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Russian Investigations in the Field of Atmospheric Radiation in 2011–2014

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Abstract—A short survey prepared by the Russian Commission on Atmospheric Radiation contains the most significant results of work in the field of atmospheric-radiation studies performed in 2011–2014. It is part of the Russian National Report on Meteorology and Atmospheric Sciences prepared for the International Association on Meteorology and Atmospheric Sciences (IAMAS)[1]. During this period, the Russian Commission on Atmospheric Radiation, jointly with the concerned departments and organizations, organized two International Symposiums on Radiation and Dynamics (ISARD-2011 and ISARD-2013). At these conferences, the central problems in modern atmospheric physics were discussed: radiative transfer (RT) and atmospheric optics; greenhouse gases, clouds, and aerosols; remote methods of measurements; and new measurement data. This survey presents six directions covering the whole spectrum of investigations performed in the field of atmospheric radiation.[2]

Keywords: atmospheric optics, remote methods of measurements, greenhouse gases, atmospheric dynamics, radiation climatology

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THEORY OF RADIATIVE TRANSFER

Investigations in this area are devoted to studying the processes of radiative transfer (RT) in different media and for different measurement geometries and to the development of methods and algorithms for solving the radiative transfer equation (RTE) as applied to the problems of atmospheric optics.

Different methods of RT theory are being actively developed at the Moscow Power Engineering Institute. The substantiation of the RTE from a statistical optics point of view is presented in [1]. One important peculiarity of the method [1] is the usage of the matrix Green functions of L.V. Keldysh, which allowed more general results when deriving kinetic equations in the geometrical-optics approximation. A solution of the discrete RTE for the stratified layer with arbitrary boundary conditions is obtained in [2] in analytical matrix form. The separation of the anisotropic part of the RTE solution in other geometries and numerically finding its smooth part is discussed in [3–7]. The generalization of the small-angle modification of the spherical harmonics method (SHM) is obtained in the work [8] to refine the dispersion of the paths of the scattered photons. The series of papers [9, 10] is devoted to a comparison of different algorithms for the solution of the RTE for a plain layer. In order to increase the accuracy of the solution, it is suggested in [11, 12] to use synthetic iterations developed in the neutron transport theory. The authors of [13] suggested the algorithm of light-field calculation in a medium with arbitrary geometry accounting for multiple re-reflections from the borders based on the double local estimation with the expansion of the desired angle distribution into a system of spherical functions; this allows removing the divergence of the double local estimation. By comparing it with the other algorithms and with in situ measurements, the analytical solution of the discrete RTE for a plain layer with the separation of the anisotropic part based on the SHM is tested for the extreme case of a semi-infinite medium with the single scattering albedo of 1 [14]. It is shown that, to find the eigenvalues of the system matrix in this case, one needs to use its Jordan form. In [15], the investigation of the coherent scattering effect on the formation of the light field in a turbid medium is carried out.

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A strict approach based on the usage of the tensor Green function for the solution of the system of Maxwell's equations for the monochromatic field in a homogeneous monoaxial medium is considered in [16]. A general solution is presented that satisfies the arbitrary given boundary conditions. The different models of exponentially correlated random fields, related to the Poissonian point ensemble, and also algorithms of the RT simulation in stochastic media of this type are discussed in [17].

In a series of papers, methods of the RTE solution are developed for applications related to the problems of deriving parameters of the atmosphere, clouds, snow cover, and the sea surface. The multiple scattering effect on polarization and angular distribution of the radiation reflected from clouds is considered in [18] on the basis of the Monte Carlo method. The results make it possible to develop techniques for analyzing the microphysical cloud structure. The methodology for retrieving the clouds and aerosol vertical structure from the passive sensing satellite data is developed by the authors of [19]. The new vector versions are presented in [19] for the longwave and shortwave spectral regions in the RT fast line-by-line model (FLBLM), which allow calculating the Stokes parameters with any spectral resolution. Variations of the angular characteristics of the reflected radiation, the albedo, and the snow-cover absorptivity, caused by the snow roughness in the form of zastrugi, are analyzed in [20]. The numerical simulation is performed within a statistical approach based on the analytical averaging of the RTE and the statistically homogeneous model on the basis of Poissonian fluxes of the points on the straight lines. The impact of the 3D effects of the rough snow surface on the radiation characteristics is analyzed depending on the optical and geometrical parameters of the zastrugi and the illumination conditions. The sea-surface and land models used for the solution of the remote sensing tasks are presented in [21, 22].

ATMOSPHERIC MOLECULAR SPECTROSCOPY

The main directions for the work devoted to the molecular spectroscopy of atmospheric gases are as follows: the experimental study of spectroscopic parameters of atmospheric gases, the development of methods for calculating the parameters of spectral lines and transmission functions, and the completion of spectroscopic databases.

The intensive analysis and theoretical modeling of the experimental spectra of H_2O, CO_2, O_3, O_2, CH_4, N_2O, NO_2, and C_2H_2 molecules and their isotopologues in the various spectral regions and at various conditions take place in the Institute of Atmospheric Optics, Siberian Brunch, Russian Academy of Sciences (IAO SB RAS), together with foreign specialists. These investigations are forwarded towards the study of spectroscopic gas parameters, peculiarities of the spectra obtained with various methods, and intermolecular interactions. The results are presented, for example, in the works [23–39] and have filled spectroscopic databases and information systems with new and improved information on atmospheric gases [40–44]. In the framework of the "Database of Water Transitions from Experiment and Theory" project of the International Union of Pure and Applied Chemistry (IUPAC), in collaboration with scientists from other countries, a critical expertise of the water vapor rotational-vibrational spectra and transitions is carried out [45–47].

A series of investigations is devoted to the analysis of the effect of spectroscopic parameters on the results of atmospheric simulation applied to atmospheric optics. The main spectroscopic factors are studied that introduce uncertainty to the calculation of the atmospheric RT within strong near-infrared absorption bands of methane; these bands are used for the retrieval of the methane content in the atmosphere. The degree of uncertainty in the absorption line parameters of atmospheric gases in modern databases and the impact of the methane line mixing effect are estimated. Methods to increase accuracy when simulating atmospheric transmittance are suggested. The total methane content in the atmosphere is derived from the ground-based Fourier spectrometer measurements of the direct solar radiation spectra with high spectral resolution. It is shown that the results of the retrieval of the CH_4 atmospheric column can vary up to 7% and more when using different spectroscopic databases with methane line parameters [48, 49]. Based on the laboratory measurements of the methane absorption spectra with the optoacoustic and photometric diode-laser spectrometers, the absorption line parameters of overlapping methane multiplets R5 and R9 are derived for nitrogen and neon broadening gases at pressures of 0.005–0.5 atm. [50, 51]. An analysis of laboratory data has shown significant deviations of the observed line shapes from the Voigh profile widely used in atmospheric simulation. The use of the Rautian–Sobel'man profile has made it possible to describe experimental spectra with an error of less than 1%. In [52], the impact of differences between CO_2 line parameters in HITRAN-2008 and CDSD spectroscopic databases on the simulation of the atmospheric transmittance is investigated; it is shown that the difference in transmittance can reach 10% in strong CO_2 bands.

RADIATION CLIMATOLOGY

Investigations in this area were carried out in several directions: monitoring the radiative balance (RB) components and of the atmospheric components having an effect on the radiation regime, studying the climatic trends of RB components near the land surface, and analyzing radiation effects caused by atmospheric gases.

Estimations of the effect of meteoparameter variations and differences in the models of the water vapor continuum absorption on calculated fluxes of the solar and thermal radiation in the atmosphere are made for conditions specific for different seasons in Western Siberia [53–55] and in the Lower Volga region [56]. A calculation of the fluxes of the total, direct, and diffuse solar radiation in the spectral region of 0.2–5 μm in a cloudless atmosphere is made for different models of water vapor continuum absorption upon varying specific humidity in the atmospheric column specific for the summer and winter conditions of Western Siberia. It is shown that the CAVIAR continuum model, based on the new experimental data, causes higher sensitivity of the calculated fluxes of solar radiation to the total water vapor content in the atmosphere when compared to the widely used MT_CKD model. This is caused by the fact that the water vapor continuum absorption in the CAVIAR model, on average, exceeds the prediction of the MT_CKD model in the near-infrared transparency windows by an order of magnitude [53, 54]. For the Lower Volga region, the regression dependence of the radiative forcing of CO_2 on the total water vapor content is calculated. The role of the H_2O continuum absorption is investigated and it is shown that CO_2 forcing, to a great extent, depends on the strength of the continuum. Atmospheric conditions are derived for which the contribution of the H_2O foreign continuum (caused by the interaction of the water molecules with air molecules) into downwelling radiation fluxes is the maximum [56].

In 2011–2014, scientists from the IAO SB RAS continued many years of observations of the total and UV radiation in Tomsk; the Tomsk area; and, in particular, regions of Western Siberia. At the TOR station (56°28' N, 85°03' E), systematic measurements of the total solar radiation have been carried out since April 1995 and of the integral intensity of the UV–B radiation since October 2002. Since 2004, the IAO SB RAS, together with the National Institute for Environmental Studies (Japan), has been monitoring the total solar radiation and various atmospheric gases in the measuring network created on the territory of Western Siberia. The joint analysis of the spatiotemporal variability of the total solar radiation in the region of Western Siberia is performed for 2004–2011 [57]. On the basis of long-term monitoring, the radiation regime in Tomsk and the effect of the city on incoming UV radiation was investigated [58, 59]. The authors of [60] have analyzed the dynamics of the levels of the biologically active UV–B and short-wave UV–A radiation in Tomsk at the time of the ozone anomaly in spring 2011 and estimated the variability in the UV radiation depending on the total ozone content.

Comprehensive work has been done at Moscow State University (MSU) on investigating UV radiation, the impact of various factors on different types of biologically active radiation were estimated [61], methods that qualify the income of UV radiation in the winter period were developed, and estimations of the spatial distribution of UV radiation and UV resources on the territory of Russia and Northern Eurasia at different conditions were performed [62]. Based on the improved measurement methods and new methodology for determining UV resources, the state of UV resources in Moscow has been characterized in the period of measurements from 1999 to 2013 [63]. A set of works has been completed on investigating long-term variations of ecology–climatic characteristics in Moscow and, in particular, variations of the radiative balance components; the radiation in different spectral regions has also been investigated in 60 years of observations [64]. The resources of the solar radiation in the Moscow region were estimated with accounting for modern climatic changes [65]. The analysis of long-term total radiation variability (from 1955 to 2012) testifies to the increase in solar-energy resources in Moscow and the Moscow area at the beginning of the 21st century. The character of the total radiation changes observed in the MSU Meteorological observatory corresponds to the world tendencies [66]. The largest changes were for the radiation balance: since 1994 a sudden growth in the values of the radiation balance has been observed, with the largest changes noticed in nighttime hours during winter seasons [67]. The main role in this process is played by increasing sky counterradiation [68].

AEROSOL AND RADIATIVE FORCING

Extensive laboratory and ground-based measurements of aerosol parameters and estimations of its effect on radiation characteristics of the atmosphere are taking place in the IAO SB RAS, St. Petersburg State University (SPSU), Institute of Atmospheric Physics (IAP) RAS, and the Voeikov Main Geophysical Observatory (MGO).

Systematic laboratory investigations of aerosol parameters (under its artificial moistening) (since 1998) and optical and radiative properties of smoke are carried out at the IAO SB RAS [69, 70]. The results of long-term investigations of the aerosol condensation activity in the city of Tomsk are summarized in [71]. At SPSU, an analyzer of hygroscopic properties of aerosol particles has been created that exceeds by its technical parameters the known models based on the measurement of a wet particle diameter [72]. A theoretical model of hygroscopic growth was developed for multicomponent particles, which describes all stages of the wet growth of the particles, including their volume dissolution and the water vapor surface adsorption [73]. New information about hydroscopic properties of atmospheric particles in the Siberian region were obtained [74].

In 2011–2013, the Scientific and Research Centre (SRC) of Space Hydrometeorology "Planeta", along with scientists from the Kurchatov Institute, the IAP RAS, and the MSU Meteorological Observatory, investigated the opportunities and limitations of the well-known AERONET network for estimations of optical and microphysical properties of the coarsely dispersed aerosol. Quantitative estimations of the effect of coarse dust particles on the accuracy of retrieving aerosol optical parameters from ground-based measurements of the direct and scattered solar fluxes are obtained in [75] on the basis of mathematical simulation. In the work [76], the possibility of forecast adjustment for the propagation of volcanic aerosol in the atmosphere is considered on the basis of ground-based actinometric measurements. The calculated prognostic concentrations of volcanic ash from the Grímsvötn volcano in Iceland (May 2011) were bound to the results of aerosol optical depth measurements in Hamburg at one of the AERONET stations. A comparison of corrected concentrations with the data obtained at the other AERONET stations has shown the validity of the approach suggested. The aerosol properties of the atmosphere above Moscow were estimated using the AERONET data. On the basis of a comparison with the measurements in the Moscow area, the effects of aerosol pollution of the capital were revealed and found, on average, to be rather small [77].

Regular investigations into optical and microphysical aerosol properties have been carried out in different regions of the planet (the shore of the Arctic Ocean, Primorskii krai, the Antarctic, and the Spitsbergen archipelago). A methodological basis has been developed in the IAO SB RAS and an instrumental complex has been created that makes it possible to carry out a complex experiment on the investigation of microphysical, chemical, and optical properties of aerosol particles, as well as on the estimation of the atmospheric aerosol contribution to the radiation balance of the planet [78, 79]. The experimental investigations of aerosol parameters in the marine and high-latitude regions of the planet (the shore of the Arctic Ocean, Primorye, the Antarctic, the Spitsbergen archipelago, and the Atlantic) are carried out regularly by scientists from IAO SB RAS and the Arctic and Antarctic Research Institute. The latitudinal dependence of aerosol parameters and its interannual trend in the Atlantic Ocean were derived [80]; the seasonal and interannual variability of the parameters on the Spitsbergen archipelago [81] and in the northern and southern regions after 2000 was estimated [82]. The results of measurements of the optical and microphysical properties of atmospheric aerosol above the Russian Antarctic intracontinental station Vostok [83] and the Caspian Sea [84] have been analyzed. The totals of simultaneous measurements of the mass concentrations of aerosol and soot and the number concentrations and size distributions of particles were studied in the surface layer near the city of Vladivostok and in the near-water area of the Sea of Japan and Sea of Okhotsk [85]. The peculiarities of the spatiotemporal variability in the microphysical properties of the atmospheric aerosol and variations in microphysical parameters of the atmospheric aerosol in the land–ocean transition area were investigated [86].

Numerous investigations are devoted to the study of aerosol optical depth (AOD) of the atmosphere in different regions of the Earth. The monograph [87] was published in 2014, where the results of comprehensive investigations of atmospheric aerosol in the Asian part of Russia are summarized. Regularities in the spatiotemporal AOD variability in the Asian part of Russia [88–91] and in the marine and the Polar Regions [92, 93] are being studied. Similar investigations are also being carried out within the framework of International programs [94, 95].

An investigation into the thermal effects and radiative forcing of smoke aerosol during forest fires has been performed in a series of works. Parameters and radiative effects of smoke aerosol in the period of extreme forest and peat fires in summer 2010 in the Moscow region are investigated in [96–98]. An approximation of aerosol forcing at the lower border of the atmosphere is suggested in [99]. A comparative analysis of the effect of smoke aerosol on solar radiation has been carried out in a few spectral regions in 1972, 2002, and 2010 in Moscow. It is shown that the most pronounced weakening of the solar radiation took place in 2010 [100]. A comprehensive experiment devoted to the study of dynamics of optical and microphysical parameters of submicron aerosol in the surface layer was carried out in the IAO SB RAS in June–August 2012 during the intrusion of an extremely dense smoke hase from wide-scale Siberian forest fires into the region. Peculiarities in the differences between optical and microphysical parameters of the surface-layer aerosol in the smoke hase of forest fires compared to the smoke-free atmosphere are revealed [101, 102].

Methods for the remote retrieval of aerosol parameters and models for parameterization of its characteristics are being developed and improved. A new method is suggested and tested in [103, 104] devoted to the retrieval of optical and microphysical aerosol parameters based on the data of spectral ground-based measurements of the AOD and scattered solar radiation in the almucantar (SSMART). A modified version of the method [105] is verified in conditions of intermediate and strong aerosol turbidity of the atmosphere in Tomsk and Dakar [106, 107]. It is shown that aerosol characteristics retrieved with the SSMART program agree within the method accuracy with the data presented on a website of the AERONET. Based on the data of the long-term airborn sensing of the vertical profiles of small-angle scattering coefficients, the disperse composition of atmospheric aerosol, and the amount of absorbing particles, a generalized empirical model of the optical aerosol properties in the lower 5-km atmospheric layer of Western Siberia is developed [108, 109]. A two-parameter model was developed for retrieving the aerosol scattering coefficients at visible and near-infrared wavelengths on a long near-surface path using a small number of parameters obtained in the local air volume [110].

Along with the investigations accessing the radiation forcing of aerosol and of the other anthropogenic factors causing changes in the radiation regime, their impact on the climate change is also studied. In the review [111], the authors discuss the modern state in the investigations of several atmospheric components (greenhouse gases and aerosols) and the sources and mechanisms of their depletion; estimations of their contents, emissions to the atmosphere, and impact on the Earth's climate are also presented. The indices of the factors that form different-scale climate changes, estimations of the rates of their variations, and contributions to the expected variation rates of climatic parameters for the different scales and cases are analyzed in the works [112, 113]. Some factors affecting the formation of the Arctic climate are considered in the work [114]. Model estimations of the contribution to the warming caused by the changes in the ocean surface temperature and by in area of the sea ice for two periods (1980–1989 and 2002–2011) and the seasonal variations of the meridional energy transfer to the high latitudes of the Northern Hemisphere are presented. An investigation of the impact of the size distribution and particle structure of stratospheric sulfuric aerosol on its optical parameters and radiation forcing is performed [115].

Investigations of the photophoresic interaction of aerosol particles present in the rarefied atmosphere and illuminated by solar radiation are being continued. A detailed theoretical investigation of this effect is performed for the vacuum camera conditions [116] and for conditions in the real atmosphere [117]. A theoretical analysis of photophoresic movement of soot aerosol in a field of the short-wave solar radiation is fulfilled in [118]. A hypothesis of gravitational–photophoresic support of the middle atmospheric aerosol layers was further elaborated [119]. The lidar observations of the systematic appearance of aerosol layers in the upper stratosphere and mesosphere at altitudes of 35–50 and 60–75 km above Kamchatka can be explained by gravitational–photophoresic forces causing the levitation of the aerosol particles at altitudes mentioned [120]. The transfer of the aerosol layers of volcanic origin [121] and of the polar stratospheric clouds above Tomsk [122] is identified; the transfer of aerosol created in the stratosphere after the fall of the Chelyabinsk meteorite on February 15, 2013, is tracked [123].

REMOTE SENSING OF THE ATMOSPHERE

Ground-based investigations of climatically important atmospheric gases with the use of IR spectroscopy of the direct solar radiation (SPSU, UFU (Ural Federal University), CAO (Central Aerological Observatory), IAP RAS, IAO SB RAS, etc.) continue.

Investigations into the Atmospheric Physics Department of the SPSU on the basis of ground-based measurements of the direct solar infrared spectra of high spectral resolution made it possible to obtain a large amount of new data about total contents of a series of greenhouse, ozone-depleting, and toxic gases (H_2O, CH_4, N_2O, CO, CO_2, C_2H_6, CFC-11, O_3, HCl, HF, HNO_3, $ClONO_2$, and NO_2) near St. Petersburg (Petrodvorets, 59.88° N, 29.83° E, 20 m above the sea level). A large amount of data was obtained for the first time in Russia. These investigations were aimed at (1) the study of the temporal variations and trends of climatically important atmospheric gases [124–133], (2) the validation of satellite measurements by different devices [134–138], (3) comparing ground-based measured contents of climatically important gases with the results of numerical simulation [139, 140], and (4) obtaining new information about some elements of the vertical ozone distribution [141, 142].

A comprehensive program of comparing different methods for measuring the water-vapor content, the most important greenhouse gas in the Earth's atmosphere, has begun in SPSU. A comparison of the infrared spectroscopic method with the data of the microwave and radiosonde measurements is made [143]. Investigations into the temporal variations of NO_2 and O_3 total contents with the use of ground-based measurements of the visible and UV solar radiation scattered in zenith were carried out. These measurements were also used for validating the various satellite measured data [144–149]. The analysis of quality of the temperature–humidity sensing of the troposphere with the RPG-HATPRO radiometer is performed. It is shown that, in the conditions of St. Petersburg, the radiometer allows obtaining real information up to the altitudes of 3–4 km, depending on the season [150]. The measurements of the aerosol optical and microphysical characteristics are started in the framework of the AERONET observations. The work on improving methods for interpreting the remote sensing measurements is being continued [151, 152].

The scientists of the IAP RAS continue the comprehensive measurements of trace gases above Moscow, the Zvenigorod Scientific Station (ZSS), and in the framework of the TROICA experiment by means of a mobile laboratory. The results of the measurements of the total carbon monoxide (CO) amount with the spectrometers of average resolution in the center of Moscow are presented for the period of 2005–2008; their comparison with similar data obtained in Moscow in 1986–2005 and in Beijing in

1992–2007 is performed [153]. The results of long-term observations with a mobile observatory (the TROICA experiments) of the ozone and nitrogen oxide concentration in the ground air along the Trans-Siberian Railway from 1995 to 2008 were analyzed [154]. Atmospheric pollutions in the center of the European part of Russia at the time of fires in summer 2010 are investigated on the basis of ground-based (IAP, MSU and ZSS stations) and satellite (MOPITT, AIRS onboard satellites Terra and Aqua) measurements of the total CO content and concentration [155]; also, the increase in the concentrations of chemically active gases NO, NO_2, CO, O_3, and SO_2 is investigated using experimental data of the Moscow station in IAP RAS [156]. Based on the modern understanding of the processes forming the global methane field in the Earth's atmosphere, the climatic trends and the main features in the formation of seasonal variations and anomalies of methane concentration in the ground layer of the Earth' atmosphere are considered. The measurement data of the ground methane concentration in Moscow and in some stations in Europe and Siberia are analyzed for the autumn–winter period of the first decade of the 21st century [157].

At the Ural atmospheric Fourier station, intended for monitoring various gases in the background atmosphere and for the validation of satellite data based on measurements of the solar radiation spectra with the modern Bruker IFS-125M Fourier spectrometer, the results of a retrieval of the content of heavy water molecules in the Ural atmosphere are obtained [158].

Since 2011, the algorithms of hyperspectral remote sensing of the atmospheric characteristics and parameters of the underlying surface and clouds are being developed in the Keldysh Institute of Applied Mathematics (Russian Academy of Sciences) and implemented in the ATM-RF program package [159].

In 2011–2014, scientists at the CAO developed and manufactured a trial prototype of the ground-based microwave multichannel system for monitoring the atmospheric thermodynamical parameters and performed its experimental approbation [160]. This system allows making continuous measurements of temperature profiles in the altitude region from the surface up to 10 km (in a clear sky atmosphere) and up to 2–4 km (in a cloudy sky); it also allows continuous measurements of the total water vapor column and the cloud liquid water content. The system also provides measurements of the temperature profiles in the atmospheric boundary layer in practically any meteorological condition. With its help, information about the liquid water content in thin clouds and hase is obtained [161]. Together with the specialists of the Hydrometeorological Centre of Russia, investigations into the vertical structure of the heat island above Moscow are continued with the help of microwave temperature profiler MTP-5 installed inside the megalopolis and in the suburb [162]. Specialists from the CAO, IAP RAS, MSU, and the State Environmental Institution "Moskomonitoring" have conducted an analysis of unique data on the heat island and its vertical distribution above Moscow at the time of a powerful blockading anticyclone in summer 2010 [163]. The experiment on estimating the impact of meteorological conditions and precipitations on the measurements by the microwave profiler MTP-5 was carried out in the Bergen valley (Norway) in collaboration with specialists from Nansen Environmental and Remote Sensing Center (Norway), the Finish meteorological Institute, the IAP RAS, and the Institute of Applied Physics RAS [164]. The data on the variability in the vertical structure of the atmospheric boundary layer during solar eclipses is generalized and published [165]. At present, a new generation of Doppler meteorological radars (DMRL-S) is being implemented and an observation network is being created that covers nearly the whole territory of Russia. With the participation of the CAO, the meteorological-laboratory aircraft of new generation has been manufactured (Yak-42D Rosgidromet) for investigating and monitoring the environment. It is equipped with various modern devices for in-city and remote sensing of the atmosphere and has performed a few research flights to the arctic regions of the Russian Federation.

INTERPRETATION OF SATELLITE MEASUREMENTS

Investigations devoted to the development of methods for retrieving different parameters of the atmosphere and underlying surface from the satellite data, as well as to problems of calibration and validation of the satellite data, form the main part of works in this direction.

In the SRC Planeta, the investigations continue that are devoted to the development of methods for interpreting and applying the data provided by domestic polar-orbital and geostationary meteorological satellites of the Meteor-M and Elektro-L series, and to the creation of on-line technologies for the processing of satellite data and retrieval of different parameters of the atmosphere and underlying surface. A new method is developed for the estimation of the near-surface air temperature for the regional and global coverage from the data of the microwave scanner/sounder MTVZA-GYa installed on a spacecraft of the Meteor-M series [167]. The problems of validating the satellite data from temperature–humidity sensing of the atmosphere are considered. The comparative characteristics of the modern satellite microwave radiometers (SSMIS, ATMS, AMSU, AMSR2, and MTVZA) are discussed; these radiometers are intended for obtaining information about the parameters of the atmosphere and underlying surface. The methodical aspects of retrieving the atmospheric moisture content, and cloud liquid water contents, and temperature and humidity profiles of the atmosphere online with the use of ground-based microwave radiometers are presented. The results of a comparison of the satellite temperature–humidity sensing with the data of aerological and ground-based microwave sounding of the atmosphere are analyzed in [168]. A description of an on-board measuring system; the composition of the output data; and the ground-based system for receiving, processing and disseminating the Meteor-M no. 2 spacecraft (launched in July 2014) data is given in [169]. The analysis of the prospects for retrieving atmospheric parameters from the data of hyperspectral infrared sounders, including the IRFS-2 device of the Meteor-M no. 2 spacecraft, is presented in [170]. Together with the Institute of Numerical Mathematics and Mathematical Geophysics (INM&MG) SB RAS, a fast radiation model is developed that is intended for the analysis and validation of the data from the IRFS-2 infrared sounder. The model is tested and its efficiency is estimated. The possibility of creating radiative models based on the Monte Carlo method and applicable for analysis and the simulation of the infrared-sounding data in the presence of clouds is analyzed [171].

To prepare for the interpretation of new space experiments on the Meteor-M no. 2 Russian meteorological spacecraft, algorithms and programs were created in SPSU for retrieving the vertical profiles of temperature, humidity, ozone content, ocean and land temperature, cloud liquid water content, and near-water wind. Numerical experiments were carried out to analyze the retrieval accuracy of all these parameters using satellite equipment (the IRFS-2 Fourier Spectrometer and MTVZA microwave spectrometer) with the help of various techniques for inverse problem solving: multiple linear regression, iteration technique of optimal estimation (statistical regularization), and artificial neural networks [172–174]. Together with the SRC Planeta, a numerical simulation of the technique for obtaining the data of atmospheric temperature–humidity sensing from measurements of the infrared and microwave sounders on the Meteor-M spacecraft was performed [175].

A description of the on-board measuring system on the Elektro-L no. 1 geostationary meteorological spacecraft is presented and methodical issues related to obtaining information from the radiometer/imager MSU-GS data are considered [169]. The regression method for the retrieval of the total ozone content (TOC) in the atmosphere using the MSU-GS data from the Elekto-L spacecraft is suggested and tested on real satellite data. The validation of the TOC estimations is made by comparison with ground-based ozonometric network data and with independent satellite estimations of the TOC from the data of the OMI equipment [176]. In [177], the description of the multiregional satellite recording system (MSRS) on the Meteor-M no. 1 spacecraft, the results of its 3 years of work in orbit, and the ways to develop recording instruments for online monitoring are presented.

Many investigations are devoted to the retrieval of atmospheric and underlying-surface parameters from the measurement data of various overseas satellites and instruments (SEVIRI/METEOSAT-9, AVHRR NOAA, MetOp, SSM/I, Terra, Aqua, etc.) or to the comparison of these retrieved results with the data of independent measurements. In [178], the vertical profiles of O_3, CO, CO_2 and CH_4 concentrations, measured with the aircraft-laboratory Tu-134 Optik, are compared with the data of the IASI Fourier spectrometer on the MetOp satellite of the European Space Agency. The improved scheme for the retrieval of the CO_2 and CO_4 total contents from the AIRS and IASI data and a comparison of the satellite estimations with quasi-synchronous airborne measurements are presented in [179]. The NO_2 tropospheric content above the Moscow region is analyzed for the period of 2004–2009 from the data of OMI measurements [180]. Opportunities for the diagnostics of long-term variations in the NO_x emissions in megalopolises are investigated in [181] using the data of satellite measurements and results of simulations. Using the satellite data from the MODIS, MOPITT, MLS, and OMI instruments, the variations of aerosol optical parameters and the trace atmospheric gases (O_3, NO_2, CO, CH_2O, SO_2) and water vapor (WV) are analyzed for the period of the long blocking anticyclone and fires in the European part of Russia (EPR) in summer 2010. The maximum increase is revealed for AOD and CO [182, 183]. It is shown that the distribution of the WV total content over EPR was anomalous in this period, with the surplus in the north and shortage in the south [184, 185]. A comparative analysis of two large-scale smoke pollutions caused by the summer fires in EPR in 2010 and in Western Siberia in 2012, was performed using the satellite measurements with MODIS and the data of ground-based observations. The average AODs, radiative forcing at the atmospheric borders and radiative heating rates for the smoke-filled atmosphere were retrieved for both events [186]. Preliminary results of the comprehensive investigation of the smoke air pollution in the Moscow region and the results of its ground-based monitoring are presented in [186–188]. Similar investigations for EPR are described in [189–191]. A comparative analysis is performed between the vertical temperature and humidity profiles obtained from the MODIS satellite measurements and the test radiosondes data from the RAOB archive. These results made it possible to study the issue of applicability of the satellite meteodata for radiative calculations and for resolving the problems of atmospheric correction of satellite infrared images of the surface of the Earth [192]. The development of the methods and techniques for the automatic classification of the measurement data from the scanning radiometer–imagers at the polar orbital meteo satellites is continued for deriving the cloudiness and precipitation parameters [193, 194]. Based on the developed method for retrieving the atmospheric parameters from the remote sensing data obtained by geostationary meteorological satellites [195], the evolution of the wind-field parameters (horizontal wind speed, mesoscale turbulent diffusion coefficient, and vorticity) is investigated for the regions of the tropical and temperate-latitude cyclones activity at different stages of their evolution, including the transformation of the tropical cyclone into an extratropical one [196]. The method is developed for retrieving the parameters of precipitation from the frontal cloudy systems [197] and the automated method for retrieving the parameters of the atmospheric jet streams from the remote sensing data of geostationary meteorological satellites; using this method, a spatial distribution of the jet streams and intra-annual variability of their parameters are investigated in the upper stratosphere of the Northern and Southern hemispheres [198]. A series of investigations is performed on developing the methods of satellite diagnostics and forecasting of summer squalls and thunderstorms [199–201].

Several works are devoted to the results of satellite monitoring the oil and inorganic pollutions of the seas and lakes [202–205] and the parameters of snow and ice covers [206–208].

Joint investigations of the Water Problems Institute of the RAS and the SRC Planeta devoted to using remote sensing data on the underlying surface parameters for the simulation of components of the water and thermal balance for a river spillway were continued. With this aim, the methods and algorithms are developed for a subject processing of the information from AVHRR/NOAA, MODIS/Terra, Aqua, and SEVIRI/Meteosat radiometers for the estimation of the soil temperature and emissivity, the air temperature near the plant cover, the normalized vegetation index, the leaf area index, and the vegetation projective cover. The model of the vertical heat and moisture transfer in the system soil–vegetation–atmosphere (SVAT) is improved; the model is intended for the use of satellite data on the underlying surface and some meteorological parameters. Using the SVAT model, the calculations of the water regime for a broad agricultural region are carried out. The results of these investigations are reported in [209, 210].

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