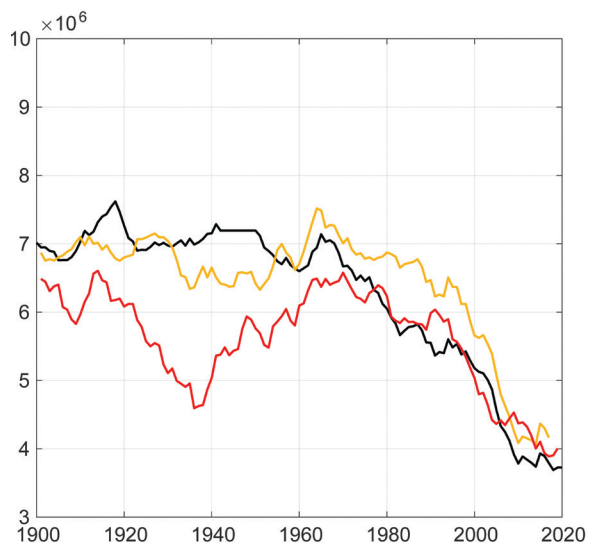
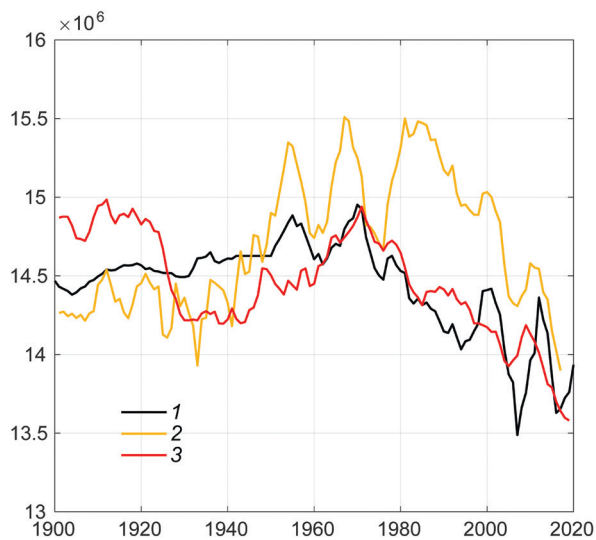
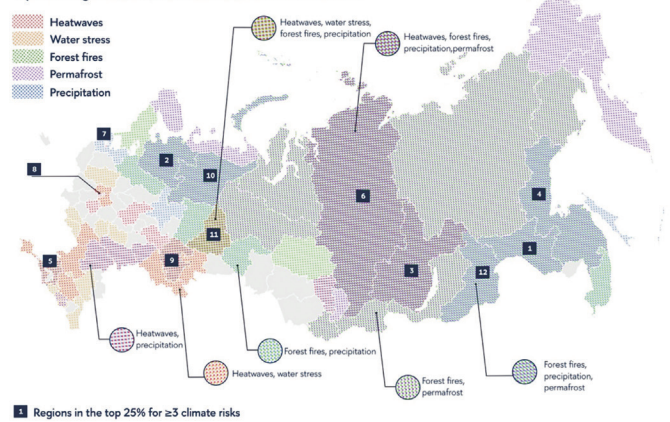


Fig. 1. Top: Arctic sea ice area (million km²) in March (left) and September (right) based on the new IAP RAS reconstruction (3, red curve), HadISST1.1 data (1, black curve), and SIBT1850 reconstruction data (2, yellow curve). Bottom: Arctic sea ice concentration trend (%/10 years) for the period 1915–1945 in September based on the new IAP RAS reconstruction.

Rating of regions by climate risks: summary map

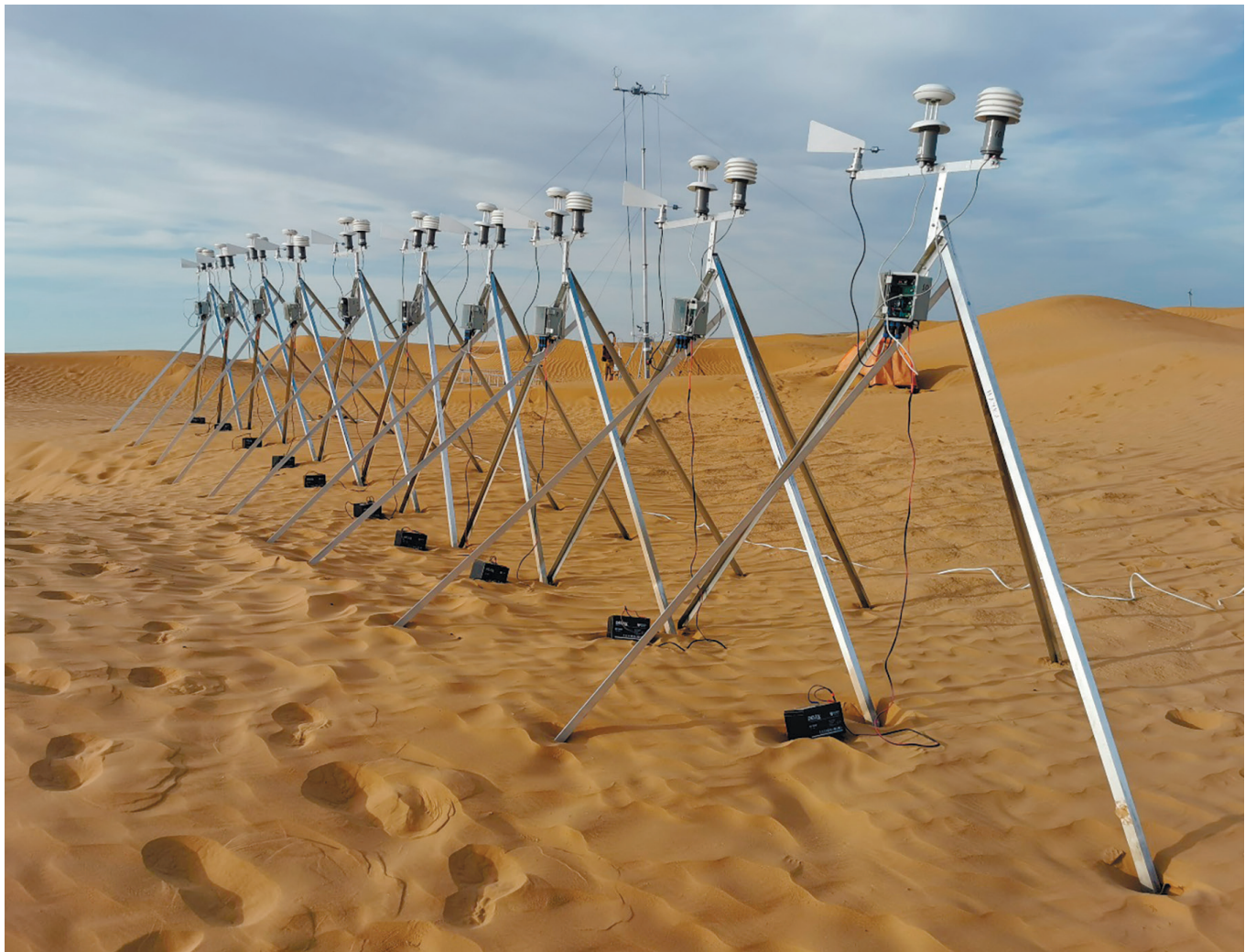
Top 25% regions for five climate risks, SSP1-2.6 scenario



Regions in the top 25% for ≥3 climate risks

Fig. 2. Regions of Russia with a high level of climate risks..





DEPARTMENT OF ATMOSPHERIC DYNAMICS

- LABORATORY OF GEOPHYSICAL
HYDRODYNAMICS
- RADIOACOUSTIC LABORATORY
- AIR-SEA INTERACTION
LABORATORY
- LABORATORY OF
TURBULENCE AND WAVE
PROPAGATION

LABORATORY OF GEOPHYSICAL HYDRODYNAMICS (LGH)

Head of the Laboratory:
Doctor of Sciences O.G. Chkhetiani

History of the laboratory

The history of the Laboratory of Geophysical Hydrodynamics (LGH) is inextricably linked with the development of fundamental concepts of atmospheric and oceanic dynamics. The laboratory was established in the 1970s on the basis of the Theoretical Department of the Institute of Atmospheric Physics, founded and directed by A.M. Obukhov. It was A.M. Obukhov, who stood at the origins of modern geophysical hydrodynamics, who established the traditions of deep theoretical analysis that defined the department's scientific identity for many years. Since then, theoretical research in geophysical hydrodynamics has been conducted in close collaboration with laboratory and field experiments. For nearly twenty years, the laboratory was headed by renowned hydrodynamicists: first F.V. Dolzhansky and then V.M. Ponomarev. Under their leadership, pioneering research was conducted in the fields of climate theory, eddy dynamics, and large-scale waves, and the foundations for unique laboratory facilities were laid. Since 2008, the laboratory has been headed by O.G. Chkhetiani, who continues modern research at the intersection of theory, numerical modeling, and physical experiments.

Main areas of activity

- development of the theory of hydrodynamic invariants (potential vortex and helicity), its application to the analysis and diagnosis of atmospheric processes of various scales;
- research on the dynamics of the climate system;
- low-mode models of atmospheric circulation;
- stochastization in nonlinear geophysical systems;
- structure formation and turbulence, problems of hydrodynamic stability;
 - development of Hamiltonian methods for describing vortex regimes and impurity transport;
- experimental studies of turbulent, vortex, and transport processes in the atmosphere;
- laboratory and numerical modeling in geophysical hydrodynamics;
- mathematical methods for analyzing geophysical data.

Key results

1. The laboratory conducted a series of studies devoted to the analysis of temperature frontal jets that generate specific turbulence due to the equatorial beta effect. The variability of the integral characteristics of jet streams (JS) and the planetary upper-air frontal zone over the past decades was studied in detail. Stable statistical relationships between JS dynamics, blocking processes, and El Niño-Southern Oscillation phenomena were identified, contributing to an understanding of the mechanisms of long-term climate forecasting.

2. An extensive series of theoretical papers was completed on the problems of baroclinic instability of tropospheric and periodic zonal currents. Taking into account Ekman friction, an analysis was conducted of the conditions for the emergence of nonlinear oscillation regimes and transitions to deterministic chaos. For the first time, problems of linear and nonlinear stability of surface quasi-geostrophic periodic flows are investigated. A new class of optimal disturbances is considered, which is important for both geophysical and astrophysical applications. Based on the obtained results, original mechanisms for the development of blockings — stationary anticyclones that determine weather anomalies in mid-latitudes — are proposed.

3. Using laboratory and numerical experiments on setups with annular rotating channels, the multi-mode equilibrium states of atmospheric circulation are investigated. Effects of a reverse energy cascade are experimentally detected: the generation of large-scale sub- and superrotational vortices, as well as the formation of jet streams from small-scale disturbances, are recorded. These results are important for understanding the mechanisms of spontaneous organization of large vortex structures in planetary atmospheres. 4. The team developed a theory of velocity field helicity — a fundamental hydrodynamic invariant. A wide range of problems in the dynamics and reproduction of helicity in turbulence and the atmospheric boundary layer (ABL) were considered. Methods for estimating helicity based on remote sensing and reanalysis data were developed.

To verify the theoretical models, comprehensive expeditions were organized and successfully conducted, during which in-situ measurements of turbulent vorticity and helicity were performed using a unique instrument—a circulometer—developed at the IAP RAS.

5. It was shown that the vertical helicity flux from the boundary layer to the free atmosphere can serve as an effective index of seasonal and interannual climate variability. A stable correlation was found between this parameter and summer blocking events in the Northern Hemisphere, as well as with the state of the sea ice cover in the Arctic. This opens up prospects for using helicity as a diagnostic feature in monitoring the climate system.

6. A series of experimental and theoretical studies were conducted, including scientific expeditions to the arid and subarid zones of southern Russia. The mechanisms of dust and aerosol transport and their relationship with mesoscale eddy structures in the surface layer were investigated. Physical mechanisms of thermoconvective dust aerosol transport, operating below the saltation threshold, were discovered, which is important for understanding dust emissions into the atmosphere under low-wind conditions. Universal particle size distribution functions were established, and the influence of electric fields and dune orientation relative to the wind on the removal rate was studied. A series of studies on the dynamics and statistics of dust devils ("devils") on Earth and Mars was completed.

7. Universal vertical distribution profiles of submicron aerosol were established for light wind conditions. A model for the development of submesoscale disturbances in the ABL responsible for the intensification of the removal and transport of aerosol particles was proposed. Based on the obtained experimental data, new parameterizations of turbulent momentum and heat fluxes were developed, including transfer coefficients over sea ice, as well as parameterization of the convective mechanism of submicron aerosol removal. The developed schemes have been adapted for use in global and regional climate models, as well as in weather forecast systems.

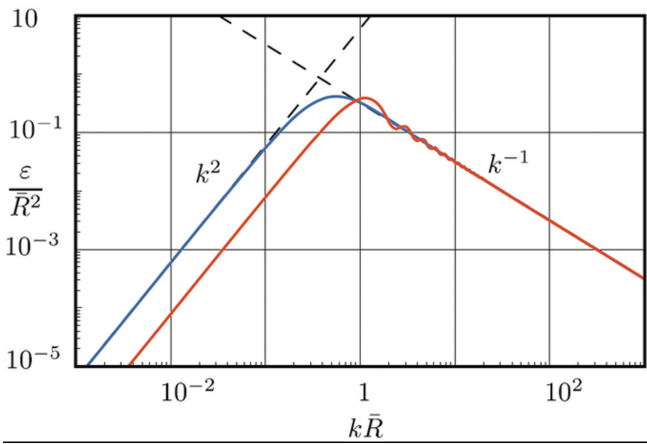


Fig. 1. Energy spectrum generated by turbulent temperature jets near the equator. The dotted line represents the power-law asymptotics. In the lower graph (red line), the equatorial beta effect is disabled.

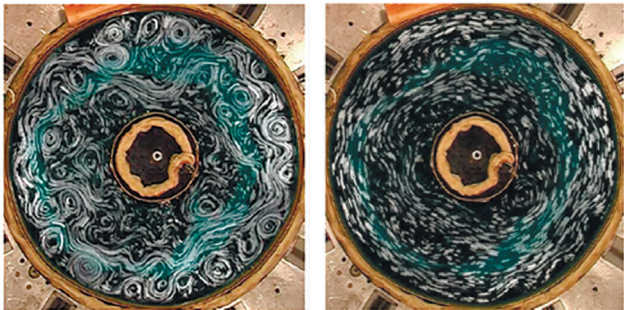


Fig. 2. Jets and vortices in a rotating channel.

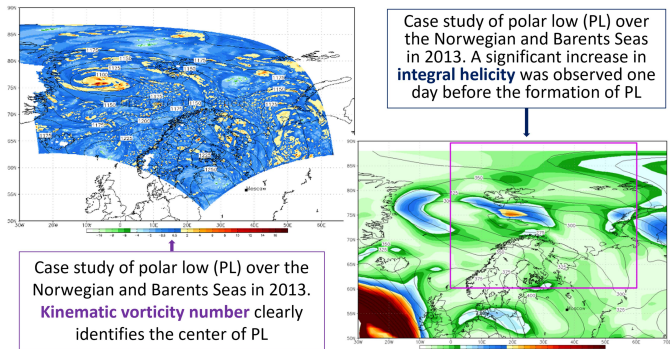


Fig. 3. Using helicity together with the kinematic vorticity number as a prognostic criterion and indicator of the development of extreme events..

RADIOACOUSTIC LABORATORY (RAL)

Head of the laboratory:
Doctor of Sciences S.N. Kulichkov

History of the laboratory

The Radioacoustics Laboratory (RAL) was one of the first divisions established at the Institute of Atmospheric Physics of the USSR Academy of Sciences, inheriting the scientific traditions of the Atmospheric Turbulence Department of the Geophysical Institute (GEOPHIAN).

A.M. Obukhov, the institute's founder, developed an interest in the problems of wave propagation in the atmosphere long before the RAL was established. As early as the 1940s and early 1950s, during his time at GEOFIAN, he conducted fundamental research on wave propagation and fluctuations in turbulent media. This work laid the foundation for the theory of the influence of turbulence on wave processes—a scientific field that later emerged as an independent and important branch of atmospheric physics.

To continue and develop this research, a new laboratory, called the "Radio Acoustics Laboratory," was established at the IAP. V.I. Krasilnikov played a significant role in its organization. It was on his recommendation that V.M. Bovsheverov was invited to the position of head of the RAL. Bovsheverov recruited his talented students from Moscow State University — V.I. Tatarskii, A.S. Gurvich, and I.P. Chunchuzov—to work with him. The resulting team largely determined the laboratory's high scientific level for many years to come.

The laboratory was led by V.M. Bovsheverov (1956–1985), M.A. Kallistratova (1985–2002), and S.N. Kulichkov (2002 to the present).

Main areas of activity

- study of the propagation of acoustic waves, light, and radio waves in the atmosphere;
- study of fluctuations in the parameters of acoustic waves, light, and radio waves;
- development of acoustic and optical methods for measuring meteorological quantities and turbulence parameters;
- application of methods for measuring meteorological quantities and turbulence parameters for fundamental and applied atmospheric research.

Key results

The development of RAL research into fluctuations and scattering of sound light, and

radio waves in a turbulent atmosphere has led to the emergence of a new field of atmospheric physics. The laboratory's key achievement in this field was V.I. Tatarsky's theory of fluctuation phenomena during wave propagation in randomly inhomogeneous media. Tatarsky's internationally recognized work not only provided a profound understanding of the physical nature of these phenomena but also provided a powerful theoretical framework for solving a wide range of applied problems.

1. Under the supervision of V.I. Tatarsky and A.S. Gurvich, experimental studies were conducted at the RAL that confirmed Obukhov's "5/3 law" and the theoretical principles of Tatarsky's theory. During the study of light fluctuations on long paths, new physical phenomena were discovered—the saturation of strong intensity fluctuations and the backscatter enhancement effect in a turbulent atmosphere. Theoretical and experimental studies of laser beam parameter fluctuations, conducted under the supervision of A.S. Gurvich and A.I. Kon, made a significant contribution to practical applications.

2. Under the supervision of V.M. Bovsheverov, the foundations of acoustic anemometry and thermometry methods were laid, which subsequently became widely used in turbulence research worldwide. He, together with B.M. At RAL, Koprov developed unique instruments — cirulimeters — designed to measure mesoscale helicity. These cirulometric measurements serve as the experimental basis for verifying helicity theory.

3. M.A. Kallistratova's pioneering experiments on sound scattering in the atmospheric surface layer provided quantitative confirmation of Tatarsky's theory. These results formed the basis for the method of atmospheric acoustic location and the development of acoustic locators (sodars) capable of measuring vertical profiles of refractive index and wind speed fluctuations in the atmospheric boundary layer (ABL). RAL staff have developed and manufactured several generations of research sodars. This equipment is used to study the structure of the ABL, low-level jet streams, internal gravity waves, and many other problems.

4. Key experimental and theoretical studies of infrasonic wave propagation in the lower and middle atmosphere were conducted at RAL under the supervision of S.N. Kulichkov and I.P. Chunchuzov.

Infrasonic signals were detected for the first time in acoustic shadow zones, their origin explained by the scattering and reflection of low-frequency waves from layered atmospheric inhomogeneities.

Models for the formation of thin layered structures were proposed, taking into account the role of internal gravity waves. Practical methods for infrasonic sounding of the atmosphere were developed, as well as methods for determining the parameters of explosive sources by measuring the characteristics of the recorded waves. The structure of wind speed in the upper stratosphere, mesosphere, and lower thermosphere is studied using an infrasonic sounding method developed by the laboratory.

This method is based on the effect of infrasound scattering from highly anisotropic inhomogeneities of wind speed and temperature in the middle and upper atmosphere. It has been established that extremely high vertical wind speed gradients, reaching 10 m/s at 100 m, can be observed in the mesoscale linear layer of the atmosphere (90–102 km). The influence of the small-scale wind speed structure on the shape of infrasound signals is studied. Vertical wavenumber spectra of the reconstructed wind speed fluctuations for the upper stratosphere are obtained. The obtained spectral characteristics of the wind fluctuations are used to improve the parameterization of gravity wave drag for numerical weather forecasting.

The physical mechanisms underlying the generation of infrasound signals by sea waves ("voice of the sea") are investigated. Based on the analysis of infrasound recording data in the Black Sea area, together with the analysis of the wave conditions and wind speed field, a conclusion was made about the combined influence of the mechanism of infrasound generation by standing surface waves and atmospheric stratification on the observed parameters of infrasound waves.



Fig. 2.
(a) A.M. Obukhov with RAL staff next to a Doppler sodar, Tsimlyansk, 1981.
(b) Sodar measurements in Kalmykia.

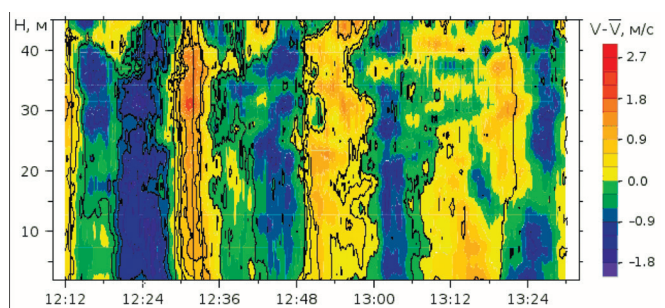


Fig. 1. Wind speed fluctuation field obtained by a high-resolution sodar..

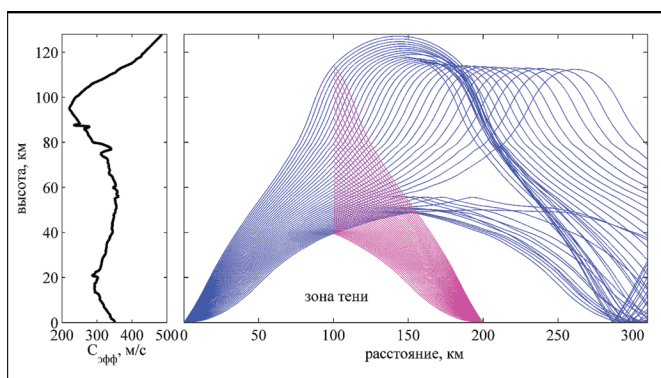


Fig. 3. Diagram of partial reflection of an acoustic wave from layered inhomogeneities of the atmosphere at altitudes of 40–120 km.

AIR-SEA INTERACTION LABORATORY (ASIL)

Head of the laboratory:
Doctor Sciences I.A. Repina

History of the laboratory

The laboratory's history began in 1962 with the organization of research on the interaction of the atmosphere and water surface in the Department of Atmospheric Turbulence, which became the basis for the creation of the Atmospheric Surface Layer Laboratory in 1978. In 1985, in light of growing interest in the ocean's role in weather and climate formation, the Atmosphere-Ocean Interaction Laboratory was established on the basis of this laboratory. Its first director was the renowned oceanologist Yu. A. Volkov. Since 2008, the laboratory has been headed by Academician G. S. Golitsyn, and from 2014 to the present, it has been headed by I. A. Repina.

Main areas of activity

- Theoretical and experimental studies of turbulent energy and gas exchange between the atmosphere and water surfaces.
- Development of theories of turbulent exchange under conditions of convective mixing and stable stratification.
- Study of the interaction between the atmosphere and the hydrosphere (cryosphere).
- Study of the structure and dynamics of the surface (water-surface) and boundary layers of the atmosphere over inhomogeneous surfaces.
- Analysis of wind wave parameters.
- Mesoscale modeling of atmospheric processes in coastal zones, polar regions, and over large lakes.
- Development and modification of measuring equipment for studying the boundary and water-surface layers of the atmosphere and surface structure, including the use of unmanned aerial vehicles.
- Development of algorithms for interpreting satellite data, including for analyzing the state of the sea surface and ice cover.
- Analysis of changes in transparency and aerosol optical thickness of the atmosphere.

Основные результаты

1. Laboratory staff regularly participate in marine and ocean expeditions, including major international projects, and conduct annual

work in Antarctica, the Arctic, and the Spitsbergen archipelago. Significant contributions have been made to the organization and implementation of observations at the International Hydrometeorological Observatory in Tiksi. In recent years, a network of stations has been established and maintained to study the structure of the atmospheric boundary layer (ABL) over various types of inhomogeneous surfaces. Measuring systems are deployed in tundra, marsh, and lake landscapes, in coastal zones, and in urban areas, enabling the acquisition of representative data for a wide range of applications.

2. Fundamental results have been obtained from theoretical and experimental studies of turbulent energy and gas exchange between the atmosphere and water surfaces. Exchange mechanisms under extreme weather conditions, including hurricane-force winds, as well as under calm convection and highly stable stratification, were studied. Based on these data, parameterizations of turbulent momentum, heat, moisture, and gas (including CO₂) fluxes were developed, adapted for use in Earth system models. Simultaneously, in-situ measurement methods and data processing algorithms are continuously improved in marine and terrestrial conditions.

3. Comprehensive modeling of atmospheric processes in the Arctic is conducted using non-hydrostatic mesoscale models, eddy-resolving models, and one-dimensional models. This resulted in a physical description of the formation mechanisms of mesoscale wind circulations in the Arctic region and parameterization of exchange processes under stable, convective conditions and in the presence of stratocumulus clouds. A coupled atmosphere, ocean, wind wave, and sea ice model was adapted to study lee storms. Statistically significant correlations were found between long-term trends in lee storm characteristics and changes in large-scale atmospheric circulation in both the Arctic and mid-latitudes. Using Svalbard as an example, the influence of foehn winds on the heat balance of glaciers was quantified.

4. A fourth-generation wind-wave interaction model has been developed, which, given a given wind field, allows for the calculation of not only wave parameters but also the characteristics of the atmospheric surface layer and the parameters of the upper quasi-homogeneous ocean layer.

A methodology for studying waters with complex bottom topography and indented coastlines has been developed and verified using the modern WAVEWATCH III and SWAN wave models. An analysis of the wind-induced wave climatology of the World Ocean and coastal zones on various spatial and temporal scales has been conducted.

5. Unique results have been obtained from comprehensive studies of the carbon balance in Siberian rivers, various types of lakes (including rare meromictic lakes), wetland ecosystems, and reservoirs in various climatic zones of the Russian Federation. An original methodology for assessing the carbon neutrality and climate impact of artificial water bodies has been developed, taking into account their age, size, flow rate, and geographic location.

6. The development and application of unmanned aerial systems for atmospheric sensing is actively developing. A hybrid unmanned aerial vehicle, the "Tsimlyanin," with vertical takeoff and landing capabilities has been developed, equipped with an onboard measuring system for studying turbulence at various altitudes in the APS. Methods have been developed and tested for monitoring vertical profiles of temperature, humidity, and wind speed, conducting measurements over hard-to-reach areas (e.g., over polynyas), and mapping thermal heterogeneities of the underlying surface. 7. Based on an extensive database of in-situ experiments and small-scale modeling data, the applicability limits of the classical Monin–Obukhov similarity theory (MOS) were determined for calculating turbulent exchange over heterogeneous surfaces: in coastal zones, urban areas, and forests with lakes. Criteria and approaches for modifying MOS for such complex landscapes were developed. The contribution of various elements of high-latitude wetlands and polygonal tundra (tussocks, hollows, thermokarst lakes) to greenhouse gas emissions and absorption was quantitatively assessed.

8. New algorithms for interpreting satellite data are being developed to analyze the state of the sea surface and ice cover. Systematic validation of satellite experiments and mesoscale modeling results is being conducted in comparison with data from specialized marine and land-based measurements, which allows for increasing the accuracy of Earth remote sensing methods.



Fig. 1. The Tsimlyanin UAV on Lake Ladoga; a quadcopter-based complex for measuring atmospheric boundary layer dynamics on Spitsbergen.

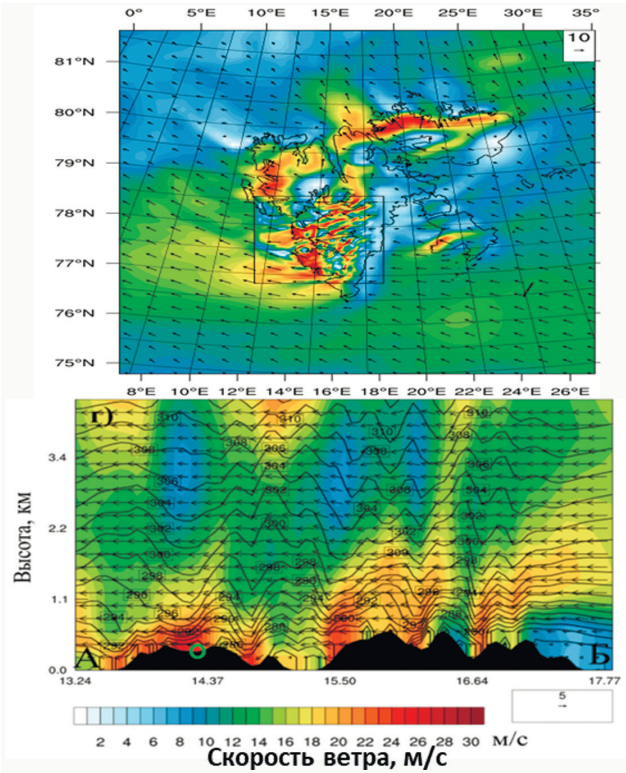
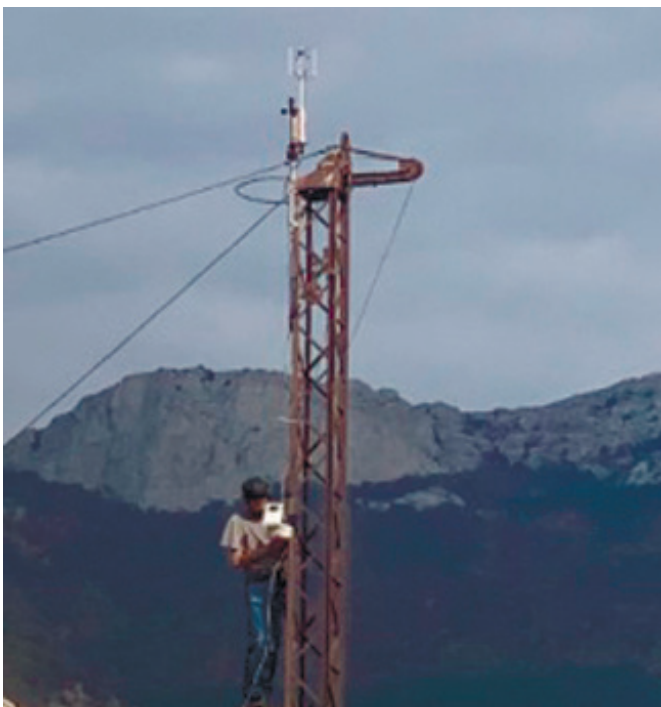
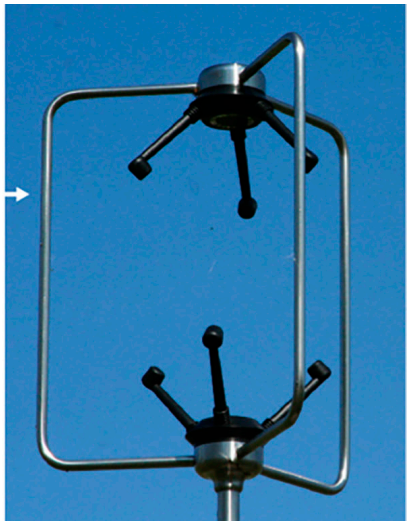


Fig. 2. Results of mesoscale modeling of the dynamics and structure of the foehn on Spitsbergen.



Measurements of the structure of the atmospheric boundary layer and atmospheric turbulence over different landscapes.



LABORATORY OF TURBULENCE AND WAVE PROPAGATION (LTWP)

Head of the laboratory:
Doctor of Sciences M.E. Gorbunov

Key results

History of the laboratory

In 1986, at the IAP, at the suggestion of Doctor of Physics and Mathematics A.S. Gurvich, the Laboratory of Atmospheric Research by Space Means (LIAKS) was established under the direction of G.M. Grechko. The laboratory was engaged in the reconstruction of ozone and trace gas component altitude profiles from satellite measurements, and developed algorithms for using satellite refractometric remote sensing data for numerical weather forecasting. In 1992, LIAKS was renamed the Laboratory of Remote Refractometry, headed by Candidate of Physics and Mathematics S.V. Sokolovsky. The main focus of the laboratory became radio occultation sounding of the atmosphere. In 1997, following a reorganization of the Department of Atmospheric Wave Propagation, two laboratories were merged into the Laboratory of Turbulence and Wave Propagation in the Atmosphere (LTWP), headed by Doctor O.G. Nalbandyan. Since 2007, the Laboratory of Turbulence and Wave Propagation in the Atmosphere has been headed by Doctor M.E. Gorbunov.

Main areas of activity

- Development of the theory and methods of atmospheric radio occultation sounding using signals from the GPS and GLONASS navigation satellite systems, including the development of new approaches to the analysis of multipath zones and the retrieval of vertical temperature profiles.
- Lidar sounding of the atmosphere to detect clear-air turbulence and study the spatial spectra of aerosol density fluctuations at civil aviation flight altitudes.
- Study of internal gravity wave (IGW) activity in the atmosphere based on radio occultation data, including the development of methods for retrieving IGW statistical parameters (structural characteristics, external scale, temperature fluctuation variance, and potential energy).
- Development of theoretical methods for wave field analysis, including the application of the Wigner distribution and Kirkwood density to signal processing in multipath zones.

1. Theoretical foundations and practical methods for remote satellite radiosensing of the atmosphere have been developed. The method is based on the use of highly stable signals from the GPS and GLONASS navigation satellite systems, which are received by a low-orbiting satellite equipped with a special receiver after passing through the Earth's atmosphere. Measuring the radio signal phase allows for the radio beam refraction angle to be determined with high accuracy, and a series of measurements during a radio set (when the satellite sets behind the Earth's horizon) makes it possible to reconstruct the vertical temperature distribution in the sounding area.

A statistical comparison of the refractive indices reconstructed using the radio occultation method was conducted with data from the European Centre for Medium-Range Weather Forecasts (ECMWF) for various latitudinal zones: the tropics (0–30°), mid-latitudes (30–60°), polar latitudes (60–90°), and globally. The obtained results confirmed the high reliability and accuracy of the radio occultation method.

Modern theoretical approaches have been developed for analyzing wave fields in multipath zones, including the Wigner distribution and the Kirkwood phase-space rotation-averaged density. These methods enable the efficient processing of complex signals in conditions of multipath radio wave propagation in the atmosphere.

2. From 2009 to 2015, the laboratory actively participated in the international DELICAT (DEmonstration of LIdar-based Clear Air Turbulence Detection) project. The goal of the project was to develop an airborne lidar for detecting clear-air turbulence (CAT) ahead of an aircraft at distances up to 30 km in real time. One of the main obstacles in turbulence sensing is fluctuations in the intensity of scattered radiation caused by aerosols. An original method for identifying aerosol clouds was proposed, based on a two-dimensional Fourier transform. Spatial spectra of aerosol density fluctuations were obtained for various flight segments, enabling a quantitative characterization of aerosol inhomogeneities at altitudes of approximately 10 km.

3. Internal gravity waves (IGWs) are the main source of small-scale fluctuations in wind speed and temperature in the atmosphere.

The laboratory has developed methods for studying IGW activity based on radio occultation observations, in particular using data from the COSMIC satellite constellation, which includes six satellites and conducts up to 3,000 measurement sessions per day, uniformly distributed across the globe. Given the high spatiotemporal variability of IGW parameters, the research utilizes a statistical description of the amplitude fluctuations of radio occultation signals. The team has derived the basic theoretical relationship between the measured spectra of amplitude and phase fluctuations of radio occultation signals and the spatial spectra of IGWs. A method for reconstructing the main statistical parameters of IGWs from amplitude fluctuation spectra has been developed. The method was tested using COSMIC observations for 2011. Using data collected in January–February and June–July 2011, the altitude–latitude distributions of key IGW parameters—the structural characteristic and the external scale—were reconstructed. The variances of temperature fluctuations and specific potential energy were also obtained in the altitude range from the tropopause to 28 km.

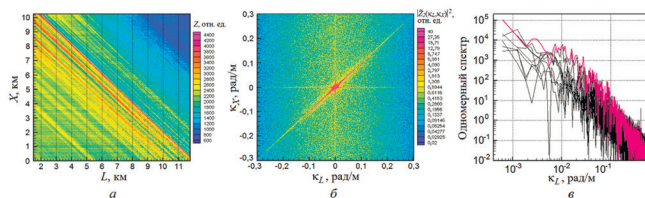


Fig. 1. (a) Lidar response on August 12, 2013, UTC 13:52:04.54–13:53:07.91, altitude 10,290 m; (b) 2-dimensional spectral density; (c) 1-dimensional spatial spectra of aerosol density fluctuations. UTC 13:50:54.54–13:56:18.54.

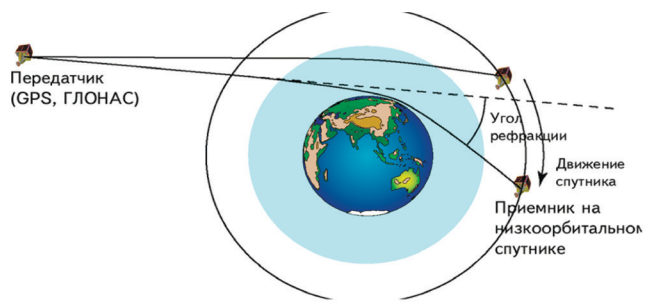


Fig. 2. Scheme of radio occultation sounding of the Earth's atmosphere using radio signals from navigation satellites.



a



b



c



d

Fig. 3. Cessna Citation-2 aircraft: general view (a); side with protruding window transmitting ultraviolet radiation (b), lidar installed inside the cabin (c), nose boom with additional equipment (d).



ATMOSPHERIC COMPOSITION RESEARCH DEPARTMENT

- LABORATORY OF ATMOSPHERIC SPECTROSCOPY
- LABORATORY OF OPTICS AND MICROPHYSICS OF AEROSOL
- LABORATORY OF ATMOSPHERIC GAS IMPURITIES
- SECTOR OF ATMOSPHERIC COMPOSITION REMOTE RESEARCH

LABORATORY OF ATMOSPHERIC SPECTROSCOPY (LAS)

Head of the laboratory:
Doctor of Sciences A.A. Vigasin

History of the laboratory

The Laboratory of Atmospheric Spectroscopy (LAS) was established at the IAP in 1968 under the direction of V.I. Dianov-Klovov, who remained in this position for the next 20 years. At the IAP, V.I. Dianov-Klovov continued his earlier research on the spectra of atmospheric oxygen from the far IR to the UV range. V.I. Dianov-Klovov's works are still widely cited in international publications on molecular oxygen spectroscopy. E.I. Grechko, who headed the laboratory from 1987 to 2024, made a significant contribution to the development of spectroscopic methods for atmospheric studies at the IAP. In 2024, the leadership of the LAS was transferred to A.A. Vigasin, who had headed the theoretical group of the Laboratory since 1984.

Main areas of activity

- Theoretical spectroscopy of atmospheric molecules, including those in planetary atmospheres.
- Spectroscopic measurements and data analysis of the total atmospheric content of carbon monoxide, water vapor, and methane at stationary sites.
- Collection and analysis of atmospheric composition data obtained using remote sensing systems.
- Development of specialized software for the automatic collection and analysis of orbital atmospheric composition data.
- Study of inter-period variations and long-term trends in atmospheric composition in urbanized and background regions of Eurasia.

Key results

It has been established that the absorption bands of weakly bound oxygen complexes must be taken into account when solving inverse problems of atmospheric sounding. As with oxygen, the spectrum of CO₂ also contains poorly resolved induced absorption bands. The work conducted at LAS on CO₂ absorption spectra at high pressures and temperatures generated great interest for

modeling the conditions of the Venusian atmosphere in the 1960s–1980s, when spacecraft exploration of the Venusian atmosphere began. A unique array of data on the radiative properties of high-density carbon dioxide was obtained, both in terms of volume and quality.

1. Results of laboratory and field studies of the continuum absorption of water vapor were obtained. A conclusion was reached regarding the most likely "dimeric" nature of continuum absorption in the atmosphere. The absorption bands of water dimers under equilibrium conditions were identified only forty years later.

2. The contribution of van der Waals dimers to the formation of induced CO₂ absorption bands was reliably identified for the first time. Furthermore, CO₂ dimer "fingerprints" were detected in the IR and Raman spectra obtained in freely expanding gas jets. The fundamental concepts of the nature of the water vapor continuum, formulated by A.A. Vigasin, are physically substantiated and widely used in modern continuum models.

3. LAS staff (A.A. Finenko, D.N. Chistikov, A.A. Vigasin, and others) are developing a trajectory method for calculating induced spectra, which is currently one of the best in the world for calculating the induced spectra of polyatomic molecules. This approach is based on the use of high-precision electron energy and dipole moment surfaces obtained using quantum chemistry methods. The trajectory calculation method developed at LAS is highly accurate and can be implemented using moderate and widely available computing power. Some of the results obtained at LAS have been included in the international HITRAN database, a reference for atmospheric spectroscopy. This method was used to accurately describe observations of the Cassini spacecraft in Titan's atmosphere.

4. Important results were obtained by modeling the conditions of the Martian paleoatmosphere taking into account induced absorption, which is a possible cause of the existence of liquid water on the Martian surface. The discovery of magnetic dipole absorption of CO₂ in the Martian atmosphere sparked interest in developing a theory of this phenomenon. Such a quantum theory was first developed in the work of LAS staff. Theoretical spectroscopy of atmospheric molecules and their complexes is being developed at LAS using methods of classical and quantum mechanics, statistical physics, quantum chemistry, and neural network algorithms.

5. For over 50 years, LAS has been studying the spatiotemporal characteristics of trace gas fields in the atmosphere using spectroscopic methods. During the Soviet era, measurements were conducted during marine and field expeditions, in Antarctica, and at a drifting station in the Arctic. In the works of V.I. Dianova-Klokov, I.P. Malkova, E.I. Grechko and others studied the characteristics of photon ranges in clouds with multiple light scattering from on board an airborne laboratory.

6. Currently, in-kind studies of the LAS (carried out by a group led by V.S. Rakitin) include the implementation and analysis of our own spectroscopic measurements of the total content of carbon monoxide, water vapor and methane in the atmosphere at five stationary points: IAP RAS, Moscow (since 1970), Zvenigorod Scientific Station (since 1968), High-Mountain Scientific Station (Shadzhatmaz, since 1986), Zotino (Krasnoyarsk Territory, since 2008) and Beijing (1992–2019).

7. Atmospheric composition data obtained from the AIRS, OMI, MODIS, TROPOMI, and OCO orbital instruments and ground-based stations of the NDACC, TCCON, and AERONET atmospheric monitoring networks is being analyzed. This data analysis allows, in particular, for quantitative characterization of the intensity of wildfire emissions and an assessment of their impact on atmospheric composition over Russia.

8. The measurement quality of several space-based monitoring systems (MOPITT, AIRS, MODIS, IASI, OMI, and TROPOMI) was validated and assessed. A multifunctional software package, "TROPOMI tools," was developed and registered, enabling the processing, validation, and correction of orbital information on atmospheric composition and parameters. Methodologies for filtering and correcting satellite data were developed. 9. Atmospheric composition trends in different regions of Eurasia were studied. Estimates of the response of carbon monoxide trends to climate change and the increase in methane concentrations are obtained, and a photochemical hypothesis is proposed to explain the transition of atmospheric carbon monoxide content to an increase in recent years.

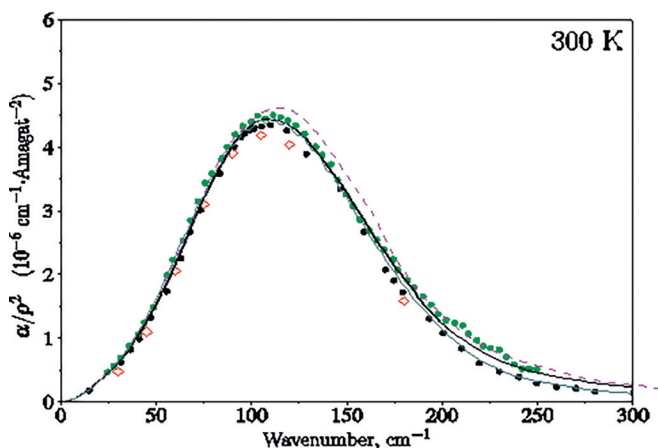


Fig. 1. Induced spectrum of nitrogen. Dots represent experiment, solid line represents calculation.

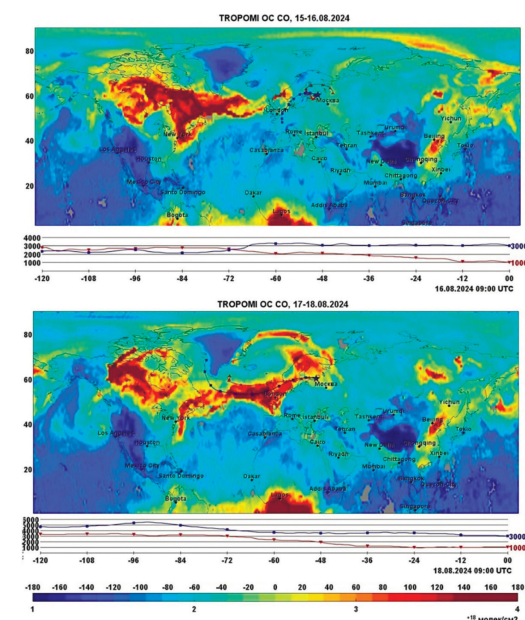


Fig. 2. An example of analysis of atmospheric composition disturbance episodes over Russia using orbital information. Transoceanic transport of CO from forest fire areas in North America in 2024..

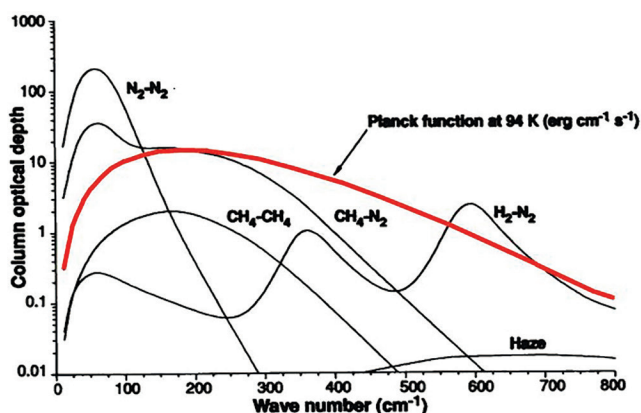


Fig. 3. Induced spectra in the atmosphere of Titan.

LABORATORY OF OPTICS AND MICROPHYSICS OF AEROSOLS (LOMA)

Head of the laboratory:
Doctor of Sciences G.I. Gorchakov

History of the laboratory

The Laboratory of Optics and Microphysics of Atmospheric Aerosols continues and develops the traditions of atmospheric aerosol research established at the Institute of Atmospheric Physics since the mid-1950s. The founder of this scientific field was Professor Georgy Rosenberg, a distinguished physicist who established the Laboratory of Optics of Scattering Media in 1956. Under Rosenberg's leadership, the laboratory became one of the world's centers for the study of the optical properties of atmospheric aerosols and the theory of light scattering in dispersed media. During these years, fundamental foundations were laid for understanding the interaction of electromagnetic radiation with aerosol particles of various natures, shapes, and chemical compositions. Particular attention was paid to the study of aerosol microstructure, its spatiotemporal variability, and its role in the atmospheric radiation balance. The laboratory's work during this period had not only fundamental but also important applied significance for the problems of remote sensing, optical communications, and atmospheric purity monitoring.

Main areas of activity

- Study of desertification processes (saltation, electrification).
- Study of dust aerosol emissions in desertified areas: optical and microphysical characteristics of dust aerosol in the surface layer and in the atmosphere, vertical turbulent dust aerosol flows.
- Study of large-scale atmospheric smoke pollution (optical and microphysical characteristics of smoke aerosol).
- Study of aerosol pollution of the Moscow region air basin.
- Study of aerosol pollution of the atmosphere and its impact on the environment in the Arctic.

Key results

1. The laboratory team obtained fundamental results in the study of the optical and microphysical properties of various types of atmospheric aerosol.

A detailed analysis of the temporal variability of black carbon (BC) concentrations in the Moscow region was conducted. Characteristic periods of decline and stabilization of BC concentrations were identified, and the average daily cycle of its content in the metropolitan area's surface atmosphere was reconstructed.

These data are key for assessing anthropogenic impacts on air quality and radiation balance.

Anomalous selective absorption was detected in a study of smoke aerosol generated by the massive forest fires in Alaska in 2019. Spectral dependences of the imaginary part of the refractive index of smoke aerosol were obtained, allowing for refinement of models of the radiative impact of biomass combustion products on the climate system. A study of dense non-photochemical smog in China revealed for the first time the presence of brown carbon (at a wavelength of 440 nm) and selective absorption with a maximum at 1020 nm. It was shown that the fine aerosol fraction dominates in dense smog, determining its optical properties and impact on visibility and radiative forcing.

For dust aerosol, selective absorption in the visible spectrum at a wavelength of 675 nm was established, due to the presence of the mineral goethite (FeO-OH). It was determined that the particle fraction with a modal radius of 2 to 3 μm dominates in dust aerosol, which is important for modeling dust transport and deposition.

2. A series of studies was conducted to study the physical mechanisms that determine the dynamics of wind-sand flow—a key process in desertification and dust aerosol emission. A detailed study of dust plasma formed in a wind-sand flow, in which both saltating particles and dust aerosol particles and the underlying surface are charged, was conducted. It was shown that the distribution of saltating particles at heights greater than 2–3 cm is determined by high-velocity particles generated by electrodynamic saltation. At heights greater than 9 cm, turbulence begins to significantly influence the concentration profiles, manifested by the appearance of characteristic branching points in the normalized concentration profiles. These results significantly refine existing understanding of the mechanisms of mineral dust uplift and transport.

3. The vertical turbulent flux of dust aerosol during burst saltation was studied in detail for the first time. It was found that the flux is characterized by pronounced low-frequency intermittency, which is absent in turbulent heat flux.

It was shown that the dust aerosol removal velocity, with 30-minute averaging, can reach 16 cm/s. These results are of fundamental importance for the parameterization of dust emissions in climate and pollutant transport models.

4. Since the mid-1980s, laboratory staff have conducted systematic studies of aerosol pollution in the Arctic, combining in-situ measurements with model estimates. The first experimental data on the elemental composition of aerosol were obtained on the Severnaya Zemlya archipelago and Wrangel Island in 1984–1985. This ongoing work has led to the following key results:

- It was established that the frequency of air transport from the continents to the Arctic islands decreased by 2-3 times between 1986 and 2016, which has significant consequences for the conditions of terrestrial ecosystems in high-latitude territories.
- The annual balance of anthropogenic heavy metal (HM) content in the mixing layer within Arctic latitudes was estimated. It was shown that heavy metal fluxes from the atmosphere to the surface of the Kara and Laptev Seas are comparable to the removal of the same metals by large rivers flowing into the Arctic Ocean. This indicates a significant role of atmospheric transport in the pollution of the Arctic seas.
- Spatial variations in black carbon pollution along the Arctic coast of Russia were assessed. Contributions from forest fires, flares from oil production enterprises, and other anthropogenic sources in winter and summer were differentiated.
- A sharp increase in black carbon concentrations in the air near the Tiksi Observatory was found to coincide with days of higher temperatures in both summer and winter. The associated changes in the atmospheric radiation balance were assessed.
- Black carbon measurements conducted in 2019–2020 in the Pechora-Ilychsky Nature Reserve (western slope of the Urals) confirmed the background nature of this area, with little influence from sources in the Southern Urals.
- An analysis of the contributions of various sources to black carbon pollution on Wrangel Island was conducted. It was found that, on an annual scale, contributions from Eurasian sources predominate. In certain months, contributions from American territories from anthropogenic sources and fires reach 7% and 37%, respectively.

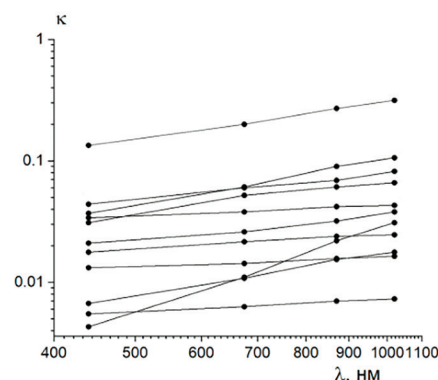
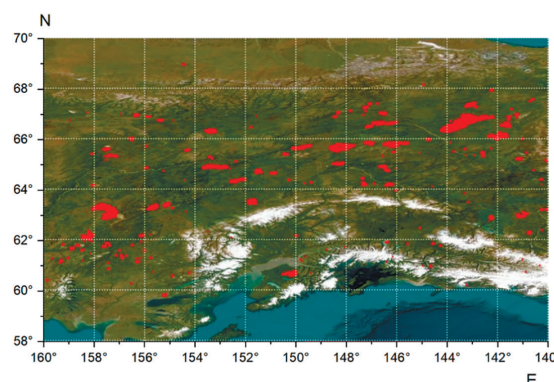


Fig. 1. Massive forest fires in Alaska in 2019 (a) and spectral dependences of the imaginary part of the refractive index of smoke aerosol (b).



Fig. 2. Annual cycle of anthropogenic heavy metal content in the mixing layer within the Arctic latitudes [2006-2007].

LABORATORY OF ATMOSPHERIC GAS IMPURITIES (LAGI)

Head of the laboratory:
PhD K.B. Moiseenko

History of the laboratory

In 1976, the IAP RAS was designated the lead organization responsible for conducting a full-scale research project aimed at answering all key questions in ozonometry—from the possibility of partial or complete ozone depletion to its impact on human life. The Laboratory of Gaseous Impurities (AGIL) was established at the IAP under the direction of N.F. Elansky, focusing on fundamental and applied problems in ozone physics and chemistry. Currently, LGPA researchers conduct research on a wide range of atmospheric physics and chemistry issues, drawing on many years of experience in similar research, including direct air composition measurements at the IAP RAS operating permanent sites in Moscow, the Moscow region, and the Caucasian Mineral Waters region, seasonal observations at ZOTTO, and expedition data.

Main areas of activity

- Measurements of the gas and aerosol composition of tropospheric air using stationary and mobile instrumentation systems.
- Numerical modeling of atmospheric transport and chemistry using the GEOS-Chem global model and the WRF-Chem regional chemical-dynamic model.
- Study of the transport and chemical transformation of biomass combustion products (forest fires) and their impact on the tropospheric photochemical system.
- Study of volcanic ash transport and fallout during explosive volcanic eruptions.
- Study of long-range and regional atmospheric transport of dust and combustion aerosols to temperate and high-latitude zones of European Russia and its impact on the physicochemical characteristics of aerosol particles in the surface layer of the atmosphere.
- Analysis of the variability of microphysical parameters, elemental composition and morphological structure of ground-level aerosols in the conditions of the Moscow metropolis, taking into account synoptic and meteorological conditions, seasons and specific features of a large city.

Key results

1. Laboratory staff have developed automated integrated instrumentation systems for continuous measurement of a wide range of gaseous and aerosol pollutants, including ozone (O_3), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and aerosol particles. These systems combine instruments from leading international and domestic manufacturers and provide long-term, high-quality observations.

They have been used to create a unique observation network, including stations in Moscow, the Moscow region (Zvenigorod Research Station), and the Caucasian Mineral Waters region (Kislovodsk and the Shadzhatmaz Plateau). Through a partnership with the Sukachev Institute of Forestry, measurements are being conducted at the ZOTTO observatory in the boreal forests of Central Siberia. Since 2015, the laboratory has regularly participated in Arctic expeditions on the research vessel Akademik Mstislav Keldysh. This allowed us to obtain unique long-term data on air composition in a wide range of conditions—from the extremely polluted atmosphere of the Moscow metropolis to background regions of Siberia and the Arctic.

2. A series of studies was conducted to study the aerosol composition of air in Moscow and the surrounding region. Quantitative estimates of the impact of urban sources on gas and aerosol pollution levels were obtained. It was established that local dust sources can create a "dust haze" effect—a sharp and abnormally high increase in aerosol concentration, comparable in magnitude to the arid aerosol content over the desertified areas of the Northern Caspian region. A detailed analysis of the elemental composition of ground-level aerosol in Moscow revealed elevated concentrations of not only naturally occurring lithophile elements but also potentially toxic elements of man-made and mixed origin (heavy metals, metalloids). This indicates additional environmental risks to the urban environment and public health.

3. Using ZOTTO observatory data and a state-of-the-art vegetation map, we refined combustion product emissions for various types of boreal forests in Siberia. We also examined the influence of wildfire emissions on the air composition in the atmospheric boundary layer over Northern Eurasia.

We obtained CH₄/CO concentration ratios in fire plumes based on observations from ZOTTO (2012) and the TROICA expeditions (2005, 2007). These data allowed us to refine emission characteristics depending on the type of fire and vegetation, which is important for modeling atmospheric processes and assessing the contribution of fires to climate change. 4. For the first time, systematic estimates of the contribution of anthropogenic emissions and wildfires to the background content of chemically active and greenhouse gases in the troposphere over the continent were obtained using instrumental data and calculations using transport-chemical models. An increase in background levels of CO, O₃, and NO_x in the atmospheric boundary layer was established depending on the increment of CO emissions in Siberia (the region 60–150° E). These results are key to understanding the anthropogenic impact on the atmosphere of regions traditionally considered ecologically clean.

5. Quantitative estimates of the ozone production efficiency per NO_x molecule—a key parameter for understanding photochemical processes in the troposphere—were obtained. Odd nitrogen lifetimes (τ_N) were determined as a function of NO_x concentration in different months based on measurements at the ZOTTO and Background observatories. It has been shown that regional emissions of ozone precursors (primarily nitrogen oxides) play a key role in the photochemical generation of ozone and other secondary compounds in the atmospheric boundary layer over the boreal forests of central and southern Siberia. This is an important conclusion, as these areas have traditionally been considered regions with minimal anthropogenic impact. However, the obtained results demonstrate the significant influence of regional pollution transport on their atmospheric composition.

These results represent a significant contribution to our understanding of the mechanisms underlying the formation of atmospheric gas composition over Russia, from megacities to remote Arctic and Siberian regions, and provide a basis for improving climate models and air quality forecasts.

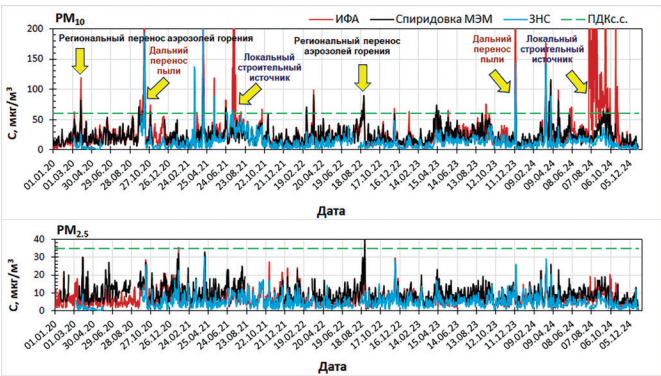


Fig. 1. Time course of the average daily mass concentration of aerosols in the Moscow region based on observations by the IAP RAS and at the Spiridonovka ASCAA of the State Budgetary Institution MosEcoMonitoring.

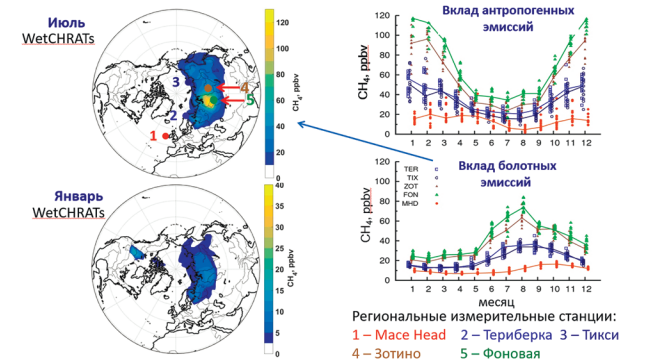


Fig. 2. Contribution of natural and anthropogenic emissions in Russia to the atmospheric concentration of methane (2007–2024).

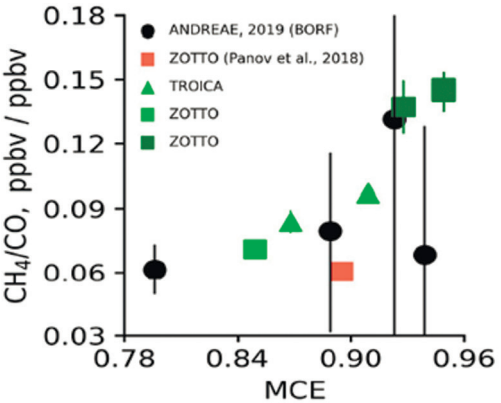


Fig. 3. The ratio of CH₄/CO concentrations in fire plumes in ZOTTO in 2012 and in the TROICA expeditions in 2005 and 2007 depending on MCE=(1+CO/CO₂)-1.

SECTOR OF ATMOSPHERIC COMPOSITION REMOTE RESEARCH (SACRR)

Head of the sector -
Ph.D. A.N. Borovsky

History of the sector

The sector was established in 2013. The main objective of the research is to develop methodological foundations for remote optical sensing of atmospheric composition and anthropogenic sources of atmospheric impurities, as well as other related characteristics used in chemical transport modeling.

Main areas of activity

- Development of technologies for remote measurement of atmospheric gas impurity and aerosol content using optical methods (preparation of measuring equipment, development of remote measurement methods from the Earth's surface and from space).
- Modeling of radiation processes in the atmosphere.
- Development of methods for solving inverse problems of atmospheric optics.
- Organization and implementation of measurements of atmospheric gas impurity and aerosol content using remote and contact methods.
- Analysis of the spatiotemporal variability of atmospheric gas impurity and aerosol content.
- Methodological and experimental support for the validation range of remote sensing spacecraft at the Institute's Kislovodsk Research Station.

Key results

The Atmospheric Composition Remote Sensing Sector (ACRS) specializes in developing methodological foundations for atmospheric remote sensing using spectral optical measurements, as well as estimating the distribution of atmospheric pollutant sources and other characteristics used in chemical transport models. Research covers a wide range of tasks: from the development of instrumentation and measurement methods to the analysis

of spatiotemporal variability of atmospheric composition and the validation of space-based remote sensing tools.

1. The ACRS staff has developed methods for retrieving the content of trace gases in the atmosphere from spectral measurements of scattered solar radiation. This approach is based on differential optical absorption spectroscopy (DOAS), which allows for the separation of contributions from various gases with characteristic absorption spectra. To account for the contribution of individual atmospheric layers to the measured effective gas thickness, a linearized radiative transfer model adapted for solving inverse problems has been developed. Particular attention is paid to multi-angle sounding, in which a set of measurements taken at different angles makes it possible to reconstruct the vertical distribution of pollutants. Currently, the sector has developed methods for determining the integrated content and vertical profiles of nitrogen dioxide (NO₂) and formaldehyde (HCHO) in the lower troposphere based on zenith and multi-angle measurements of scattered radiation spectra. Methods are also being developed for determining the content of glyoxal and nitrous acid—compounds that serve as indicators of the intensity of photochemical processes involving volatile organic compounds. This work is directly related to air quality monitoring and understanding the mechanisms of photochemical smog.

2. Since 2016, the sector has been actively using data from the hyperspectral instrumentation (HSA) installed on Russian satellites of the Resurs-P series. The staff developed an original algorithm for reconstructing the distribution of NO₂ content in the troposphere based on GAW data, providing a record-high horizontal spatial resolution: 2.4 km with representation on a 120 m grid. This significantly exceeds the capabilities of the best foreign systems: OMI/Aura (NASA, resolution 13×24 km) and TROPOMI/Sentinel-5P (ESA, 7×7 km).

To correctly process the resulting ultra-detailed fields and interpret the fine spatial structure of impurities, analytical and numerical chemical transport models adapted for modeling on a 120-meter grid were developed in the sector.

This allowed for the transition from regional assessments to the localization of specific pollution sources.

3. The high resolution of the GSA/Resurs-P data, for the first time in global practice, made it possible to identify plumes emanating from individual industrial enterprises using satellite imagery. Using the developed methods, an analysis of an area with increased anthropogenic pollution near the city of Xingtai (China) was performed. It was possible to identify the contribution of the large chemical company China Risun Group Limited to the total NO₂ content in the region and estimate its emissions. This result demonstrates fundamentally new capabilities of space monitoring for monitoring compliance with environmental regulations and inventorying pollution sources at the local level.

4. A validation range for space-based remote sensing instruments has been established and maintained at the Institute's High-Altitude Research Station. Systematic ground-based spectral measurements are conducted here, serving as a benchmark for verifying satellite data. Specifically, the variability of the vertical distribution of NO₂ over various areas of Kislovodsk has been thoroughly studied, allowing for the consideration of orographic features and local sources when interpreting space-based measurements.

5. To accurately account for the influence of cloud cover on remote sensing results, the sector is developing methods for determining cloud cover parameters from spectral and accompanying ground-based measurements. These data are used both to correct satellite observations and to validate climate models. Radiative transfer models developed in the sector are focused on solving inverse problems and ensure high accuracy in reconstructing gas composition, even under challenging conditions (presence of aerosols, variable cloudiness).

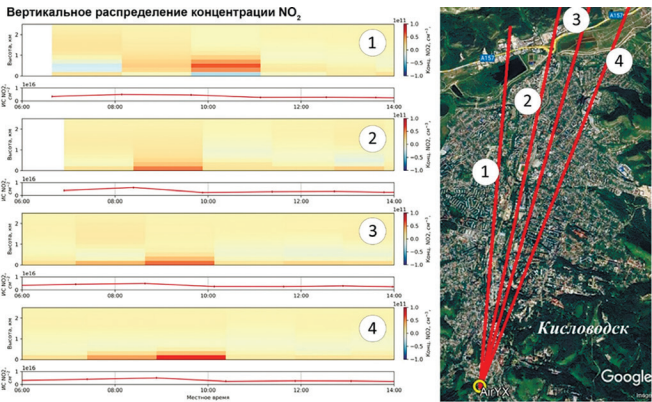


Fig. 1. Variability of the vertical distribution of NO₂ concentration over different areas of Kislovodsk.

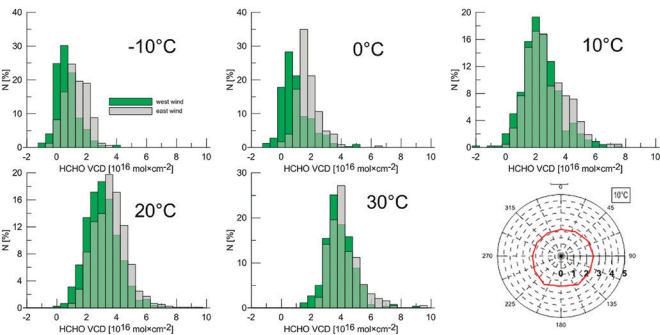


Fig. 2. Distribution of the integral content of formaldehyde (HCHO) in the atmospheric boundary layer at the Zvenigorod scientific station with easterly and westerly winds (more than 2 m/s) at different temperatures.



Fig. 3. Model of a stereo installation for determining the height of the lower cloud boundary on the roof of the IAP RAS.



SCIENTIFIC STATIONS

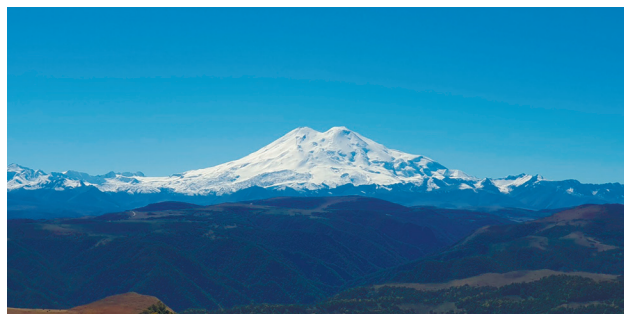
- ZVENIGOROD SCIENTIFIC STATION



- TSIMLYANSK SCIENTIFIC STATION



- HIGH-ALTITUDE SCIENTIFIC STATION



ZVENIGOROD SCIENTIFIC STATION

The history of the Zvenigorod Scientific Station of the A.M. Obukhov Institute of Atmospheric Physics RAS is linked to the Geophysical Institute of the USSR Academy of Sciences. Its construction on two sites near Zvenigorod, near the villages of Lutsino and Novoshikhovo, began in 1953 as part of the Stratospheric Complex Expedition. The location was no accident: the sites were located on elevated ground in one of the cleanest areas of the Moscow region, free of industrial enterprises and light pollution. It was here in 1951 that some of the world's first photographs of noctilucent clouds were obtained. The station's early years, the organization and development of observations of the free atmosphere and the distribution of impurities within it, are associated with the name of the outstanding Soviet geophysicist, Papaninist, and RAS Academician E.K. Fedorov. Following the reorganization of GEOFIAN and the formation of the Institute of Atmospheric Physics of the USSR Academy of Sciences in 1956, the Zvenigorod station was assigned to the IAP and became the institute's main base for experimental research. By 1957, the station had already earned the status of one of the most important Soviet research sites for the International Geophysical Polar Year. The station acquired instrumentation for studying night airglow, atmospheric aerosol optics, and the propagation of light and sound in the atmosphere.

Gradually, the station evolved into a scientific settlement, possessing all the necessary infrastructure for large-scale scientific research. In the 1970s and 1980s, experiments were conducted at the ZNS to compare instruments for measuring atmospheric turbulence characteristics, study concentrations of trace gases and aerosols in the atmosphere, conduct atmospheric spectroscopy, study explosion physics, and investigate the propagation of infrasound, radio waves, and light in the atmosphere, as well as to study processes in the upper atmosphere. In the 1990s, the station became a testing ground for international radiation and cloud experiments. Studies of variations in gaseous impurity content have been conducted at the Zvenigorod Scientific Station since 1970 and are the longest-running in the world. For over 30 years, research has been conducted on the structure of atmospheric turbulence using acoustic locators — sodars. Unique studies of the upper atmosphere have provided information about its complex dynamics, including the existence of internal gravity waves, and have led to the conclusion that its temperature has been trending negatively in recent decades.



Station buildings

*fluctuational,
optic,*

*upper
atmosphere,*

*Meteorological
site.*



Currently, the station has three research sites with a total area of 32 hectares: the main area, a site for upper atmosphere research, and a plot of land near the village of Sharapovo. Located in close proximity to Moscow, the Zvenigorod research station serves as a reference site for assessing the city's environmental status. Research at the station is also useful for identifying sources of air pollution, forecasting hazardous meteorological events, and assessing climate change in the region.

The following research is being conducted at the station:

- monitoring of the gas composition of the atmosphere (including spectroscopic observations), including gas traces (NO_2 , NO , O_3 , H_2CO , CO , CO_2 , $\delta^{13}\text{C}$, CH_4 , H_2O , volatile organic compounds);
- monitoring of the aerosol composition of the atmosphere (number and mass concentration, size distribution of aerosol particles with $d=0.15\text{-}20\ \mu\text{m}$, elemental composition, geochemical profile)
- study of the composition, structure, and dynamics of the upper atmosphere;
- acoustic studies (atmospheric pressure fluctuations, vertical profile of wind speed and direction, atmospheric turbulence);
- study of the structure and dynamics of the atmospheric boundary layer, including vertical profiles of temperature and humidity, heat, momentum, and climatically active gas fluxes, cloud height, radiation balance, and the total heat balance in the surface layer of the atmosphere;
- meteorological research; development of methods for forecasting hazardous meteorological phenomena.

The station operates a test site for measuring the structure of the atmospheric boundary layer in heterogeneous terrain, which includes continuous profile measurements of meteorological parameters and atmospheric turbulence. These measurements are used to develop mathematical models of the Earth system. Work on atmospheric spectroscopy and measurements of the state of the upper atmosphere, as well as systematic measurements of trace gas components in the atmosphere and aerosol content and properties, continues. ZSS is the only station in the world where the vertical profile of nitrogen dioxide in the stratosphere is determined. The "Upper Atmosphere" test site is located away from roads and residential buildings and allows for background monitoring of the gas composition of the atmosphere and fluxes of climate-active gases. Climate-critical monitoring of the aerosol composition of the upper atmosphere is also conducted at the test site using an aerosol lidar.



An instrument complex for measuring atmospheric boundary layer parameters:

temperature meteorological profiler,

water vapor radiometer.

Turbulence measurement mast and meteorological platform,

sodars (acoustic locators).



Atmospheric composition measurement data from the ZSS are used to validate satellite measurements and chemical transport modeling results, as well as to assess air quality. Data assimilation by chemical transport models allows for the identification of air pollution sources, assessment and refinement of their emissions, and forecasting of regional air quality.

The ZSS is part of the international Network for the Detection of Atmospheric Composition Change (NDACC). The station's capabilities are in demand by third-party organizations, including those of Roshydromet. The station houses a MosEcoMonitoring observation post and an automatic Roshydromet station of the Storm Ring system.



TSIMLYANSK SCIENTIFIC STATION

On August 30, 1955, a decree of the USSR government allocated a plot of land on the outskirts of Tsimlyansk in the Rostov region to the then Geophysical Institute of the USSR Academy of Sciences, which would later become the Institute of Atmospheric Physics a few months later, for the creation of a specialized atmospheric turbulence research site. The site offered a unique combination of climatic conditions with stable summer anticyclones and the terrain — a flat landscape with wind acceleration of over 2 km over a uniform surface, with prevailing north and northeast wind directions—creating favorable conditions for conducting regular measurements of turbulence and related or induced phenomena in the surface layer of the atmosphere. The station's experimental work focused on:

- with the improvement of long-term weather forecasting schemes, atmospheric general circulation models, and climate models developed on their basis;
- with special attention to issues of turbulent diffusion of impurities in the atmosphere;
- with the increase in the volume of construction of high-rise buildings and structures;
- with the needs of aviation, especially in connection with the tasks of aircraft takeoff and landing;
- with the significant role of turbulence in the propagation of light in the atmosphere, and in particular, laser radiation, etc.
- with the development of the theory of atmospheric turbulence and similarity theory for the surface layer of the atmosphere;
- with the creation of fundamentally new methods for measuring wind speed pulsations, temperature, humidity, and methods for statistical processing of measurement results.

From its very first years, the station became a unique platform for testing scientific equipment, verifying theoretical constructs, developing new theories, and studying atmospheric processes. Along with experiments in Kansas and Australia, measurements at the Tsimlyansk Test Site in the 1960s made a significant contribution to defining the universal functions of the Monin-Obukhov similarity theory, which are necessary for calculating the characteristics of turbulent mixing in the atmospheric boundary layer.

In 1970, the Tsimlyansk Test Site became part of the International Turbulence Comparison Experiment (ITCE) project, the main goal of which

was to compare various instruments and devices for measuring turbulence and processing data, and to determine the accuracy of models for estimating turbulent flows. By that time, numerous instruments for measuring turbulent fluctuations in the atmospheric surface layer had been developed in many countries with the goal of determining turbulent flows using the turbulent pulsation method.



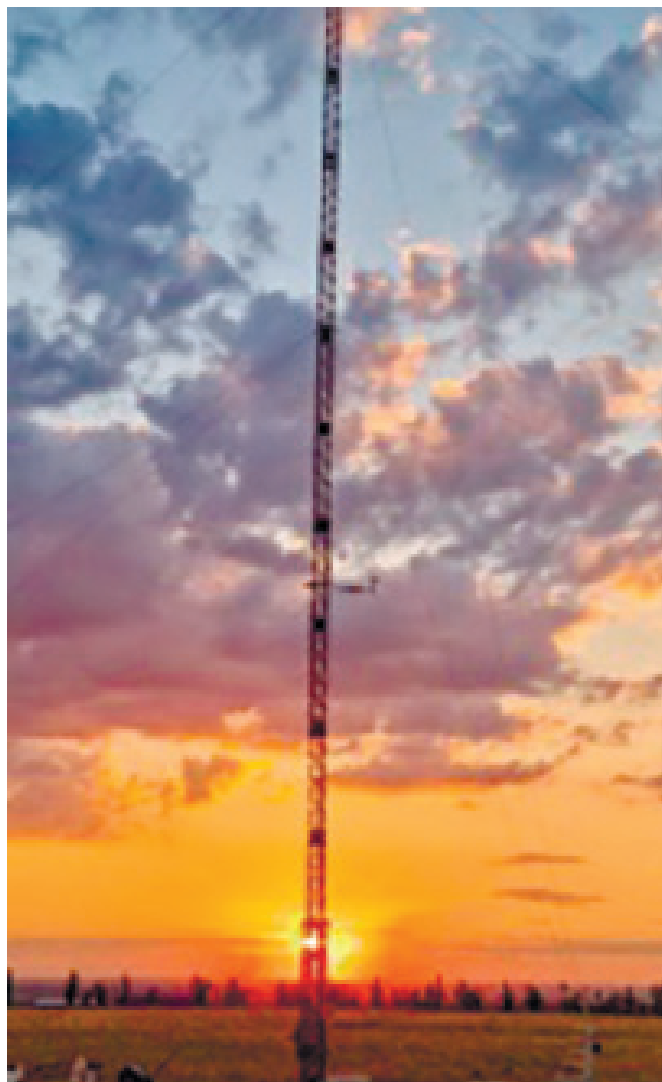
One of the important methodological tasks addressed at the TSS was field testing of new methods and instruments developed for atmospheric characterization. Thus, acoustic anemometers, developed under the supervision of V.M. Bovsheverov, were first tested here. Also here, during flights over the TSS, the first tests of aircraft-mounted acoustic anemometers were conducted, and the first measurements of vertical wind velocity component pulsations were obtained. The first direct measurements of turbulent heat fluxes and momentum in the surface and boundary layers of the atmosphere were also obtained from the mast and from an aircraft.

In 1958, the first experiments on sound scattering by turbulent inhomogeneities in the surface layer of the atmosphere were conducted at the TSS under M.A. Kallistratova. The results of these studies served as the basis for the development of new remote sensing methods for the acoustic sensing of the atmosphere (sodars), which are increasingly used in atmospheric boundary layer research and practical applications. The sodar sensing technique was also developed, primarily at the CNS, in close collaboration with measurements of micrometeorological parameters at masts.

Numerous synchronous measurements of turbulent heat fluxes (THF) at the ground surface and throughout the entire thickness of the ABL made it possible to construct a model for calculating the THF throughout this layer under unstable stratification conditions based on measured wind speed and temperature profiles in the surface layer. Similar momentum flux measurements made it possible to obtain dimensionless profiles of these fluxes throughout the ABL under the same conditions. From the first days of work at the TSS, systematic studies of light propagation in a turbulent atmosphere were conducted there. These studies, begun before the advent of lasers, intensified significantly in the 1960s due to the rapid development of laser technology.

Here at the TSS, the first studies of light propagation in the region of strong fluctuations were conducted, leading to the discovery of the phenomenon of saturation of light intensity fluctuations with increasing path length or temperature fluctuation intensity.

The theoretical assumptions of A.M. Obukhov and V.I. Tatarsky on the role of fluctuation phenomena in the propagation of sound and electromagnetic waves in a turbulent atmosphere were confirmed, which significantly contributed to the subsequent development and refinement of theoretical and practical formulas and methods.



A pioneering method for measuring turbulent vorticity and vortex flow components was developed for the first time. Currently, the TSS is a sought-after testing ground for fundamental and applied research, boasting a well-developed infrastructure.

Comprehensive expeditions to study the structure and dynamics of the atmospheric boundary layer, atmospheric turbulence, atmospheric electricity, and aerosol propagation and emission operate at the station annually during the spring and summer.

Year-round monitoring of the thermophysical properties of the surface, the dynamics of the atmospheric surface layer, and the aerosol composition has been organized. Student internships are held at the station from Moscow State University and the Higher School of Economics. In recent years, the station has become a base for research into the hydrochemistry of the Tsimlyansk Reservoir.

The station's history continues. On August 12, 2025, at a meeting of the Expert Council under the Ministry of Science and Higher Education of the Russian Federation on scientific support for the development of carbon balance control technologies (Order No. DS/115-pr), a proposal was approved to establish and operate a steppe carbon testing site in the Rostov Region based on the Tsimlyansk Scientific Station of the A.M. Obukhov Institute of Physics RAS.



HIGH-ALTITUDE SCIENTIFIC STATION

The history of the Kislovodsk High-Altitude Scientific Station (HASS) dates back to 1971, when staff from the Institute of Atmospheric Physics first organized expeditionary research on the Shadzhatmaz Plateau under the direction of Yu.L. Truttse. These photometric measurements laid the foundation for the future observatory. The idea for the station belonged to the founder and director of the IAP, Academician Alexander Obukhov, who recognized the unique advantages of this location for conducting atmospheric observations. Thanks to his initiative, on June 30, 1978, the Presidium of the USSR Academy of Sciences adopted Resolution No. 827 on the establishment of the High-Altitude Scientific Station of the IAP, which is considered the official birthdate of the HASS. Under the leadership of A. M. Obukhov, research was conducted on the parameters of the ionosphere, CO, H₂O, and orographic disturbances. Continuous measurements of total ozone and nitrogen dioxide at the HASS, which began in 1979, continue today. The station is located in an alpine meadow zone on the Shadzhatmaz Plateau north of the Main Caucasus Range at an altitude of 2070 m above sea level. The gentle northern slope promotes moderate mountain-valley circulation. Due to this, the station is weakly affected by the anthropogenic influence of the nearby city of Kislovodsk, which is located 18 km south of the station.

The station's unique location and high measurement quality allow the HASS data to reflect the state of the free regional troposphere, demonstrate sensitivity to important subtle atmospheric effects, and can be used to solve fundamental and applied problems. The main tasks addressed at the HASS include:

- study of the temporal variability of background concentrations of chemically active and climatically important gas impurities and aerosols, radiation and meteorological characteristics of the atmosphere;
- Study of the influence of mountainous terrain on the structure and dynamics of the atmosphere, as well as on energy transfer and the redistribution of matter in the atmosphere;
- Development of new methods and instruments for measuring atmospheric characteristics;
- validation of satellite measurements of atmospheric and underlying surface characteristics;
study of the dynamics of eco-resources of landscape-climatic resorts.



Mount Elbrus seen through the Brewer spectrophotometer.

Autonomous meteorological complex at the HASS.

The measuring platform and laboratory building with Mount Elbrus in the background..

The station's location allows for the study of the influence of synoptic processes, internal gravity waves of orographic origin, foehn systems, stratosphere-troposphere exchange, air exchange between the boundary layer and the free troposphere, long-range transport of pollutants, and long-term variations in circulation processes on the variability (including long-term variations) of ozone and other gaseous and aerosol impurities. The station is part of the World Ozonometric Network (station no. 282) and the Global Atmospheric Watch (GAW WMO) network for monitoring atmospheric composition. To monitor potential pollutant emissions from the populated Mineralovodskaya sloping plain to the HASS, a measuring site was established in the city of Kislovodsk. This site includes equipment for measuring the surface concentration of chemically active and climatically important atmospheric gases and aerosols. In the 2020s, the city's measuring complex was modernized and expanded with equipment for monitoring boundary layer parameters and measuring the total content and vertical distribution of atmospheric gases and aerosols. These measurement data form the basis for mesoscale modeling of gaseous and aerosol transport in the region, as well as for research into the structure and dynamics of the atmospheric boundary layer. The results of joint measurements in the city and at the HASS are used to solve a complex of interdisciplinary problems related to monitoring the state of the atmosphere and human health, forecasting biotrophic climatic factors and pollution factors, objectively recording meteopathic reactions (the body's reactions to the negative impact of the weather-ecology complex), as well as assessing the impact of aerosol pollution of the atmosphere on local recreational ecosystems (parks and other recreational areas) of mountain resort regions.



Urban measuring site: an autonomous meteorological complex for monitoring boundary layer parameters and a system for measuring the vertical distribution and total content of gas impurities and aerosols in the atmosphere..

JOURNAL "IZVESTIA RAS. ATMOSPHERIC AND OCEAN PHYSICS"

The first issue of the journal "Izvestiya AN SSSR. Physics of the Atmosphere and Ocean" (FAO) was published in January 1965, continuing the tradition of publishing geophysical journals by the USSR Academy of Sciences. The forerunners of FAO were "Izvestiya AN SSSR. Geographical and Geophysical Series" (1937–1950) and "Izvestiya AN SSSR. Geophysical Series" (1951–1964).

From its founding until 1989, the editor-in-chief of FAO was Academician Alexander Obukhov, Director of the IAP RAS. Under his leadership, the journal became one of the leading geophysical journals not only in the USSR but also in the global scientific press. Since 1965, Academician Georgy Golitsyn served as the editorial board's executive secretary (until 1984), deputy editor-in-chief (1984–1989), and then as the journal's editor-in-chief for thirty-three years. In early 2023, by decision of the Bureau of the Earth Sciences Division of the Russian Academy of Sciences, he became the chairman of the journal's editorial board, and Academician Igor Mokhov became the journal's editor-in-chief. Since 2026, Academician Vladimir Semenov has served as the journal's editor-in-chief.

From the journal's inception, its editorial board has included leading Russian experts in atmospheric and oceanic physics and related sciences. The initial editorial board included Academician V.V. Shuleikin and Corresponding Members of the USSR Academy of Sciences I.A. Kibel, G.I. Marchuk, and A.M. Obukhov (editor-in-chief), Corresponding Member of the Academy of Sciences of the Ukrainian SSR A.G. Kolesnikov, Doctors of Sciences K. Ya. Kondratyev, L.M. Levin, A.S. Monin, G.V. Rosenberg, V.V. Shtokman, M.I. Yudin, Doctors of Geographical Sciences V.A. Bugayev and A.Kh. Khrgian, Deputy Editor-in-Chief of the Editorial Board was S.V. Dobroklonsky, and the Executive Secretary was G.S. Golitsyn.

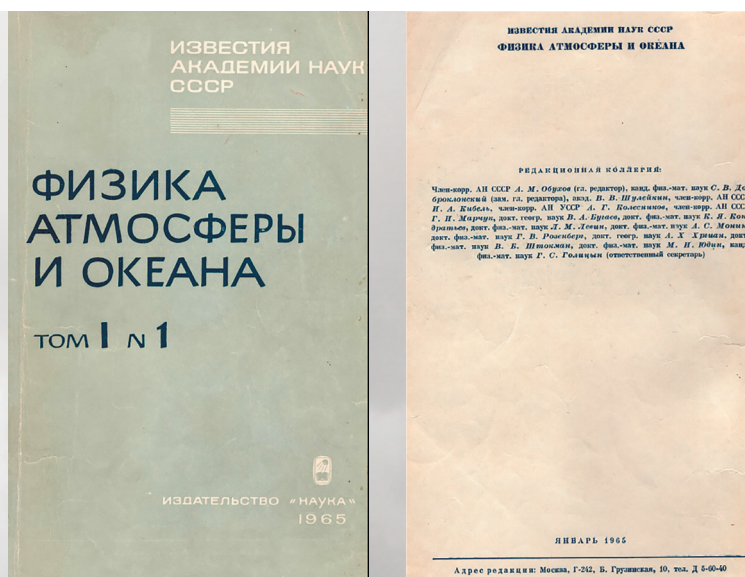
The editorial board's address to readers of the first issue stated: "The rapid development of the physical and mathematical sciences, and geophysics in particular, in our country has led to the fact that the framework of the journal 'Izvestiya of the USSR Academy of Sciences. Geophysical Series' has become cramped for the material submitted to the editorial board's portfolio. Each year, the individual branches of geophysics are becoming increasingly specialized. This has led to the need to divide the geophysical series of Izvestia into two: "Series – Physics of the Atmosphere and Ocean" and "Series – Physics of the Earth."

At the same time, complete continuity is maintained between the corresponding sections of the old series and the specialized geophysical series published since January 1965." As early as 1965, it was stated that the journal would focus primarily on research devoted to the study of physical phenomena in the atmosphere and ocean that determine climate, weather, and their changes—in particular, the processes of ocean-atmosphere interaction—and that one of the journal's main objectives would be to discuss issues of numerical weather prediction and its physical foundations.

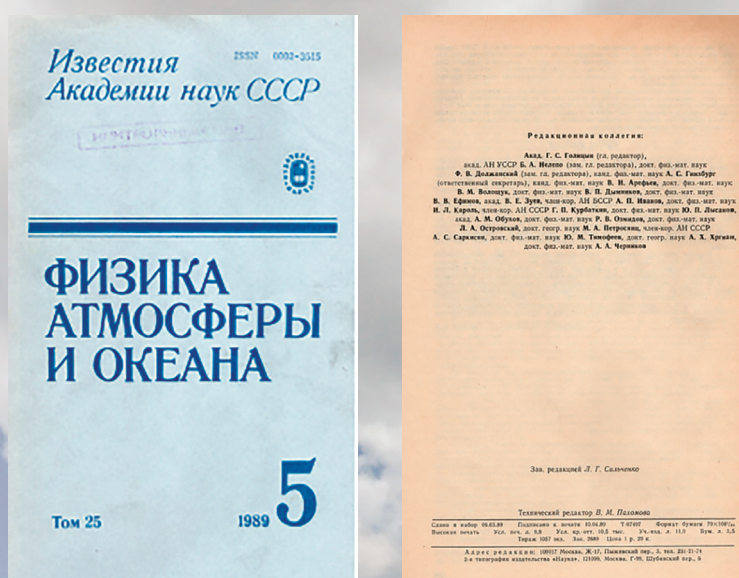
Over the sixty years of the journal's existence, it has published thousands of articles by Russian scientists and authors from near and far abroad. Currently, "Izvestiya RAS: Atmospheric and Oceanic Physics" is a highly ranked journal publishing original scientific research and reviews in the fields of atmospheric and oceanic physics, climatic processes and phenomena. It is intended for researchers, graduate students, and undergraduates. The editorial board, editorial council, authors, reviewers, and contributors to the journal include leading scientists from Russia and other countries.

The journal's publications cover the results of theoretical and experimental research and numerical modeling of the state and circulation of the atmosphere and ocean, natural and anthropogenic climate change, the hydrodynamics of gas and water environments, the interaction of the atmosphere with the ocean and the Earth's surface, turbulent and radiation processes, and the heat balance and optical properties of the atmosphere and ocean. In recent years, the journal has begun publishing more articles on such topical issues as Arctic climate, greenhouse gas emissions and budgets, adaptation to climate change, and low-carbon development strategies.

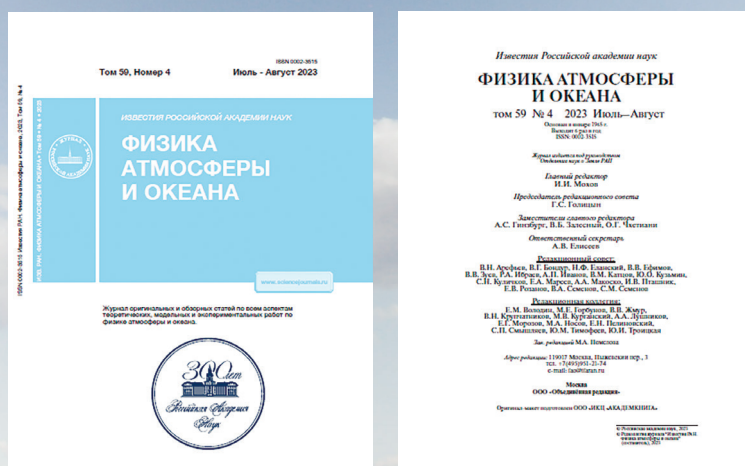
The English-language version of the journal, "Izvestiya," also features articles on the topic of climate change. Atmospheric and Oceanic Physics, which has been published since 1967, currently publishes translations of articles from the Russian scientific journals Research of the Earth from Space (editor-in-chief academician V.G. Bondur), Geophysical Processes and the Biosphere (editor-in-chief doctor of physical and mathematical sciences Yu.O. Kuzmin), Fundamental and Applied Climatology (editor-in-chief corresponding member of the Russian Academy of Sciences S.M. Semenov) and Ice and Snow (editor-in-chief academician V.M. Kotlyakov).



Cover and title page of the first issue of the magazine – January 1965. Editor-in-chief A.M. Obukhov.



Cover and title page of the magazine – May 1989. Editor-in-chief G.S. Golitsyn



Magazine cover and title page – July-August 2023. Editor-in-chief I.I. Mokhov

CONFERENCES AND SCHOOLS

For the A.M. Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences, holding scientific conferences and schools for young scientists is a key form of implementing its scientific policy. Such events not only allow for the presentation of cutting-edge research results but also play a crucial role in building human resource capacity: conferences ensure the continuity of scientific schools, create an environment for the professional development of early-career researchers, and facilitate the attraction of talented young people to climate and atmospheric research.

Starting in 2018, the Scientific Council of the Russian Academy of Sciences on Earth Climate Problems, the Earth Sciences Division of the Russian Academy of Sciences, and the A.M. Obukhov Institute of Atmospheric Physics RAS will organize the All-Russian Conference with International Participation "Climate Change: Causes, Risks, Consequences, Adaptation and Regulation Challenges" (CLIMATE). The event aims to present and comprehensively discuss the latest results of fundamental and applied research in the field of climate change, as well as to bring together interdisciplinary research teams, representatives of government, and the commercial sector to develop coordinated approaches to climate risk assessment and adaptation mechanisms.

In accordance with the Climate Doctrine of the Russian Federation, the problem of climate change is considered one of the most important interdisciplinary challenges, located at the intersection of the environmental, economic, and social spheres and directly related to the long-term security of the country. The relevance of the Conference is due to the rapid pace of ongoing changes in the climate system, manifested in a steady increase in global surface temperature, the degradation of sea ice, land glaciers, and permafrost, rising sea levels, and an increase in the intensity and frequency of extreme hydrometeorological events.

The Conference program includes work in six thematic areas: 1) climate processes and changes: mechanisms, predictability, and extreme regimes; 2) modeling the Earth's climate system and its past, present, and future changes; 3) environmental and socioeconomic consequences of climate change, risks, and opportunities; 4) climate change adaptation; 5) regulation and mitigation of anthropogenic impacts on climate, carbon neutrality; and 6) applied and technological aspects of climate change.

The Conference traditionally includes a competition for the best papers by young scientists, as well as a press conference for media representatives.

The All-Russian Conference "Turbulence, Atmospheric and Climate Dynamics" is held by the Institute every two years and is a key scientific event in the field of hydrodynamics and geophysics. The conference is dedicated to the memory of the outstanding scientist, Academician of the USSR Academy of Sciences, and laureate of the USSR State Prize, Alexander Mikhailovich Obukhov (1918–1989), whose work laid the foundation for the modern theory of turbulence, dynamic meteorology, and atmospheric physics. The event brings together specialists in the fields of geophysical fluid dynamics, general atmospheric circulation, boundary layer physics, atmospheric wave propagation, as well as atmospheric composition and pollutant transport. The conference will discuss fundamental issues of turbulence and the predictability of atmospheric processes, as well as applied aspects related to climate system modeling and the dynamics of natural environments. Regular holding of the conference ensures the continuity of scientific schools, the development of interdisciplinary research, and the strengthening of the professional community, which is especially significant for the institute named after A.M. Obukhov, and for all Russian atmospheric and climate science. As part of Russian-Chinese cooperation, the institute has been holding the annual Russian-Chinese Conference "Physics of the Atmosphere, Climate, and the Environment" for over 20 years. The conference is held every other year in various regions of Russia and China. The event is primarily aimed at strengthening scientific cooperation between Russia and China in the field of atmospheric science. The conference discusses issues of atmospheric dynamics and composition, climate modeling, ocean-atmosphere interactions, and environmental aspects, with particular attention to climate processes at high latitudes and in the Asian region..

IAP RAS is also a co-organizer of the All-Russian Conference with International Participation on Measurements, Modeling, and Information Systems for Environmental Studies (ENVIROMIS) (jointly with IMCES SB RAS and ICM RAS) and the International Scientific and Practical Conference "Fundamental and Applied Aspects of Geology, Geophysics, and Geoecology Using Modern Information Technologies"

(jointly with the Maikop State Technological University) and schools for young scientists "The Earth's Climate System: Diagnostics, Modeling, and Forecasting" (jointly with Sirius University and ICM RAS), "Atmospheric Composition. Atmospheric Electricity. Climate Processes (CIP) (jointly with the Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, and the Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences) and the CITES School for Young Scientists with International Participation on Computational Information Technologies for Environmental Sciences.

In 2026, the IAP hosted the Floating University's Winter School for the first time, conducting the track "Mesoscale Atmospheric Modeling as a Tool for Studying Climate System Sensitivity." The Floating University's Winter School is a project in which students and young scientists, under the guidance of experienced mentors, gain practical scientific knowledge in oceanography and meteorology. The Winter School is the first stage of the educational cycle. Participants who complete the school will then be able to apply for expeditions with the Floating University.



POPULARIZATION OF SCIENCE

Popularizing atmospheric and climate sciences today is not simply an educational mission, but a necessity dictated by the scale of the challenges facing humanity. First, climate change has already become a real factor in economic and social life: energy, agriculture, urban development, and healthcare depend on it. For society to make informed decisions — whether building protective structures, transitioning to low-carbon technologies, or insuring against risks — basic climate literacy is essential. People must understand the difference between weather and climate, be able to interpret forecasts, and resist panic or, conversely, denial. Second, atmospheric and climate sciences are complex and interdisciplinary: they rely on physics, mathematical modeling, and remote sensing data. Without high-quality popularization, these fields remain a "black box" for society, which breeds mistrust of scientific advice. Popularization helps create a realistic understanding of the knowledge and methods available in modern science. Thirdly, public understanding influences support for long-term scientific programs and government initiatives—from maintaining meteorological observation networks to participating in international climate agreements. If people see the benefits of scientific research (more accurate forecasts of hazardous events, sound building codes, adaptation strategies), they are more willing to support investments in science and education.

Finally, popularization plays a key role in attracting young people to science. Atmosphere and climate are a field where striking examples (space images of hurricanes, expeditions, including in polar regions, supercomputer modeling) can inspire schoolchildren and students. Popularization creates the image of a modern, in-demand profession, which is necessary for personnel reproduction in scientific institutes, universities and high-tech industries related to hydrometeorology and environmental monitoring.

Institute staff actively participate in events dedicated to the popularization of scientific knowledge. Institute Director Academician V.A. Semenov, Deputy Directors A.V. Chernokulsky, PhD (Physics and Mathematics), I.A. Repina, and Chief Researcher A.S. Ginzburg regularly appear in

the media with lectures and commentaries on atmospheric phenomena, weather, and climate.

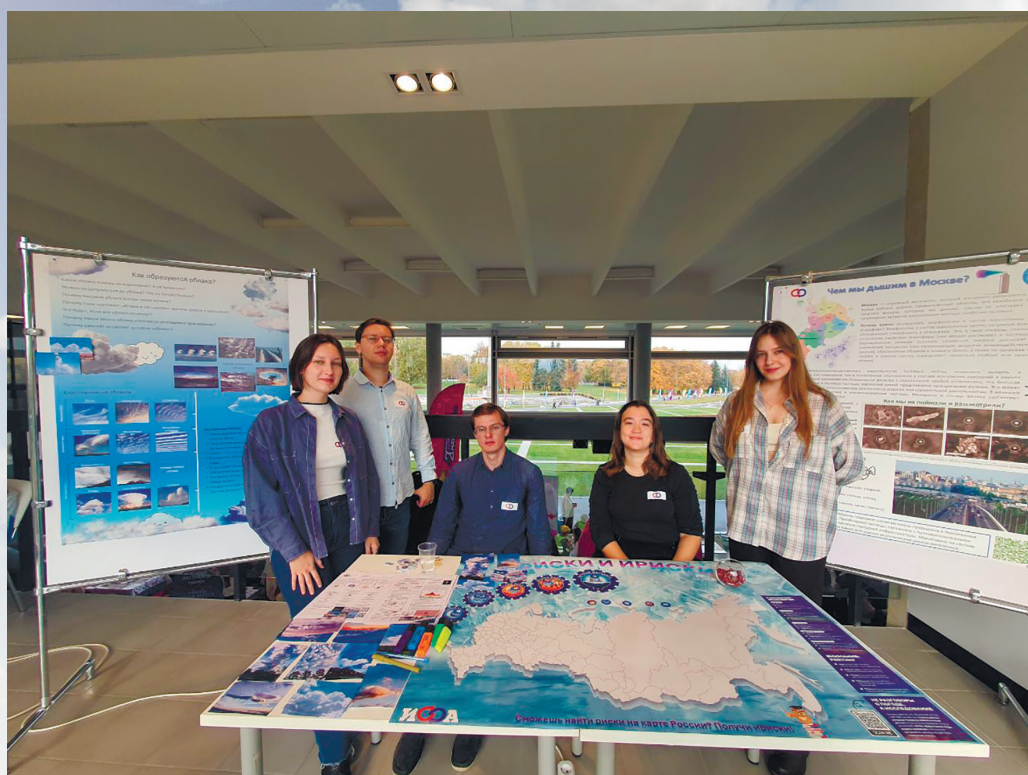
Institute staff actively participate in the "RAS Scientists to Schools" program, conducting lessons for schoolchildren in Moscow and various regions of the country and presenting lecture series at various venues of the annual Science Festival "Science 0+." In recent years, the IAP RAS has also hosted a booth at the festival, offering festival participants a truly atmospheric program, where they can analyze the air, go cloud hunting, and participate in exciting climate quests. During excursions held at the IAP Zvenigorod Research Station, attendees can not only learn about the glow of the night sky and what we actually breathe, but also literally experience unique scientific measurements.

For the 80th anniversary of Victory Day, the institute participated in the exhibition "Scientists at the Front: Contribution to Victory," which featured biographies and photos of institute employees who traveled the front lines.

The publication of the book "How to Talk About Climate?" made an important contribution to the popularization of modern understanding of climate. "Recommendations and Guidelines for Science Journalists and Communicators" was published by the Development and Environment Foundation and the Association of Communicators in Education and Science in November 2021, under the general editorship of A.S. Ginzburg. The recommendations and guidelines offered in the publication will improve the communication of scientific research results on climate change to the general public and strengthen constructive dialogue between scientists, business representatives, and civil society.

The most objective and reliable information on the latest scientific advances in atmospheric and climate research can be found on the Telegram channel of the A.M. Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences

(t.me/ifa_ran).





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