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Elementary Analysis of Galaxy Clusters: Similarity Criteria, Tully–Fisher, and Approximate Invariants

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At observations of galaxy clusters the following quantities are usually measured: luminosity L, size R, mass M, temperature T_e, sometimes velocities. They all are interbinded by the gravity field characterized by the universal constant G. These five quantities are determined by three measurements units: mass M, length L and time T. Therefore one can form two non-dimensional similarity criteria: Π_1 and Π_2. One can also form any chosen observable as a function of the other three ones. The author has at hand the data by [1, 2], rather more complete than any other. This material consists of more than thirty clusters at $0.4 \le z < 1.26$ and $z \le 0.23$ and represents various stages of relaxation. This material gives a possibility to test the derived dimensional relationships and to determine the dimensionless numerical coefficients at these relationships. These coefficients are found nearly constant with a scatter less than 30 per cent in the data above and could be considered as other similarity criteria but functions of Π_1 and Π_2. With such a small scatter they may be called approximate invariants. The luminosity L and universal constant G are forming the dynamical velocity scale U_d, which immediately explains the empirical Tully-Fisher law as: $L \approx U^5/G$. Having the temperature T_e one may determine the thermal velocity of the gas plasma particles U_T. The ratio $U_d/U_T = \Pi_1$ is used here as a new similarity criterium which is found to be constant within six per cent for nearly 30 objects cited above: $\Pi_1 = 0.163 \pm 0.009 \approx 1/6$ and may be interpreted as the Mach number. The other criterium Π_2 is the ratio of the cluster potential energy to its doubled kinetic one and is the virial one. It is found to be a function of the cluster age. This is an evidence of cluster evolution during their life time, evidently through “cannibalism” of neighbours. At $z > 0.5$ the mean cluster mass is five times less, that at small $z \le 0.2$. It is demanding to expand these results to other clusters and different objects: singular galaxies, stars and their clouds, etc. As an example it is found that for the Sun $\Pi_1 = 0.078$, only about a half of the cluster values despite 14–15 orders of magnitude difference in mass and 4–5 magnitude difference in radiation temperature.

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Minor Gas Constituents and Cloud Properties Retrieved from TANSO-FTS/GOSAT spectra

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The Greenhouse gases Observing Satellite (GOSAT) is a joint mission of the Japanese Ministry of the Environment (MOE), the National Institute for Environment Studies (NIES), and the Japan Aerospace Exploration Agency (JAXA), which is dedicated to observation of CO_2 and CH_4 concentrations from space. The main sensor of the satellite is a Fourier Transform Spectrometer (FTS) designated as the “Thermal and Near infrared Sensor for carbon Observation (TANSO)-FTS”, which can sense a wide spectral range including short wavelength infrared (SWIR) bands for measuring columnar concentrations of CO_2 and a thermal infrared (TIR) band for upper air concentrations. It has been operated normally even more than four years has passed after the launch on 23 January 2009. Although the calibration accuracy of TIR band, which was designed to be better than 0.3 K for CO_2 retrievals, has not been achieved yet, gas concentrations and cloud properties have been retrieved as well as temperature profiles.

These results were compared with in situ measurements such as a commercial airline project, CONTAIL, and balloon measurements of ozone. It is shown that biases in gas concentrations correspond to the spectral biases estimated through the comparison with the data from a well calibrated sounding sensor, AIRS. One of the benefits of TANSO-FTS is the synergetic usage of mulch-band spectra for retrieving gas concentrations in the lower troposphere. This method has been applied to analyze the data obtained during the “GOSAT specific observation mode” targeting at mega-sized city such as Tokyo city. These observations have been conducted by the GOSAT science team for more than two years in order to estimate CO_2 emission strength from the urban area. CO_2 concentrations in the boundary layer were tentatively estimated based on the boundary layer thickness estimated from temperature profiles retrieved from TIR spectrum. The results were compared with ground-based in situ measurements made at MRI/JMA observation site in Tsukuba city near Tokyo.

Aerospace and Ground-Based Monitoring of Smoky Atmosphere over European Part of Russia

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Extreme smoke pollution over the European part of Russia (EPR) in summer 2010 influences greatly the ecological situation and the radiative regime of the atmosphere in this region [1, 2]. Evaluation results of the thermal and radiative regimes of the smoky atmosphere over EPR on the aerospace and ground – laser monitoring data are presented.

Thermal regime of the atmospheric boundary layer was estimated using microwave sounding data of the air temperature profilers at three stations in Moscow region, aerospace sounding data (AIRS), and reanalysis data of the meteorological parameters in the troposphere. Essential feature of the thermal regime into blocking anticyclone was found the strong thermal anomaly in the surface layer and the troposphere. The thermal anomaly characteristics for the intensive smoke screening region have been reported in [3].

Smoke aerosol parameters, among them smoke radiative properties were retrieved using ground – based aerosol monitoring data [1], aerosol properties monitoring in the atmospheric column data (AERONET stations) and aerospace monitoring data (MODIS, MISR). An area of the peak smoke screening evolution was being followed.

Water vapor content assessments in the atmospheric smoky layer were received on the data of the measurement in the urban boundary layer at Ostankino TV-tower, on the aerospace monitoring data and on meteorological parameter reanalysis data. Radiative effects of smoke aerosol over EPR were calculated including aerosol forcing on upper and lower boundaries of the atmosphere [3, 4]. Gaseous pollution in smoky atmosphere over EPR has been summarized.

This work was supported in part by RFBR (pr. No 11-05-01144, No 11-05-00704).

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Remote Sensing of Snow and Ice in Polar Regions with Satellite Optical Sensors

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Satellite remote sensing is an important and sometimes the only tool for monitoring sea ice condition, especially over difficult-to-access polar regions. The core of the remote sensing algorithms is the relation between measured radiative characteristics and retrieved physical conditions of the surface. The recent studies of the snow remote sensing (mainly retrieval of the snow grain size, the snow covered area and the snow albedo) have been published extensively.

In this presentation we restrict ourselves to a short summary of the current situation. Also there are plenty of works on the satellite remote sensing of ice (including the retrieval of the melt pond fraction and corresponding variations of ice albedo). The main approach used in these works is based on the *a priori* assignments of the spectra of the pixel constituents, such as melt ponds, dry ice, snow, or open water.

We present the new technique to investigate the ice melting process: to retrieve the melt pond fractions and the sea ice albedo. It is based at the newly developed model of the optical properties of melting sea ice as a scattering medium (in more detail the theory of radiative transfer in sea ice will be presented at Sec. 3). The model of radiative transfer is implemented in the software *IRS* (Ice Reflectance Simulator) that computes the signals of a satellite spectral radiometer under various atmosphere and sea ice conditions.

This theory of the reflectance of melting sea ice and the computer simulation performed was used to develop the algorithm for satellite remote sensing of sea ice. The algorithm includes newly developed atmosphere correction procedure. Each pixel is considered as consisting of white bare ice (can be snow-covered) and melt ponds. The algorithm retrieves the melt pond fraction in a pixel and its spectral albedo. The last values are crucial for various problems concerning climate change and specifically for understanding and prediction of the drastic changes in Arctic environment. Melt Pond Detector software (MPD) implementing the developed algorithm has been designed to be installed and run under the LINUX and WINDOWS operating systems. Currently it is installed in the MERIS processing chain in the Bremen University. MPD product is the maps of the melt ponds area fraction and the pixel spectral albedo. Processing of the historic MERIS data has been established (the data are stored to the online archive). The produced maps allow monitoring the long-time global changes of Arctic ice conditions.

These studies are a part of European Projects DAMOCLES and SIDARUS (6^{th} and 7^{th} EU Framework Programme).

Radio Occultation Monitoring of Internal Waves in the Earth's and Planetary Atmospheres

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Internal gravity waves (IGWs) modulate the structure and circulation of the Earth's atmosphere, producing quasi-periodic variations in the wind velocity, temperature and density. Similar effects are anticipated for the Venus and Mars since IGWs are a characteristic of stably stratified atmosphere. In this context, a new method for the determination of IGW parameters from a vertical temperature profile measurement in a planetary atmosphere had been developed [1–4]. This method does not require any additional information not contained in the profile and may be used for the analysis of profiles measured by various techniques. The criterion for the IGW identification has been formulated and argued. In the case when this criterion is satisfied, the analyzed temperature fluctuations can be considered as wave-induced. The method is based on the analysis of relative amplitudes of the wave field and on the linear IGW saturation theory in which these amplitudes are restricted by dynamical (shear) instability processes in the atmosphere. When the amplitude of an internal gravity wave reaches the shear instability threshold, energy is assumed to be dissipated in such way that the IGW amplitude is maintained at the instability threshold level as the wave propagates upwards. We have extended the developed technique [1] in order to reconstruct the complete set of IGW characteristics including such important parameters as the wave kinetic and potential energy and fluxes of the IGW energy and horizontal momentum [2]. We propose also an alternative method to estimate the relative amplitudes and to extract IGW parameters from an analysis of perturbations of the Brunt-Vaislala frequency squared [2,4]. An application of the developed method to the radio occultation (RO) temperature data has given the possibility to identify the IGWs in the Earth's, Martian and Venusian atmospheres and to determine the magnitudes of key wave parameters such as the intrinsic frequency, amplitudes of the vertical and horizontal wind velocity perturbations, vertical and horizontal wavelengths, intrinsic vertical and horizontal phase (and group) speeds, kinetic and potential energy per unit mass, vertical fluxes of the wave energy and horizontal momentum. The results of the wave studies found from temperature data of the RO missions CHAMP and COSMIC (Earth), Mars Global Surveyor (Mars), Venera 15 and 16, Magellan and Venus Express (Venus) have been presented and discussed.

The joint USA-Taiwan satellite mission Formosat-3/COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) consists of six micro-satellites, and each of them has four GPS-antennas. It was launched in April 2006, orbiting around the Earth at approximately 800 km. The primary scientific goal of the mission is to demonstrate the value of near-real-time RO observations in improving operational numerical weather predictions (NWP). The goal is readily shown by assimilating the measurements of atmospheric parameters into used NWP-models. These parameters include density, temperature, pressure and relative humidity fields in the atmosphere. An analysis of their geographic and seasonal distributions is necessary to the understanding of the energy and momentum transfer, and the reaction of the polar atmosphere in response to global warming. This task is especially important as the Polar Regions are very sensitive to the change in global temperature and it may be a major cause of global sea level rising. A statistical analysis of the IGW activity in polar atmospheric regions (latitudes > 60º) using Formosat-3/COSMIC RO temperature data collected from July 2006 to March 2009 has been performed. Geographic and seasonal distributions of the IGW potential energy (wave activity indicator) in the altitude interval from 15 to 35 km have been determined and analyzed. The obtained results show that the wave activity in the polar atmosphere is strong in winter and spring. The potential energy of IGWs in spring is largest in Antarctic atmospheric region, while it is largest in winter in Arctic region. The wave potential energy increases with altitude up to 35 km in the atmosphere of both Earth's hemispheres. In Antarctic region, internal waves with high potential energy occur in the atmosphere over the Antarctic Peninsula. In Arctic region, a high wave activity is mainly observed over North Atlantic Ocean (Iceland) and Scandinavian Peninsula. The results on an analysis of the wave activity and factors influencing upon it in the polar stratosphere of Arctic and Antarctic have been presented and discussed.

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Current State and Prospects of Satellite Hydrometeorological Systems

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In accordance with Russian Federal Space Program 2006-2015 Roskosmos (VNIIEM Corporation, Lavochkin Association) and Roshydromet (SRC Planeta) jointly develop various satellite hydrometeorological systems, such as "Meteor-3M", "Electro-L", "Arctica-M". A new generation systems "Meteor-MP", "Electro-M" are also now under development, including advanced onboard instruments. "Meteor-3M", "Meteor-MP" constellations should consist of 3 operational meteorological satellites and one oceanographical satellite on sun-synchronous orbits (manufacturer VNIIEM Corporation). "Electro-L", "Electro-M" constellations are to be comprised of 3 spacecrafts on geosynchronous orbit, and "Arctica-M" – of 2 spacecrafts on high elliptical orbits (manufacturer Lavochkin Association). Basic payload of all the mentioned satellites is briefly described. Ground segment based on European, Siberian and Far Eastern Centers of SRC Planeta is also outlined. A comparison is given of current and forthcoming satellite meteorological instruments, both Russian and foreign (Metop, Metop-SG, Suomi NPP, MSG, MTG).

Solar Radiation: Regular/Irregular Changes and Uncertainties

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The investigation of the deterministic or stochastic dynamics over the widest possible range of time scales of the spectral solar radiation (SSR) is attempted, based on the available ground-based, in-situ, and satellite observations. To this aim, the temporal and spatial variability of principal atmospheric parameters for the SSR field is analysed by utilizing modern tools of non-linear analysis. In particular, the spatio-temporal variability of the aerosol optical depth, the atmospheric ozone content, the solar radiation, the sea-surface temperature, the tropospheric temperature as a function of height, and the near-ground albedo for different surfaces and in different atmospheric conditions is discussed. The results obtained provide a clear picture of regular/irregular changes and uncertainties of the SSR-considered as a crucial component of the Earth's climate - indicating plausible improvements to the present modeling of the atmospheric and climate-dynamics.

Calibration Activities at the World Radiation Center, PMOD/WRC

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The World Radiation Center is currently composed of four sections, the absolute radiometry section (ARS), the infrared radiometry section (IRS), the world optical depth research and calibration center (WORCC) and the World Calibration Center for UV WCC-UV)). At the WRC, pyranometers are calibrated using the composite sum method with the WSG for the direct beam and a diffuse reference CM22 pyranometer, while pyrheiometers are calibrated directly against the WSG. The WSG has been compared several times to the cryogenic radiometer at NPL, with differences equal or below 0.1%. A new reference cavity for pyrgeometer characterisations has been built at the Infrared Radiometry Section of the WRC. A prototype IR Radiometer using an integrating sphere has been designed and constructed to become a future reference instrument for longwave radiation which has been compared to the absolute cavity radiometer developed at the National Renewable Energy Laboratory in the US. The triad PFR operated at WORCC form the reference for spectral aerosol optical depth measurements. A new spectroradiometer for direct beam spectral irradiance has been developed for absolute radiation measurements in the range 300 to 1040 nm. Finally, the newest addition to the WRC, the world calibration center for UV radiation, is providing calibrations of broadband UV radiometers following stringent quality procedures according to ISO 17025. Furthermore, the traveling reference spectroradiometer QASUME provides quality assurance of spectral UV irradiance measurements by collocated measurements at solar UV monitoring sites in Europe since 2002 and now world-wide. This presentation will show highlights of these activities which aim at providing calibrations of radiation sensors with state-of-the-art reference instruments developed at PMOD/WRC.

Short-lived Atmospheric Drivers of the Current Climate Changes and Their Radiative and Temperature Indexes

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Studies of the radiatively active gases and aerosols having the mean life time in the global atmosphere not exceeding 10–12 years (the life time of methane) are reviewed. Special attention is paid to the black carbon aerosols producing a significant positive greenhouse effect. The physical, chemical and medical properties of these aerosols are considered together with their atmospheric cycles, their seasonal and diurnal variations over the particular regions.

Radiative and temperature forcing indexes of gases and aerosols are critically evaluated. Some new issues are presented on the possible efficiency of these forcings by using the simple analytical model of the atmospheric thermal regime with parameters close to the real ones.

Atmosphere and Climate Response to Potential Decrease of the Solar Activity in the 21st Century

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It was suggested by several publications that the solar activity will decline within the next century. Such a change can affect future state of the atmosphere and climate due to an alteration of solar spectral irradiance and precipitating energetic particles. To understand the resulting changes we simulate the evolution of the atmosphere in 21st century using atmosphere-ocean-chemistry-climate model in transient mode driven by anthropogenic forcing and natural forcing with and without solar activity decline in the future. We show that potential decline of the solar activity has an important contribution to the climate and ozone layer evolution. In particular we find that the drop of the solar activity is able to compensate about 20% of the warming caused by greenhouse gases emissions prescribed according to IPCC RCP4.5 scenario and slows down the expected ozone layer recovery.

Spectral Characteristics of the Radiation Balance and the Spherical Albedo of the Earth as a Global Characteristic of Climate Change

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The present report focuses on the application of the theory of radiative transfer with polarimetry and hyperspectral approach to space projects of remote sensing of the global climate system of the Earth, by analogy with the approach of studying the solar system planets and galaxies. Polarization observations – one of the most important channels of information in astronomy and astrophysics. Measurement of the polarization produced in all spectral intervals – from radio waves to X-rays. Measurement of the polarization of light provides important information about the properties of both the sources and mechanisms of radiation and about the environment, which absorbs or scatters electromagnetic waves.

The purpose of the report – to draw attention to a class of problems for ekzaflopsnyh supercomputers. It is no coincidence supercomputers put in NASA, as well as in the centers of the climate and space research in Japan, China, Germany, etc. Before creating an expensive and space-effective global monitoring of the Earth it is advisable to model the system based on the "scenario" approach.

As part of the development of computational tools in order to create information and mathematical software for solving direct and inverse (big) problems of the nanodiagnostics of natural and man-made environments methods of hyperspectral (hundreds and thousands of bands of the electromagnetic spectrum from the ultraviolet to the IIM) of Earth remote sensing are considered spherical model of radiation transfer.

These studies are supported by the Russian Fund for Basic Research (Projects No. 11-01-00021, 12-01-00009) and Russian Academy of Sciences (Project No. OMN-3(3.5)).

SESSION 1. "SATELLITE SOUNDING OF ATMOSPHERE AND SURFACE"

Chairman: Prof **A.B. Uspensky** (SRC “Planeta”, Moscow)
Co-Chairmen: Prof. **V.E. Kunitsin** (MSU, Moscow), Prof. A**.F. Nerushev** (SPA "Typhoon", Obninsk), Dr. **L.P. Bobylev** (Nansen Center, SPb), Dr. **A. Kokhanovsky** (Institute of Environmental Physics, University of Bremen, Germany)

The study of the physical parameters of stratospheric aerosols in the Earth's atmosphere

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As it is known, the aerosol plays an important role in the formation of the thermal regime of the Earth and its ozone layer therefore the scientific community is focused on its study very much. The first investigations of the aerosol layer were the space experiments on determining the optical thicknesses from measurements of weakening the sunshine at the entrance (exit) of the artificial Earth satellite (AES) in the shadow (from the shadow) of the Earth (the eclipse experiments). In the early 1990s, being based on the experience of analysis of polarization observations of Venus, a group of J. Hansen (NASA USA) has developed a space experiment with observation complex GLORY that includes scanning polarimeter in the wavelength range $410 \le \lambda \le 2250$ nm. The purpose of this experiment is to study the physical properties of aerosols and their spatial and temporal variations. However, as for the observations of the Venusian atmosphere at $\lambda > 300$ nm the phase dependence of the polarization degree $P(\alpha)$ is formed only in gas-aerosol medium, then in the case of the Earth's atmosphere a significant (and in some cases dominant) role plays the surface. Therefore, a variety of known reflectance of the "atmosphere + surface" makes it almost impossible to get complies with the condition of optical homogeneity of the dependence of $P(\alpha)$, and it is difficult to distinguish the atmospheric and surface component.

During the observations at wavelengths $\lambda < 300$ nm the absorbing ozone layer completely cuts off the influence of the surface and the tropospheric aerosol as well, i.e. those elements that give the greatest horizontal heterogeneity of optical properties and have significant and unpredicted temporal changes. The polarization degree is formed only in the gas-aerosol medium at heights $h > 25$ km. The scanning in a plane that is parallel to the equator provides us with quasi-homogeneous phase function of the $P(\alpha)$, which is suitable for the determination of physical parameters of the stratospheric aerosol at different latitude belts and for identifying their changes over time.

Unexpected Increasing AOT Trends over North-West Bay of Bengal in the Early Post-Monsoon Season

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The Indian subcontinent is characterized by a significant population growth. According to demographic predictions, India will become the most highly populated country in the world by the year 2030 (~1.4 billion). This significant population growth is accompanied by developing industry and increasing transportation, resulting in increased anthropogenic emissions and declining air quality over the Indian subcontinent and surrounding sea areas. The main point of our study is that aerosol trends can be created by changes in meteorology, without changes in aerosol source strength. Over the ten-year period 2000–2009, in October, MODIS showed strong increasing aerosol optical thickness (AOT) trends of approximately 14 % per year over north-west Bay of Bengal (BoB) in the absence of AOT trends over the east of the Indian subcontinent. This was unexpected, because sources of anthropogenic pollution were located over the Indian subcontinent, and aerosol transport from the Indian subcontinent to north-west BoB was carried out by prevailing winds. In October, winds over the east of the Indian subcontinent were stronger than winds over north-west BoB which resulted in wind convergence and accumulation of aerosol particles over north-west BoB. Moreover, there was an increasing trend in wind convergence over north-west BoB. This led to increasing trends in the accumulation of aerosol particles over north-west BoB and, consequently, to strong AOT trends over this area. Our analysis showed that natural aerosols, neither desert dust no sea-salt aerosol, are likely to be the cause of the AOT trends over north-west BoB in October. These increased AOT trends over north-west BoB in October indicate an increase in anthropogenic pollution over the sea. In contrast to October, November showed no increasing AOT trends over north-west BoB or the nearby Indian subcontinent. The lack of AOT trends over north-west BoB corresponds to a lack of trends in wind convergence in that region. Finally, December domestic heating by the growing population resulted in positive AOT trends of similar magnitude over land and sea. Our findings illustrate that, in order to explain and predict trends in regional aerosol loading, meteorological trends should be taken into consideration together with changes in aerosol sources.

Comparison of ground-based and satellite measurements of the total amount of different atmospheric gases

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The ground-based complex for measuring the direct solar IR-radiation spectra with a high spectral resolution on the basis of Fourier-spectrometer Bruker is described. Information on techniques and codes for interpreting the ground-based measurements and obtaining the total amount of various gases is provided. Errors of ground-based measurements of various gases are analyzed. A number of methodical questions concerning the problem of comparing satellite and ground-based measurements is considered. Examples of comparison of ground-based measurements of total amount ozone, water vapor, CH_4, CO, $ClONO_2$, HCl, HF, NO_2, HNO_3, CO_2, etc. with satellite measurements by means of OMI, SCIAMACHY, GOME, MLS, ACE, GOSAT devices are given.

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CLAUS: a CM SAF Cloud Dataset Derived from SEVIRI on Geostationary Meteosat Second Generation Satellites

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EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF) uses space-based observations from geostationary Meteosat Second Generation (MSG) satellites plus polar orbiting NOAA and MetOp satellites to provide satellite-derived geophysical parameter data sets suitable for research on smaller time-scales as well as climate monitoring. CM SAF's portfolio includes cloud parameters, radiation uxes, surface albedo, and atmospheric water vapor, temperature and humidity layered profiles on a regional and partially on a global scale.

CM SAF has recently officially released the dataset CLAUS (CLoud property dAtaset Using SEVIRI). CLAUS comprises micro and macrophysical cloud properties derived from geostationary

MSG1 and MSG2 satellites, covering the time span 01/2004–12/2011. Along with this, a surface albedo dataset has also been composed based on the same measurements and using CLAUS cloud mask as input.

CLAUS was derived from measurements of SEVIRI (Spinning Enhanced Visible and Infrared Imager) which is a broadband line by line scanning radiometer with 12 spectral channels (0.4–13.4 μm), its spatial resolution is 3x3 km^2 at sub-satellite point. SEVIRI radiances are calibrated against MODIS in channels 0.6, 0.8 and 1.6 μm. Cloud fraction, cloud type and cloud top fields were created with the NWC SAF algorithm by Meteo France, while CPP of the Royal Netherlands Meteorological Institute was employed to derive cloud optical and microphysical properties. The surface albedo was retrieved with the SAL algorithm from the Finnish Meteorological Institute.

CLAUS was produced with the following features: The data is available as daily and monthly means, as well as monthly mean diurnal cycles and monthly histograms. They possess a high spatial and temporal resolution 0:05x0:05° for the daily and monthly averages from hourly data, the latter are available on SEVIRIs 3x3 km^2 grid. The careful calibration of SEVIRI radiances significantly increased the quality of the microphysical cloud properties. Due to the high temporal resolution, errors resulting from sampling are very low. The quality of the derived cloud parameters is assured in a validation framework including satellite-based reference observations (e.g. CALIOP, MODIS, AMSR-E) and ground-based data (e.g. LIDAR and spectroradiometer measurements as well as synoptic data).

With CLAUS numerous applications on various temporal and spatial scales are possible. Due to the low sampling errors, the accurately retrieved mean cloud properties allow to evaluate numerical models concerning various cloud parameters such as cloud fractional cover, cloud top parameters or microphysics. With unaveraged fields also the evolution of parameters during a day can be studied down to spatial mesoscale. The monthly mean diurnal cycles allow to study e.g. variations of diurnal fluctuations during a year.

Analysis of dimensionality reduction techniques for ozone retrieval from GOME instruments

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The new generation of European atmospheric sensors Sentinel 5 precursor, Sentinel 4 and Sentinel 5 are expected to provide high spatial and spectral resolution spectra. The TROPOMI instrument on the Sentinel-5 Precursor is expected to produce about one order of magnitude more data than its predecessor OMI, and about 50 times more data than GOME-2 on METOP A/B (launched 2006/2012). In this regard, a fast processing of the data in the UV-VIS spectral domain is required. To accelerate the processing of data, V. Natraj proposed to use the principal component analysis (PCA) to reduce the dimensionality of the optical parameters of the atmosphere.

We demonstrate the flexibility of this method by introducing several dimensionality reduction techniques for the optical parameters. Besides the principal component analysis, these techniques include local linear embedding methods (locality pursuit embedding, locality preserving projection, locally embedded analysis), and discrete orthogonal transforms (cosine, Legendre, wavelet). By linearizing the corresponding radiative transfer model, we analyze the applicability of the proposed methods to a practical problem of total ozone column retrieval from GOME measurements.

The design of a linearized radiative transfer model has been established in a natural way, without specializing the linearization approach to a specific dimensionality reduction method. The numerical analysis, dealing with the retrieval of total ozone column from the GOME instrument, has revealed the following conclusions:

1. The maximum relative difference of the total ozone column retrieved by the PCA-based radiative transfer model is less than 0.006, while the speed improvement is of about 6.24–8.06.

2. The local linear embedding methods are more accurate than PCA, and have comparable efficiencies. For example, the root-mean-square relative difference of the locality preserving projection is 2 times smaller than that of PCA, while the increase in the computational time is of about 1.05–1.08.

3. The discrete orthogonal transforms suffer from a lower accuracy and a lower computational efficiency as compared to the linear embedding methods. However, the differences are not considerable. For example, the accuracy of discrete wavelet transform is comparable to that of PCA, and the growth in computational time is of about 1.22–1.30. In fact, the great merit of the discrete orthogonal transforms consists in the simplicity of their construction, e.g., the discrete cosine basis functions have a closed form representation, which does not depend on the statistic of the data set.

Numerical Simulations of Microwave Thermal Radiation of Inhomogeneous 3D Rain Fields in the Millimeter Band

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Passive microwave sounding is a very effective and commonly applied technique for investigation of atmospheric precipitation from space. Progress in this field is largely related to the experiment SSM/I within DMSP project. Sounding was performed on several frequencies within 19–85 GHz band from the 833 km high polar sun-synchronous orbit. Results of these measurements have been involved in many papers [1].

As it is known, typical signature of the raining atmosphere in the microwave band is its dichroism due to non-spherical shape of falling rain drops. Polarization of both the thermal radiation and radar echoes is determined by this dichroism. Most applied theoretical model of this situation is a homogeneous flat slab medium.

Atmospheric clouds, and therefore rain fields, are typically spatially ingomogeneous (the so-called broken clouds). In practice, a rain field consists of separate rain cells of several kilometers size. Numerical simulations of radiative transfer in such cell is very complicated in comparison with flat layered slab medium.

In the present work, numerical results of computer simulations of thermal radiation in the flat layer, 2D and 3D rain cell are presented. Radio brightness temperatures for vertical and horizontal polarization are assessed. It has been shown that the 2nd Stokes parameter Q (difference between vertical and horizontal poalrization) can reach up to 3–5 K, which is enough for reliable identification of rain with space-borne microwave radiometer. Specifications of the orbital interferometric radiometer necessary for detection and estimation of isolated rain cells are discussed.

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The Operational Monitoring System of the Ozone Total Column Values from Russian Geostationary Meteorological Satellite Electro-L N1

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The paper describes the system of the total ozone column (TOC) values operational monitoring using imager MSU-GS (Multichannel Scanning Unit-Geostationary) measurements from Russian geostationary meteorological satellite Electro-L N1. The TOC estimation is based on the linear regression algorithm (ridge regression) using the MSU-GS measurements in 3 IR channels 8.2–9.2, 9.2–10.2, 10.2–11.2 μm as predictors. The data on atmospheric temperature profiles within the "ozone" layer, on surface temperature and pressure provided by NCEP Global Forecast System Model are used as additional predictors. The products of developed operational monitoring system are the TOC fields on the regular grid with step 0.5° by both latitude and longitude above the Eastern hemisphere in the satellite field of view (disk centered in the satellite point on 76°E within the radius of 65°). The fields are represented in numerical and graphical forms. The comparison to respective OMI-based TOC estimates and NCEP TOC estimates demonstrates the reasonable error level for MSU-GS-based TOC estimates: the relative absolute biases are in the range 1–2%, while the relative RMSE values are about 5–7%, depending on the surface type.

Utilization of Information on Meteorological and Land Surface Characteristics from Polar-Orbital and Geostationary Meteorological Satellites for Modeling Water and Heat Regimes of a Vast Territory

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The methods have been developed to estimate water and heat regime characteristics of a vast agricultural region for vegetation season based on physical-mathematical model of land surface-atmosphere interaction. The model is intended for simulating evaporation from bare soil, transpiration by vegetation, soil water and heat content and other water and heat regime characteristics for the study area as well as soil and vegetation surface temperatures and vertically distributed soil temperature and moisture. It is adapted to the satellite-derived estimates of vegetation cover and meteorological characteristics. The case study has been carried out for agricultural Central Black Earth region (CBER) of the European Russia of 227.300 km^2 containing 7 regions of the Russian Federation for years 2009–2012 vegetation seasons.

In the study the new and pre-existing methods and technologies of radiometer AVHRR/NOAA, MODIS/EOS Terra and Aqua and SEVIRI (geostationary satellites Meteosat-9, -10) thematic processing data have been developed or refined providing the retrieval of vegetation cover and meteorological characteristics which could be used as the model parameters and variables. The methods of their utilization in the model have been also developed. The estimates of three types of land surface temperature (LST): land skin temperature T_{sg}, air temperature at a level of vegetation cover T_a and efficient radiation temperature $T_{s.eff}$, emissivity E, vegetation index NDVI, vegetation cover fraction B, leaf area index LAI, cloudiness and precipitation have been derived from AVHRR data. The set of remote sensing products derived from MODIS data has comprised estimates of LST T_{ls}, E, NDVI и LAI. The SEVIRI-based retrievals have included T_{ls}, T_a, E at daylight and nighttime and precipitation. Verification of the AVHRR-derived LST estimates has been performed through comparison with temperatures measured at agricultural meteorological stations of the region. The reliability of MODIS-based LST estimates has been confirmed by the results of their comparison with ground-based observation data and similar estimates derived from synchronous AVHRR and SEVIRI data. The SEVIRI-derived Tls estimates have been built using developed original method of thematic processing based on the consecutive application of a local "Split Window" algorithm and the method of "Two Temperatures" and using SEVIRI data for cloud-free conditions in the IR channels N9 (10.8 µm) and N10 (12 µm) at three successive times without accurate a priory knowledge of *E*. The reliability of Tls estimates has been verified by comparison with similar synchronous independent SEVIRI-derived T_{ls} estimates produced in LSA SAF (Land Surface Analysis Satellite Applications Facility, Lisbon, Portugal). The SEVIRI-based Ta estimates have been built using new developed and tested method utilizing satellite-derived T_{ls} estimates and its regression relationship with T_a determined by ground-based data. Obtained satellite-derived T_a estimates have been compared with data of synchronous standard network timed observations at agricultural meteorological stations of CBER for the vegetation seasons above.

The complex threshold method (CTM) for automatic pixel-by-pixel classification of AVHRR and SEVIRI data has been developed and tested that designs for the cloud detection and identification of its types, estimation of the maximum liquid water content and water content of the cloud layer, allocation of precipitation zones and determination of instantaneous maximum intensities of precipitation in the pixel range as well as other cloud cover characteristics around the clock throughout the year independently of the land surface type. Results of measurements in 5 AVHRR channels or in 11 SEVIRI channels as well as their differences are used in the CTM as predictors. Dynamic threshold predictor values are calculated for each pixel as a function of the height of the sun, calendar day, the surface air temperature as at 2 m as reduced to sea level, the maximum temperature in the atmospheric column above given point, latitude and altitude of site above sea level, the angle of the satellite sighting, etc. In this study estimates of daily, monthly and annual sums of precipitation for the considered CBER area have been built using the CTM. Validation of the method has been carried out using observation data on rainfall during the day at agricultural meteorological stations. The AVHRR- and SEVIRI-derived daily and monthly precipitation totals have been in good agreement with ground-measured values and with each other. Discrepancies have been registered only for local maxima for which satellite-derived rainfall estimates have been considerably less than for the ground-based ones that may be due to the different spatial scales of area-averaged satellite-derived and point ground-based estimates. The obtained satellite-derived estimates of precipitation can be considered as equivalent of ground-measured meteorological data.

To utilize described remote sensing products in the model the special techniques have been developed that included: 1) replacement the values of the model parameters LAI and *B* determined by observations at agricultural meteorological stations by their satellite-derived estimates. Adequacy of such replacement has been confirmed by the results of comparing time behaviors of LAI built by ground- and satellite-based data, as well as modeled and measured values of soil water content *W* and evapotranspiration E_v and the ground-measured and satellite-derived values of LSTs; 2) entering the values of LSTs $T_{s.eff}$, T_{ls} and T_a retrieved from the AVHRR, MODIS and SEVIRI data and AVHRR- and SEVIRI-derived estimates of precipitation into the model as the input variables instead of the respective ground-measured temperatures and rainfall; 3) taking into account spatial variability of satellite AVHRR-, MODIS- and SEVIRI-derived estimates of LAI, B, LST and precipitation by inputting their area-distributed values into the model.

The final results of the study are fields of soil moisture, vertical water and heat fluxes and other characteristics of the water and heat regimes of SBER territory simulated using the model adapted to satellite data for years 2009–2012 vegetation seasons.

About Supercomputing in Problems of Space Environmental and Climate Monitoring

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New and promising possibilities of mathematical modeling of the Earth's atmospheric radiation for solving direct and inverse problems on the basis of the kinetic equation of radiative transfer and hyperspectral remote sensing of the atmosphere and the Earth's surface are connected not only with the development of a universal information and a mathematical system for a wide range of applications on supercomputers and clusters with supercomputing and parallel computation distribution of resources, but also with the creation and development of international GRID-systems and thematic of cloud systems.

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The possibility to Extract Information about Aerosol and Cloud Structure from Satellites Equipped with High-Resolution Polarization Sensors

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Clouds and aerosols “remain the dominant uncertainty in the radiative forcing” (IPCC, 2007). So retrieval of clouds and aerosols is a big issue in satellite remote sensing. At present the satellites, such as MODIS, provide *more* or less enough information about global distribution of their optical thicknesses. However the radiative forcing depends not only on the optical thickness but also on the structure of the optical active components, especially on their vertical profiles. Thus, it’s necessary to develop suitable experimental and theoretical methods for the retrieval of the cloud and aerosol structures.

In this report we discuss the passive retrieval technique that uses a combination of the cross-nadir polarimetry and high-resolution spectroscopy. It is based on the underlying principle that radiance at different spectral points possesses different penetration depth inside the scattering media due to high variability of the molecular absorption. It gives a possibility to investigate atmosphere layer by layer. Efficiency of this technique is well-recognized and NASA, CNES as well as other space agencies have already launched (e.g. POLDER) and plan to launch a set of the polarimetry sensors (e.g. Aerosol Polarimetry Sensor (APS-NG, 2018 year) and Multi-viewing Multi-channel Multi-polarization Imagers (3MI, 2020-2036 year)). The spectral resolution (bandwidth) of these and other sensors is about 10^2cm^{-1}. Unfortunately such resolution is not enough to obtain the maximum amount of information encoded in the spectra of the outgoing radiation because it takes resolution of ~ 0.01–0.1 cm^{-1} to resolve each spectral line in the troposphere and lower stratosphere. However the real usefulness of such so high-resolution instruments evidently needs to be preliminary confirmed by means of the numerical experiments.

Retrieval of aerosols and clouds structure needs not only high-resolution data, but also information about the polarization. We will show why the information from high-resolution polarization sensors plays major role and give few examples how it can help solving many remote sensing problems. One of these problems is related to the semi-transparent cirrus clouds (*Ci*) which often being 'invisible' produce essential errors in the retrieval data (surface temperature, cloud height, etc.). The technique mentioned above can be useful also for detection of cirrus clouds (*Ci*).

We present both the shortwave and longwave polarized 1-D “forward” models recently developed for this remote-sensing technique. These models are based on the combination of Line-by-Line (LbL) and Monte Carlo (MC) methods. Their principal feature is rigorous treatment of molecular absorption and scattering along with particulate scattering of the polarized radiation and emission of the longwave radiation by atmosphere. The models and their original algorithms will be briefly considered in our presentation. Finally, a set of numerical experiments with different aerosol and cloud models including realistic cirrus cloud (*Ci*) models will be discussed to make clear the real opportunities of this retrieval technique.

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Annual Cycle and Spatial Distribution of Cloud Overlap Parameter: An Assessment Based on Satellite Data

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An incorrect simulation of cloud characteristics in the up-to-date global climate models is the main source of the uncertainties in climate projections. Assumptions on cloud overlap implemented in a climate model may affect markedly modeled radiative fluxes. To increase the ability of climate models to simulate the real climate, it is preferably to know the value of the cloud overlap parameter α which is a measure of the relative weight of maximum ($\alpha = 1$) and random ($\alpha = 0$) overlap. This parameter may be used to diagnose relative contribution of convective and stratiform cloudiness to total cloud fraction.

Here we present an estimate of geographical distribution of α derived from up-to-date satellite observations. To assess values of total cloud fraction, we used cloud masks CERES and MODIS, which both are based on multispectral passive observations from Aqua satellite (CERES SSF product and MODIS collection 5.1). Active CALIOP lidar observations were used to evaluate cloud fraction at different levels (CALIPSO-GOCCP dataset). Cloud overlap parameter α was calculated by merging passive and active satellite datasets. Only monthly means for 2006–2010 were used in these calculations.

The most prominent annual cycle of α is noted in the monsoon regions where α is close to 1 in winter and almost 0 in summer. For CERES total cloud fraction, α is equal to 0.36 in July (0.38 in January) for the entire Earth, it is 0.39 (0.44) in Northern Hemisphere and 0.33 (0.33) in Southern Hemisphere. Values of α are lower when MODIS total cloud fraction is used: global annual mean α is 0.37 for CERES and 0.25 for MODIS. We found that α is linearly dependent on total cloud fraction in most regions, except in the southern tropics. The maximum cloud overlap (α is close to 1) is associated with small values of cloud fraction and occurs in subtropical highs over the ocean and in subtropical and polar deserts over land. On the other hand, the random cloud overlap (α is close to 0) occurs in regions with large values of cloud fraction (e.g. ITCZ and midlatitudinal storm tracks). Moreover, we found that vast regions of the Southern Ocean (around 60° S) are characterized by negative values of α, mostly in summer. Presumably, an assumption of the minimum overlap of cloud layers should be used in these regions due to strong baroclinic instability and horizontal shift of cloud layers.

The relationship of α with total cloud fraction in their spatial distribution is evaluated. We noted that α linearly depends on total cloud fraction worldwide (except southern subtropic ocean). The relationship of α with wind is assessed as well.

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Восстановление пространственно-временной структуры источников и стоков диоксида углерода по данным глобальных наблюдений

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Обратная задача атмосферного переноса решалась в приложении к оценке среднемесячных приземных потоков CO_2 для 2009 года с использованием наземных наблюдений CO_2, а также начиная с июня 2009 года с использованием наблюдений со спутника GOSAT. Поправки к полям потоков для интересующего нас вида источника описываются как линейная комбинация принципиальных компонент соответствующих полей газообмена на поверхности. Для расчета атмосферного переноса используется совмещенная эйлеровая-лагранжевая модель (GELCA model). В связи с тем, что используется большое количество наблюдений (6000–8000 в месяц), для решения обратной задачи была выбрана методика Калмановского сглаживания с фиксированной длиной окна ассимиляции, которая позволяет оценивать месячные потоки последовательно, в соответствии с выбранным размером окна ассимиляции.

Результаты расчетов представлены в виде двумерных полей среднемесячных потоков, а также перерассчитаны для выбранных регионов. Расчеты показывают существенное уменьшение оценки неопределенности потоков при использовании наблюдений со спутника GOSAT.

World Data Center For Remote Sensing of the Atmosphere (WDC-RSAT): Near Real-Time Measurements and Innovative Data Products

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The World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT) offers scientists and the general public free access to a continuously growing collection of atmosphere-related satellite-based data sets (ranging from raw to value added data), information products and services, focusing on atmospheric trace gases, aerosols, dynamics, radiation, and cloud physical parameters. Complementary information and data on surface parameters (e.g. vegetation index, surface temperatures) is also provided. Selected examples of near real-time data products (NRT) and archived datasets will be shown in this presentation.

Development of Interpretation Algorithms and the Numerical Simulation of the Atmospheric Sounding by IR and Microwave Devices onboard METEOR 3

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Different algorithms and codes for interpreting the outgoing IR and microwave radiation measurements by IRFS-2 and MTVZA. The algorithms and codes are intended for retrieving the temperature, humidity and ozone profiles, the land temperature and emissivity, the sea temperature and near-surface wind velocity, the water content of clouds, etc. in various versions of the code, as algorithms for solving the inverse problem, the multiple linear regression (MLR), the artificial neural networks (ANN) and non-linear iterative physical algorithm (IPA) based on the optimal estimation method. In ANN technique, to enhance the efficiency of solving the inverse problem, the principal component analysis is used for temperature and humidity profiles and IR spectra that allows to reduce significantly dimensions of problems.

On the basis the closed-loop numerical experiments errors of the temperature-humidity sounding using the outgoing IR spectra measured by the specified devices are estimated for all the above algorithms. Noticeable advantages of the ANN method in comparison with MLR are shown. So, at IR-temperature sounding at the heights of 1–12 km the MLR gives considerably greater error (a difference is to 1K), and IPA – almost the same error, as ANN technique. When using the ANN technique, retrieval errors for the relative humidity are about 10–15% at the heights. In the lower troposphere, approximately the same error gives the IPA approach, but advantages of the INS technique increase with the height growth. Results of the microwave sounding for a number of integrated parameters of the atmosphere and a surface – the water surface temperature, near-surface wind velocity and cloud water content – are considered.

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Ultraviolet Polarimeter for Studying the Aerosol Component in the Earth Atmosphere

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The changes of the weather and climate on the Earth depend on the temperature balance of the planet, i.e., on the flow of radiation coming from the Sun and emitted by the Earth into cosmic space. The changes of transparency coefficients (i.e., optical thickness of the atmosphere) and reflection coefficients (i.e., Earth surface) turn out to be decisive factors disrupting this balance. Variations of the gaseous and aerosol components of the atmosphere make an essential contribution into the changeability of the existing balance. The stratosphere and the ozone layer which protects the Earth from a severe ultraviolet radiation are of special importance in the atmosphere.

Stratospheric aerosol plays an important role in the formation of a heat regime and in providing a powerful ozone layer (at the altitude of over 30 km). Spectrophotometer investigations made it possible to obtain certain data on the thickness of aerosols on these altitudes. However, its nature (i.e., a real part of the refraction index) and size distribution functions have not be studied so far. Polarization measurements enable one to most correctly determine these characteristics.

The leading astronomical observatory of the National Academy of Sciences of Ukraine in collaboration with the National Technical University of Ukraine "Kyiv Polytechnic Institute" have been carrying out research since 2005 till nowadays on the development of on-board polarimeters for the purpose of studying the stratospheric aerosol from the orbit of Earth satellites [1, 2]. Based on this research, an experimental small sized polarimeter for investigation of a stratospheric aerosol from the orbit of the satellite was created. It is a dot one-channel ultraviolet polarimeter with a rotated polarization element. Glen prism is used as a polarization element which is initiated into motion by a miniature piezoelectric motor. "Sun-blind" low-sized photomultiplier R 1893 made by "Hamatsu" Co. serves as a radiation receiver that operates in one-electron regime. The elaborate scheme as well as the compact structure made it possible to produce an on-board device weighting 0.8 kg and having the volume of the optical-and-mechanical section of 0.33 liter, which enables one to place it on board of any microsatellite. Adjustment and experimental investigation of the developed equipment are carried out at the moment.

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Assimilation of GPS-RO Profiles and its Impact on CPTEC/INPE Global Model

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Assimilation of Radio Occultation profiles has shown to be a useful tool to reduce deficiencies in the meteorological data collection system. These profiles have the potential to improve the quality of the initial model conditions generated in the process of data assimilation, and have been applied successfully by many weather predictions centers. In order to explore the benefits of this additional data source on numerical weather prediction generated by the CPTEC/INPE global model, experiments assimilating COSMIC profiles into PSAS (Physical-space Statistical Analysis System) have been done. In order to investigate the impact of RO-GPS data on the analysis and forecast generated by the CPTEC/INPE global model, COSMIC atmospheric profiles of geopotential height and water vapor were employed for two months (January and July 2009) . Experiments show that the assimilation of GPS-RO data leads to a significant reduction of biases in the forecast of geopotential, humidity and wind in the upper troposphere and the stratosphere, as well as a better RMS fit when compared to analysis. The results show that the inclusion of GPS-RO data extends the forecast range by 36 additional hours. The impact on forecasts was most prominent when processing the data from the Southern Hemisphere. Anomaly correlation score for 500 hPa geopotential heights improves by 0.17–0.22 in the Southern Hemisphere. The benefits from assimilating GPS-RO data were also shown to apply to wind and humidity, demonstrating a significant and positive impact of GPS-RO data in the CPTEC/INPE global model forecasting.

Satellite Passive Correlation CO Sounding in Atmosphere with Usage of a Fabry-Perot Interferometer

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The carbon monoxide CO plays a major role in atmospheric chemistry, influencing on the oxidizing ability of a troposphere, pollution density of air and content of ozone in it. Total quantity on a global scale will increase. However velocity of the increase is determined difficultly because of high spatial and time oscillations of the CO content in atmosphere. In southern hemisphere, the mean ratio of CO and air for a surface of the Earth is ~ 70 ppb, in northern hemisphere it increases, reaching on the latitude 600–200 ppb. The CO destroys mainly in troposphere due to the interaction with OH. The quantities of anthropogenous and natural sinks CO are comparable.

Now the global measurements of the CO content in the atmosphere are carried out approximately in 100 terrestrial units and at 22 stations. The satellite data on the CO content in the atmosphere are obtained by interpreting IR measurements. Satellite CO measurements have been fulfilled, since 2000 г., using the MOPITT device with modulators of the pressure and optical trajectory such as LMC-1, LMC-2, LMC-3, PMC-1, PMC-2 in correlation gaseous cells with band centers of 2166 and 4285 cm^{-1}. The mean error of measuring is 7–14 %. During the long-time satellite monitoring CO in an atmosphere, the optical parameters of a cell can vary owing to the partial decay CO carrying on to change of his volume concentration, and the adsorption of atoms of carbon on cell walls. In the report the possibility of using the Fabry-Perot interferometer instead of a correlation cell is considered as a selective filter permitting to remove this deficiency. By a select of parameters of an interferometer it is possible to achieve a good fit of reflection interferometer spectrums to a spectrum of the CO attenuation in a cell.

The information system “SPECTRA” IAO was used in calculations of the IR attenuation spectra due to atmospheric gases. When the reflection factor of interferometer mirrors $R = 0.7$, the distance between mirrors $H = 0.139$ cm, the mirror absorption coefficient $K = 0.02$, the angle of mirrors W = 0.2003 rad, the level of the interferometer signal reaches 80 % of the signal level in the correlation cell. Thus, the total influence of atmospheric interferences diminishes in 1.5–2 times.

The proposed techniques of the measurements are usable to other gases in the atmosphere, especially for such, where the gas-correlation cell, according to calculation dates, should has a large length (H_2O – 5400 m, CO_2 –50 m and etc.) and in case of chemical-active gases (H_2S, O_3, SO_2 and etc.), when the usage of a cell practically becomes impossible.

The Measuring Technique of Vertical Allocation of the Content of Methane in the Atmosphere with the Help of a Correlation Radiometer

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The calculation of an output signal of a correlation radiometer involves the necessity of replacing the inhomogeneous atmospheric layers by homogeneous ones with the radiance temperature of a specific spectral radiation range corresponding with the radiation of inhomogeneous layer [1]. The transmission function of the chosen homogeneous atmospheric layer is obtained on condition that their values correspond to the transmission function of a real atmospheric layer. The brightness temperature of a layer characterizes emissive properties of homogeneous layer and it can be presented as the effective temperature of thinner homogeneous sub-layers, at which the thermal radiation of sub-layers is equivalent to the radiation of the homogeneous layer.

The change of the effective brightness temperature of a homogeneous layer with its thickness is studied in the methane absorption band of 1220–1260 $см^{-1}$. The deviation of the gas concentration from the reference its distribution in atmosphere is showed up in a change of the output signal of a radiometer measuring the total gas column in the atmosphere and using a gang of correlation cells with explored gas at different pressures. The processing of results of simultaneous measurements of the gas content from the space platform by a correlation radiometer with a gang of correlation cells allows operatively determining the changes in vertical gas distribution during the satellite motion [2]. The impact of the methane content variations in lower atmospheric layers on the output signal of the correlation radiometer located on the space platform is specified.

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An Automatically-Controlled Method for Determining Jet Flows Characteristics Based on Geostationary Satellite Measurement Data

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Jet flows (JF) as a significant element of the atmospheric general circulation not only influence on the distribution of thermodynamic parameters and on the gas admixtures contents in the upper troposphere and stratosphere, but also may be an effective source of inner gravitation waves (IGW) responsible for the energy and pulse exchange between the troposphere and upper atmosphere. Besides, JF have a significant effect on the aircraft flight range and duration in the upper troposphere.

In view of the well-known general laws of jet flows spatial distributions on the globe, their location and characteristics (geometric dimensions, maximum wind speed along the axis, a effective lifetime) undergo significant spatiotemporal variations. The knowledge of a JF location and its characteristics is crucial for solving a series of practical problems. The use of the method developed by us for determining the characteristics of atmospheric motions from the data of geostationary meteorological satellite data [1] and of the novel software makes it possible to automatically determine in the quasi-real time the location and the above-mentioned JF characteristics in the upper and middle troposphere.

The images of the Earth obtained with a temporal resolution of 15 min by the radiometer SEVIRI in the channels of water vapor of 6.2 and 7.7 micrometer from the European geostationary meteorological satellites of the second generation METEOSAT-9 and METEOSAT-10 serve the initial information. With the use of the software developed, the zones of JF are chosen automatically (the ranges with the horizontal wind speed $V \geq 30$ m/s) in the upper and middle troposphere. Their characteristics (orientation, length, width, surface area, maximum wind speed along the axis, effective lifetime) are determined. The effective lifetime means the period of time during which several JF integral characteristics are sustained within certain limits.

JF characteristics in the range of 60° S–60° N, 60° W–60° E for about an annual period are analyzed using the available database of satellite images. Certain regularities of their spatiotemporal variability have been revealed. Main directions of future studies are formulated.

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The Determination of Precipitation Characteristics from the Satellite Measurements in the Optical Wave Length

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Atmospheric precipitation refers to most important meteorological phenomena, the definition of which, and moreover the forecasting, are of a great practical importance for different spheres of human activities presenting one of most difficult problems in synoptic meteorology and climatology. There are several methods for determining precipitation characteristics from the satellite measurement data in the visible, IR and microwave regions of wave lengths. A typical characteristic of the majority of these methods is the use of a great number of atmospheric and underlying surface parameters, the knowledge of which needs diagnostic of forecasting information containing in turn the determination of measurement errors.

The present paper describes a method used for determining precipitation characteristics with the use of a minimum number of parameters. For the determination of precipitation intensity two parameters are used: the cloud optical depth in the visible wave range (τ) and the effective radius of cloud particles (*ref*). The spatial distribution of τ and *ref* is determined from the data of the spectroradiometer MODIS. To determine the total amounts of fallen precipitation it will be sufficient to use two more parameters – the cloud system extent and the velocity of its motion. The characteristics mentioned are at present determined from the measurement data of geostationary and polar-orbital satellites.

The method was tested at computations of precipitation characteristics during the cold season when cyclone Xinthia passed over West Europe in February 2010 and during intense snowfalls over Europe and the European territory of Russia in April 2012 and in January 2013 caused by Atlantic cyclones. The comparison results of computational and observational data obtained at WMO stations are presented along with the estimations of errors of the method used for determining the characteristics of precipitation from frontal cloud systems in the cold season. The range of τ and *ref* variations in precipitating and non-precipitating clouds was determined. A possibility of a 6-hr forecasting of precipitation characteristics with the use of the method proposed is considered.

Nowcasting of Aircraft Icing Conditions in Moscow Region Using Geostationary Meteorological Satellite Data

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Nowadays the Main Aviation Meteorological Centre in Moscow (MAMC) provides forecasts of icing conditions in Moscow Region airports using information of surface observation network, weather radars and atmospheric sounding. Unfortunately, satellite information is not used properly in aviation meteorological offices in Moscow Region: weather forecasters have deal only with satellites images of cloudiness. The main forecasters of MAMC realise that it is necessary to employ meteorological satellite numerical data from different channels in aviation forecasting and especially in nowcasting.

Algorithm of nowcasting aircraft in-flight icing conditions has been developed using data from Geostationary Meteorological Satellites “Meteosat-9”. The algorithm is based on the brightness temperature differences. Calculation of brightness temperature differences helps to discriminate clouds with supercooled large drops where severe icing conditions are most likely. Due to the lack of visible channel data, the satellite icing detection methods will be less accurate at night. Besides this method is limited by optically thick ice clouds where it is not possible to determine the extent to which supercooled large drops exists within the underlying clouds. However, we determined that most of the optically thick cases are associated with convection or mid-latitude cyclones and they will nearly always have a layer where supercooled large drops exists with an icing threat.

This product is created hourly for the Moscow Air Space and marks zones with moderate or severe icing hazards. Verification of the algorithms using aircraft pilot reports shows that this algorithm is a good instrument for the operational practise in aviation meteorological offices in Moscow Region. The satellite-based algorithms presented here can be used in real time to diagnose areas of icing for pilots to avoid.

Tropospheric NO_2 Trend over St. Petersburg as Measured from Space

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Atmospheric air pollution is a strong and permanent factor affecting human beings and environment. The main source of this pollution is an anthropogenic emission of different trace gases, including nitrogen oxides ($NO_x = NO+NO_2$). These gases are not only radiative- and chemical- active compounds, but also a hazardous toxins, being harmful for the human health in high concentrations.

The data of many years tropospheric NO_2 satellite measurements, carried out by the instruments GOME, SCIAMACHY and OMI in 1996–2012, were consolidated into a uniform series to analyze possible long-term change over the city of St. Petersburg. Most recent processing of satellite data was used (http://temis.nl, version 2) and compared to the results of previous similar studies. The new data was found to considerably differ over the region of study (St. Petersburg) – for instance, tropospheric NO_2 column is reduced almost twice during winter time (compared to data version 1). Resulting time series of monthly mean tropospheric NO_2 column over the duration of ~17 years, was approximated by a model function taking into account the linear term (increase or decrease) and the components to characterize meteorological conditions responsible for the accumulation or dispersion of NO_2 in the troposphere – boundary layer height, surface pressure, surface temperature and wind speed data from ECMWF. Based on that analysis, statistically significant trend is estimated to be ~ 6% per year, which is in general agreement with an official estimates of NO_x emission growth in St. Petersburg.

These studies were performed using the equipment of the SPbSU Resource center "Geomodel".

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Impact of Land Convection on Temperature Diurnal Variation in the Tropical Lower Stratosphere Inferred From COSMIC GPS Radio Occultations

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Following recent studies evidencing the influence of deep convection on the chemical composition and thermal structure of the tropical lower stratosphere, we explore its impact on the temperature diurnal variation in the upper troposphere and lower stratosphere using the high-resolution COSMIC GPS radio-occultation temperature measurements spanning from 2006 through 2011. The temperature in the lowermost stratosphere over land during summer displays a marked diurnal cycle characterized by an afternoon cooling. This diurnal cycle is shown collocated with most intense land convective areas observed by the Tropical Rainfall Measurement Mission (TRMM) precipitation radar and in phase with the maximum overshooting occurrence frequency in late afternoon.

Two processes potentially responsible for that are identified: (i) non-migrating tides, whose physical nature is internal gravity waves and (ii) local cross-tropopause mass transport of adiabatically cooled air by overshooting turrets. Relative contribution of these processes to the diurnal cycle above various geographical regions in the tropics is discussed. The impact of deep convection on the temperature diurnal cycle is found larger in the southern tropics, suggesting more vigorous convection over clean rain forest continents than desert areas and polluted continents in the northern tropics.

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Carbon Dioxide Concentration Simulation Using GELCA Model for Assimilation of Satellite Observations

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International satellite project GOSAT was started at February 2009. This work presents the approach of carbon dioxide concentration simulation using Global Eulerian/Lagrangian Coupled Atmospheric model (GELCA) developed within the framework of this project.

Comparing the model results and observations shows that GELCA model can be applied for analyzing and reconstruction of observations (monitoring stations, aircrafts and satellites). Furthermore the model is a part of the developed data assimilation system which used for the reconstruction of the greenhouse gases sources and sinks. In this work the model was used for the simulation of CO_2 but it can be successfully applied for the other atmospheric components with predetermined emissions.

Satellite-based Spectroscopic Observations of Carbon Dioxide under Significant Atmospheric Light Scattering: Application to GOSAT Data Processing

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High precision needed for global carbon dioxide observation from space requires accurate consideration of atmospheric light scattering due to aerosol and clouds. This report represents an improved Path length Probability Density Function (PPDF) method to simultaneously retrieve concentrations of greenhouse gases and light path modifications from space-based spectroscopic observations of light reflected and scattered from the Earth's surface and the atmosphere. The target quantity to retrieve is the column-average greenhouse gas mole fraction. The light path modification was involved in the retrieval process to account for high variability in the optical properties of aerosols and clouds through the atmosphere.

This method has been applied to process radiance spectra measured by the Greenhouse gases Observing SATellite (GOSAT), in orbit since 23 January 2009. The measurements of radiance spectra were provided by the Thermal And Near-infrared Sensor for carbon Observation - Fourier Transform Spectrometer (TANSO-FTS) in the short wave infrared bands at 0.76, 1.6, and 2.0 μm as the center with a high spectral resolution (interval) of about 0.2 cm^{-1}.

To test the method we have compared PPDF-based CO_2 retrievals from GOSAT with those derived from FTS ground-based measurements over the Izaña site from the Total Carbon Column Observing Network (TCCON) (http://www.tccon.caltech.edu/). GOSAT PPDF-based retrievals were collected within a large sampling domain (15° latitude × 45° longitude grid box) and ground-based FTS data were mean values measured within 1 hour of the GOSAT overpass time. These observations cover both dark (northern Atlantic Ocean) and bright (western part of the Sahara desert) surfaces. Therefore, these tests are representative of conditions where we expect both light path shortening and light path lengthening due to high -altitude cirrus or coarse aerosol particles from Saharan dust. This comparison showed a good agreement of the satellite PPDF-based CO_2 retrievals as compared with ground-based FTS measurements of CO_2 over Izaña site.

We also tested the proposed method for those GOSAT observations when high-altitude clouds were horizontally inhomogeneous within the GOSAT pixel.

Intercalibration of Russian Satellite Instruments and IR Sounder IASI

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Special studies including a comparison with data from other satellite instruments and special aircraft measurements confirmed the high accuracy and stability of measurements from two IASI sounders installed on board of ESA's two METOP satellites. In this regard, the technique of using IASI measurements as reference data for the intercalibration of national satellite instruments MSU-MR & IRFS-2 has been developed. The MSU-MR scanner and IRFS-2 sounder are and will be installed on board of the polar-orbiting weather Meteor-M # 1&2 satellites.

The main feature of proposed technique is the use of IR channels of SEVIRI or MSU-GS scanners installed on geostationary satellites Meteosat or Electro-L as transfer standards for calibration of MSU-MR & IRFS-2 from IASI measurements. For calibration, the cloud-free pixels of the territory, which is observed from a geostationary scanner, are selected for IASI measurements closest in time to measurements of test instruments. For calibration, the difference of brightness temperatures $\Delta T_1 = T_G\text{-}T_{\text{IASI}}$ is calculated, where T_G is measured in the IR SEVIRI or MSU-GS channel, T_{IASI} is calculated from IASI measurements taking into account the channel instrumental function of geostationary instrument. An analogous difference $\Delta T_2 = T_G\text{-}T_{tst}$ is calculated for the test instrument (MSU-MR or IRFS-2). Difference $\Delta T = \Delta T_1\text{-}\Delta T_2$ is a calibration correction to the test instrument.

The theoretical substantiation of the approach has been carried out by simulation of IR satellite measurements by a well-known line-by-line radiative transfer model LBLRTM. Experimental validation of the technique has been carried on satellite measurements over the Indian and Atlantic oceans under cloud-free conditions.

Estimation of Stability Indices from ATOVS/NOAA and ATOVS/METOP Measurements over Ukraine

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The scheme of the estimation of stability indices over Ukraine using ATOVS/NOAA and ATOVS/METOP measurements is developed. Stability Index is defined as the stability of the atmosphere in hydrostatic equilibrium with respect to vertical displacements and it is a critical factor in the severe weather development. Atmospheric profiles, required for estimating the Stability Index are retrieved using the IAPP package which reads ATOVS level 1D data and produces temperature and water vapour profiles. *K* index, *KO* index, lifted index, and maximum buoyancy are obtained.

The retrieved temperature and water vapour profiles based on satellite-date are in a good agreement with observed ground radio sounding data. In order to test the usefulness of this estimation of stability indices for short-term forecast, several cases of rapidly developing convective storms observed over Ukraine were analysed. The comparison between stability indices estimation from satellite derived atmospheric profiles and NWP forecast shows that the first one is able to predict instability better over pre-convective areas. Thus, it is expected that the nowcasting and short-term forecast can be improved by the operational Stability Index products derived from satellite measurements of atmospheric profiles.

Comparison of Satellite (GOSAT) and Ground-Based Spectroscopic Measurements of CO_2 and CH_4 Content Near Saint-Petersburg (59.9ºN, 29.8ºE)

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Comparison of atmospheric column mean mole fraction of carbon dioxide and methane measured with ground-based Fourier-transform spectroscopy at the Peterhof base of Saint-Petersburg State University (59.9° N, 29.8° E) in years 2009–2011 and 2009–2012 with similar data obtained with the Japanese GOSAT satellite is performed. The comparison shows that the average CO_2 mole fractions from satellite data version V01.xx are by 9.8 ± 3 ppm less than the corresponding values obtained from ground-based measurements. For the GOSAT data version V02.xx this average decrease is 4.7 ± 2.6 ppm. Some overestimating CO_2 measured near Saint-Petersburg compared to the TCCON ground based network is indirectly detected, reasons of which require further explanation.

Average CH_4 mole fractions for the GOSAT data version V01.xx are by 13 ppb less than the corresponding values obtained from the same date ground-based measurements (with standard deviation ~ 26 ppb). For the GOSAT data version V02.xx the average differences are ~ 4 ppb and standard deviations ~ 15 ppb. This shows that FTIR spectroscopic observations near Saint-Petersburg, utilizing NDACC retrieval algorithms, could agree with GOSAT satellite data.

These studies were performed using the equipment of the SPbSU Resource center "Geomodel".

This study was done with partial financial support from research grants 11.31.547.2010 and 11.37.28.2011 of Saint-Petersburg State University, as well as from the grant 12-05-00596 of the Russian Basic Research Foundation.

Two Methods for Radiation Calibration of Multi-zonal Satellite Sensors with High Spatial resolution

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The traditional method to perform the radiation calibration of satellite sensors using the test site includes measurements of the signal at the input of the calibrating satellite sensor and simultaneous field measurements of the atmosphere and surface parameters (albedo and radiance reflection coefficients of the underlying surface). The characteristics of atmosphere and underlying surface are used to compute the spectral density of the solar radiation at the input of the satellite sensor. For these calculations the altitude structure of aerosol-gaseous atmosphere is assumed to be known a priori. Besides the computations of the radiative transfer in the coupled system atmosphere-underlying surface are supposed to be performed with regards to the influence of the adjusted pixels contribution into the registered satellite signal from the test pixel. This influence exists because of molecular and aerosol scattering in atmosphere and as known is essential at the distances up to 5km.

We propose here two methods to calibrate the satellite multi-zonal sensors (MZS) of high spatial resolution. The first method requires the registration of signals from two (or more) closely located test pixels with different albedo. It enables to significantly simplify and improve the accuracy of the radiation calibration of MZS instruments. To implement this method one needs to measure the atmosphere optical thickness, irradiance, and albedo and radiance coefficients of two test sites. Compared with traditional calibration process new method eliminates the need of a priori knowledge of the vertical structure of atmosphere, the necessity to calculate radiative transfer in the coupled system atmosphere-underlying surface, and accounting for the effect of neighboring pixels in the signal recorded by the satellite sensor.

The second offered method is cross-calibration of the MZS with high spatial resolution using data of other well-calibrated satellite multi-spectral sensor (MSS) of moderate spatial resolution (MODIS, MERIS), possibly operating from its own platform. This procedure requires: (1) to find the co-located and practically simultaneous survey of the MSS and the calibrated MZS instrument; (2) to retrieve the spectral characteristics of the atmosphere and underlying surface using MSS data; (3) using this data to compute the signals in the spectral channels of the high spatial resolution MZS and to compare this calculated signal with the measured MZS signal averaging over the same MSS pixel.

We will demonstrate the results of such cross-calibration of the satellite sensors ASTER and ALOS in Visible and near IR regions using MERIS data. The relative scatter of the calibration factor was the order of 3–5%. These results are in the good agreement with the careful calibration using test sites performed by three research groups from USA and Japan.

Estimation of the Solar Activity Index Based on the Total Electron Content Measurement and IRI2012 Model

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The problem of the solar activity index estimation based on the total electron content (TEC) measurement has repeatedly been discussed in the literature. For example, in the European satellite navigation system «Galileo», it's assumed to be first of all to calculate the effective ionization parameter (A_z) to correct the ionospheric delay. The parameter A_z is calculated on the base of navigation signal measurements (at least by twenties base stations) and specifically developed semiempirical ionospheric model NeQuick. Then the maps of ionospheric delays are calculated on the base of the A_z using NeQuick model. Initially the NeQuick model has been produced for the TEC calculations where the monthly average solar activity index F10.7 data have been used as input data. However, in the process of working out methods to solve the inverse problem that consists in determination of the solar activity index based on the TEC measurements (the Global Ionospheric Maps have been used as experimental data) it's turned out that the computed index F10.7 substantially changes within 24 hours and depends on latitude and longitude of the observation point. In some cases the index can be negative or be equal some hundreds that significantly exceeds the possible F10.7 value. Consequently, the authors limited A_z in range from zero to some hundreds. In this respect, the authors suppose, that the substantial variability of A_z is accounted as well by the experimental data errors.

By working out method of the solar activity index determination based on the TEC measurements the three initial conditions have been chosen: 1) the computed solar activity index is constant during a day and doesn't depend on coordinates; 2) the method is based on IRI2012 model, as the most adequate model for the experiment; 3) measurement errors of the navigation signals and model errors of the IRI2012 model are random errors, thus the statistically mean values of the solar activity index have to be calculated.

To perform the method the IRI2012 model has been adjusted to calculate the TEC profiles with input data: time, coordinates and only daily value of the F10.7 index. The calculations of the ionospheric delay's signals is carried out along the trajectory of the radio wave propagation with the fixed step. To take into account the horizontal gradients of the ionosphere along the trajectory of the radio beam a few profiles of the vertical electron density are calculated.

To determine the experimental ionospheric delay the equation for linear combination P_4-L_4, $P_4=P_2-P_1$, $L_4=L_2-L_1$ is formulated. The measurements is performed at one point with mask of angle of altitude 20° for two adjacent time points. Then the equation is supplemented with the expression connecting the TEC for two different angles of altitude along line from receiver to satellite. Solution of the two equations allows us to select the ionospheric delay on a background of random errors due to the instrumental errors as well as parameters of the ionosphere.

Averaging of the solution within the time interval allows us to increase the ratio of signal to the noise. The daily solar activity index (FTEC) is determined on the base of the value of the experimental delay and IRI2012 simulation. The FTEC values are averaged for selected time interval at midday and for various satellites. The variations of FTEC values during January 2013 have been calculated by use of ONSA station data. In general, they coincide with variations of the daily F10.7 values during the same time period. It has to be noted that outliers on the FTEC variation curve completely correspond to outliers on curve of magnetic activity index (*Ap*) variation during January 2013.

The Method of Refinement of the Geopotential Field over Areas Uncovered by Meteorological Observations Using Meteorological Artificial Earth Satellites Data

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The question of an increase the accuracy of diagnosis of the geopotential field is issue of much interest. Papers devoted to engaging of the meteorological artificial Earth satellites (MAES) data as additional information could be technically separated into two groups. In the first group the methods of image analysis of the cloud fields are examined. The second group considers the processing methods of outgoing radiation quantity in different spectral regions. The problem of reconstruction of the geopotential field in the pressure air system is solved in the first group of papers. However, despite the presence of many approaches, the problem of the use of satellite-based data under analysis of meteorological variables has not yet been fully resolved.

The method proposed allows to use cloud fields data under the objective analysis of geopotential field based on the spline approximation. Under such approximation an information about statistical structure of the field doesn't use and an obtaining of the global continuous field of the explored variables is provided. Moreover, there is a possibility to involve not only value of the variables but their directional derivatives under the approximation. As information that we apply in analysis of the geopotential field the coordinates of the centers of cyclones data and zonal and meridional components of the wind vectors are used. This information is obtained as a result of the 1B level data (geographically attached and radiometrically calibrated images) from NOAA and Meteor-3M satellite space systems. In the first stage of this process the mask of clouds is formed. Then the presence of clouds identified by a logarithmic spiral. The third stage consists in determination of the coordinates and parameters of the spiral allowed to identify the coordinates of the center of the cyclone as well as direction and speed of wind at different points of the spiral.

The presence of clouds identified by the logarithmic spiral is determined by the correlation-extreme identification method. A set of standard spirals and related with them characteristics of directions and speeds of wind have statistically been obtained at different points. The information obtained is used for the refinement of the geopotential field in the following way. In the original minimization problem, taken as a basis of the construction of the approximating spline, the value of the geopotential data obtained from a net of the upper-air sounding and the derivative values in the directions determined according to the MAES data are used as constraints. In the free atmosphere as such information the zonal and meridional components of the wind vectors can be used for the geopotential fields.

It is possible to use them due to at the first approximation in the atmosphere above the boundary layer the mode of motion is determined by the gradient of the geopotential and the Coriolis force. In the centers of the cyclones the derivative values in the directions become zero.

Numerical experiments performed have shown a good consistency of the refined geopotential fields, that have been obtained by the developed technique, and cloud fields observed on images being obtained from MAES.

SESSION 2. "REMOTE SENSING OF ATMOSPHERE AND UNDERLYING SURFACE IN DIFFERENT SPECTRAL RANGES"

Chairman: Prof. **Yu.M. Timofeyev** (SPbSU, Saint-Petersburg)
Co-chairmen: Prof. **V.N. Arefyev** (SPA "Typhoon", Obninsk), Prof. **G.G. Shchukin** (MGO, SPb), Prof. **A.A. Troitsky** (RRI, N.-Novgorod), Prof. **Costas Vorotsos** (University of Athens, Greece)

Remote Sensing of Carbon Greenhouse Gases and Isotopes of Water Vapour in the Atmosphere Using Ground-Based FTIR of Ural Atmospheric Fourier Station in Kourovka

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The Kourovka observation site (Ural Atmospheric Fourier Station, 57.038° N, 59.545° E, 300 m elevation) is equipped with Fourier interferometer Bruker Optics IFS-125M (maximum spectral range 420–25000 cm^{-1}, maximum resolution 0.0035 cm^{-1}) conjugated with solar tracker A547N, Picarro L2130-i water vapor isotopic laser analyzer, and Gill Instruments MetPak-II meteorological station. Ural Atmospheric Fourier Station (UAFS) aims to remote sounding of GHGs in the atmosphere and validation of satellite data. Altogether with solar irradiance spectra the following parameters are measured at surface continuously: atmospheric pressure, air temperature, relative humidity, speed and direction of wind, absolute concentration of water vapor (ppm), values of δHDO and $\delta H_2{}^{18}O$ (expressed in ‰). Number of atmospheric spectra in the NIR range (4000–12000 cm^{-1}) had been recorded since summer of 2010 to summer 2013. Series of retrieved from the spectra columnar values of CO_2, CH_4, CO, H_2O and HDO in the atmosphere over Kourovka observation site are presented. Correlations between FTIR columnar values of $\delta H_2{}^{18}O$ HDO and in-situ measurements and isotopic general circulation model ECHAM5-wiso outputs are discussed.

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First Measurements of Formaldehyde Integral Content at Zvenigorod Scientific Station

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Formaldehyde (HCHO) is the most abundant organic carbonyl compound in the atmosphere. This is a short-lived oxidation product of a large number of volatile organic compounds (VOCs). Its abundance can be closely related to VOC emissions of natural origin or from human activity.

Measurements of scattered sunlight at UV-Vis spectral region are carried out at the Zvenigorod Scientific Station (ZSS). We developed a procedure of the HCHO retrieval from these measurements [1]. Using DOAS procedure we retrieved HCHO differential slant column densities (DSCDs) from measured UV spectra by JAMSTEC MAX-DOAS at the ZSS during summer and autumn 2010. Basing on obtained results we investigate the possibility to reveal 1) Moscow influence on HCHO (traces of weekly cycle in the HCHO data) and 2) temperature effect in the HCHO data.

1) When polluted air comes from Moscow, HCHO DSCD on Monday morning is less than one on Tuesday morning. It can be a manifestation of the weekly cycle of the HCHO variability related with car traffic and can be explained by delay of the transfer of the formed on Sunday (lower pollutions) and Monday (greater pollutions) air masses from Moscow to Zvenigorod. This hypothesis is confirmed by the nitrogen dioxide (NO2) DSCD variability at the ZSS.

2) The temperature effect is noticeable in our HCHO DSCD data. HCHO DSCDs are greater on warmer days, because there is HCHO formation from non-methane VOCs, for which more emission is expected at higher temperatures [2].

This study was supported by RFBR under grant 12-05-92108 and by JSPS under the Japan-Russia Research Cooperative Program.

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NO_2 Vertical Profile Retrieval at Zvenigorod Scientific Station by MAX-DOAS: Error Analysis and Preliminary Results

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Several types of measurements in which it is possible to retrieve the vertical column of NO_2 in the lower troposphere are performed at the Zvenigorod Scientific Station (ZSS). For example, spectral measurements of solar radiation scattered in the zenith (Z-DOAS) are used for retrieval of NO2 integral content [1]. Also in cooperation with Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan, Max-DOAS observation has been made from 2008. On observation site, to retrieve the vertical profile of NO2 in the lower troposphere Japanese implementation of MAX-DOAS is used [2]. New method for the determination of NO_2 at the lower troposphere is developed within the confines of Russian-Japan project. The method can be applied both to Z-DOAS and Max-DOAS observations.

This one presents retrieval algorithm, error analysis, and the preliminary results of NO_2 vertical profile retrieval. The study was performed for error and other characteristics of instruments typical for ZSS. The dependence of NO_2 profile retrieval error and profile vertical resolution on set of observational angles was found. The analysis is performed for the following atmospheric model:

- the background aerosol content (optical thickness equal to 0.45 at 400 nm)
- a priori information about the NO_2 profile was based on a NO_2 profile model for the Moscow region [3].
- in the absence of clouds.

The first results of NO2 profile retrieval for summer-autumn of 2010 are presented in the report.

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Ground-based Measurements of Total Columns of Halogen-Containing Trace Gases at Peterhof

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Results of ground-based spectroscopic measurements of the total column (TC) of some trace gases containing halogens and participating in reactions of the ozone transformation are given. The technique for solving the inverse problem, used *a priori* information are described and estimates of retrieval errors caused by various factors are given. A series of HCl, HF and freon TC measurements cover about 4 years. Temporal variability on different scales of TC of different gases is considered. Comparisons with independent ground-based and satellite measurements are performed.

These studies were performed using the equipment of the SPbSU Resource center "Geomodel".

The work was partly supported by St. Petersburg State University (research grants 11.31.547.2010 and 11.37.28.2011) and by Russian foundation for basic research (grant 12-05-00596).

The Retrieval of Ozone Vertical Structure on the Basis of FTIR Solar Spectra Measurements

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The series of ozone column (OC) measurements in different atmospheric layers made in 2009–2012 near St. Petersburg by ground-based IR Fourier spectrometer (FTIR) (Peterhof, SPbSU) have been analyzed. The series have been obtained for total OC, OC in two layers – troposphere and stratosphere and for OC on 2–3 stratospheric layers.

FTIR retrievals have been compared to independent data. For total OC measurements of filter ozonometer M-124 and Dobson spectrophotometer (Voeykovo, MGO) and OMI (AURA satellite) have been used. For comparison of stratospheric OC MLS (AURA) measurements, for tropospheric – the difference between total OC OMI and stratospheric OC MLS have been used. FTIR trospheric OC measurements also have been compared with ozone ground-based concentration measurements in Sestroreck and Zelenogorsk.

The temporal variations of OC measurements in different atmospheric layers have been analyzed and compared to those on several NDACC stations.

These studies were performed using the equipment of the SPbSU Resource center "Geomodel".

The work was partly supported by St. Petersburg State University (research grants 11.31.547.2010 and 11.37.28.2011) and by Russian foundation for basic research (grant 12-05-00596).

Investigations of Antarctic Stratosphere Gas Composition Based on the High-resolution Spectroscopy of the Moon during the Lunar Eclipse

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The work is devoted to the southern polar stratosphere investigations based on the high resolution spectroscopy of the Moon inside the umbra of the Earth. The measurements were made in Kourovka Astronomical observatory with 1.2-m telescope and fiber-fed spectrograph set up in 2011.

During the eclipse the Moon is emitted by the radiation refracted in the atmosphere of the Earth. Spectrum of reflected emission contains a number of atmospheric bands, their characteristics are sensitive to the concentration of the species near the tangent ray perigee. Its altitude and coordinates of the ray perigee are determined by the moon surface point position inside the umbra. The radiation transfer geometry is analogous to the space limb atmosphere measurements allowing to scan the distant atmosphere regions at several thousand kilometers from the observation point. Lunar eclipse is the only ground-based possibility to hold such measurements. The work is based on the spectral measurements of the Moon near the southern umbra border during the total eclipse of December, 10, 2011. The radiation was transferred through the Antarctic stratosphere near the seasonal ozone depression, that makes the investigation especially interesting.

The bands of the gases with well-known spatial distribution (O_2 bands at 630, 690 and 765 nm, O_4 absorption features between 450 and 600 nm) were used to retrieve the effective trajectory of the radiation transfer through the Antarctic stratosphere depending on the wavelength and estimate the influence of aerosol scattering. The procedure requires the exact account of absorption by both trajectory parts in the atmosphere (tangent trajectory through Antarctic stratosphere and slant trajectory through the local atmosphere). Other gases bands (O_3, NO_2, H_2O) give the values of tangent column densities of these gases in the lower Antarctic stratosphere. The accuracy is especially high for ozone, since the observational range covers the majority of Chappius bands, where absorption by the tangent trajectory is very strong (up to a factor of 6). The ozone content slightly exceeds the level determined by satellite observations.

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Detection Submicron Water Clusters in the Atmosphere

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Water in the Earth's atmosphere is present in the three phase conditions with its gaseous state (water vapor), liquid water drops and solid state, ice and has a determining role on many physical processes of planetary character. In particular, water in the atmosphere on about 75% defines the transfer of solar radiation. More than 50% of the natural greenhouse effect is also determined by atmospheric water and its phase composition.

The aim of this report is the study of the phase structure of the water in a clear (cloudless) atmosphere by using its own (thermal) radiation in the microwave range. In this paper we describe the results of the spectral radiometric investigation of the microwave spectrum emission (absorption) for atmospheric water vapour. The simultaneous measurement of the intensity of radiation of the atmosphere in the fields of microwave absorption lines of water vapour 183 GHz and 22.2 GHz at frequencies (140, 95, 37, 20.75, and 22.23 GHz) have been carried out. The ranges of significant difference microwave spectra from level of the spectra for the clear sky were observed. The microwave spectrum of those formations corresponds to the "clear" spectrum of the atmosphere in the presence of liquid clouds of invisible at optical wavelengths. The observed phenomenon is interpreted by the presence of clouds in the atmosphere consisting of water clusters of submicron size ~ 0.5 μm.

The sunlight is scattered as it passes through cluster cloud and this scattering is resonant with the maximum at the wavelength ~ 0.5 μm, which corresponds to the blue region of the visual spectrum. Thus, the color of cluster clouds is blue and they are not visible on a background of blue sky "clear" atmosphere. Note that the blue color of the sky is a result of resonant scattering of solar light on the thermodynamic density fluctuations of air, the size of which is as ~ 0.5 μm. It can be assumed that under certain conditions the density fluctuations of air can stimulate the condensation of water vapor and the formation of sub-micron clusters. Spatial-temporal scale cluster of clouds typically 4–50 min and LWP does not exceed 0.2 kg/m^2, which is several times smaller than regular clouds (about 8 μm). Typically, clusters clouds are observed in highly developed convection in the presence of internal gravity waves and after the atmospheric fronts.

Microwave Humidity-Temperature Sounding of Atmosphere and Water Surface

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Application of remote sensing of the environment for solving the number of applied problems of meteorology is very promising. Integration of heterogeneous data of meteorological observations, including data of upper-air, microwave radiometry and radar sounding of atmosphere and surface will allow to obtain the most complete and adequate information about the state of the atmosphere that contains clouds and rainfall. In the report the possibilities of the microwave radiometry method, based on the interpretation of the downward and upward thermal radiation of the atmosphere-water system in the microwave range of the spectrum, for solving the various problems of remote sensing such as the determination of profiles of humidity and temperature in the troposphere, the integrated water vapor and cloud liquid, the estimation of the precipitation intensity, the water surface temperature are discussed.

An overview of results of experimental studies of integrated water vapor and cloud liquid with ground (ship)-based radiometer at 22 GHz and 36 GHz is given. For estimating the errors of microwave measurements of meteorological parameters, a series of comparative experiments with the use of data of independent measurements in different regions (over oceans and over land) have been performed. The comparison of microwave measurements of integrated water vapor with the data of simultaneous upper-air sounding of the atmosphere in the Leningrad region showed that RMS error in the absence of precipitation was 0.7–1.3 kg/m^2. Microwave measurements of integrated stratus cloud liquid are in a satisfactory agreement with the empirical models derived on the basis of airborne sensing of clouds. At the same time, there are some differences in statistical distributions of integrated cloud liquid over ocean and land in warm and winter periods of the year.

The comparative tactical-technical characteristics of the ground-based and airborne multi-frequency microwave systems for studying the atmosphere and water surface are given. Currently, the actual problem is to develop economically-viable options of radiometric systems, with high metrological characteristics. The application of microwave radiometry for solving the problems associated with the forecasting of severe weather phenomena, validation of satellite data is discussed.

Measurement of Cloud Parameters by Means of Active-Passive Sensing

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The study of clouds is important for the atmosphere physics, as well as for solution of many practical tasks in meteorology. At that remote sensing methods play a crucial role because they allow to perform monitoring of large areas. In particular, combined use active and passive sensing on the base of weather radar and radiometer is of great interest. Radiative characteristics of clouds are described by the integro-differential equation of radiative transfer [1], which solution is quite difficult task, and in general case it is not defined yet. So various approximate methods are widely used [2], in particular, the approach of "pure absorption" is used here, when the scattering of electromagnetic waves by cloud particles can be neglected. At that brightness temperature is a function of the vertical profile of temperature and water content that does not allow to solve the inverse problem and define the cloud parameters by measurement at a single wavelength and at a fixed elevation angle.

However performed numerical simulation has shown that the dependence of brightness temperature on integral water content of cloud is almost independent on the type of vertical profile of water content as well as cloud thickness, so integral water content can be uniquely reconstructed by measurement of brightness temperature. At the same time the parameterization of the vertical profile of temperature and water content on the base of data of contact measurement allows to pass from the integral equation of radiative transfer to the transcendent equation and to retrieve the height distribution of water content by active-passive sensing. In this case, reconstruction of the water content profile is reduced to the definition of the distribution parameters. In particular, the well-known model of vertical profile of water content [3] is used, which parameter can be obtained by measurements of cloud water content using passive sensing and cloud thickness using active sensing.

Experimental measurements of the water content and the vertical profile of water content were performed by means of the 3-cm radiometer and weather radar MRL-1, operating at 3.2 cm and 8.2 mm wavelengths. As it is shown obtained results are in good agreement with the averaged data published for the studied types of clouds. Thereby performed analysis permits to make conclusions about the weak dependence of integral water content on both water content profile and cloud thickness. First experimental results of measurements of water content profile in the clouds are also presented.

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Some Regularities of Spatial Fields of Integral Water Vapor from Radio Measurements Stations Network of Satellite Navigation Systems

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The problem of continuous monitoring of the integrated water vapor content in the atmosphere with a high temporal and spatial resolution is quite a challenge to limited possibilities of modern technology. The use of a radio receiver GPS/GLONASS satellite navigation system can solve this problem for all weather conditions.

From measurements of the receiver GPS/GLONASS network, located in the territory of the Republic of Tatarstan, Russia, the integral water vapor content and its horizontal gradients were calculated. Network size is approximately 300 km on line east-west and 100 km in direction north-south. The integral moisture content estimations coincide at the level of 1.5 mm of the precipitated water with sun photometer data and at the level of 2.5 mm with NCEP/NCAR weather fields. The seasonal variation of gradients is found. Meridional gradient usually shows the decreasing of water vapor content with increasing latitude, and the monthly average is 1.8 mm precipitated water per 100 km in August and 0.1 mm/100 km in December. Absolute values of monthly average zonal gradient are somewhat smaller than the north and are 0.1 mm/100 km in March and June and – 0.8 mm/100 km in May and October. The instant values of gradients can considerably exceed mean monthly values.

Some Results on Comparison of Measurements of Atmosphere Temperature Profile Using Microwave and Radiosonde Techniques

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Data on temperature profiles of the lower atmosphere, obtained by microwave profilers MTP-5 and standard network radiosondes, released at the aerological station at Voeikovo, Liningrad District are compared in the research. The overview of both methods is given, systematic and random error estimates are conducted, and also the microwave instrument’s capability to obtain the inverse profile is estimated.

Investigation of Atmospheric Optical Properties Based on Multi-Year Photometric Solar Observations in the Crimea

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Design of the automatic solar photometer CF-1 for measuring atmospheric optical properties in the 372–1005 nm spectral region during year-round observations (monitoring) is described along with improved methods for automated data processing. The results of photometric observations performed in the Crimea over extended periods of time (with CF-1 photometer in t. Simferopol starting in 2001, and with standard solar photometer M-83 in Karadag starting in 1972) are presented. Based on analysis of observed data the inter-annual and intra-annual variability of aerosol optical thickness and the Angstrom parameter for the atmosphere over Simferopol and Karadag can be determined. A significant finding is the detection of noticeable decrease of aerosol optical thickness (i.e. increase of atmospheric transparency over the Crimea) beginning in 1993, which can be explained by a rapid decrease of anthropogenic load on the environment due to shutting down of the major industrial complexes.

In addition, regular observations of solar radiation in the ρ-band are used to determine the atmospheric water vapor content from 2001 to present. Analysis of observed data shows that water vapor content in the atmosphere over the Crimea (at Simferopol) is seasonally dependent: 1.2–1.3 cm during the summer-time and 0.2–0.3 cm during the winter-time. However, the average annual water vapor content for Simferopol remained practically constant at 0.63 cm over the 2001–2012 time period.

Solution of Inverse Problem of Aerosol Light Scattering in the Approximation of Randomly Oriented Spheroids from Direct and Diffuse Solar Radiation Measurements

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The considerable spatiotemporal variations of the atmospheric aerosol necessitate the development of new and improvement of already existing methods for retrieving the aerosol optical and microphysical characteristics. In work [1], we presented an algorithm for solving the inverse problem of aerosol light scattering ensuring the retrieval of such aerosol parameters as the single scattering albedo, the scattering phase function (the asymmetry factor), the particle size distribution function, and the complex refractive index in the approximation of homogeneous spherical particles according to data of spectral-angular photometric measurements in the visible and near-IR spectral ranges. However, the assumption on the sphericity of aerosol particles constrains the applicability of the algorithm: in particular, the atmospheric situations in the regions affected by powerful dust outbreaks are left unconsidered. Earlier, it was shown that the light scattering properties of dust particles can be described using the model of spheroids randomly oriented in space. The experience of use of this approximation as applied to the known methods for solving the inverse problem of aerosol light scattering indicates that the aerosol parameters are retrieved with appreciably higher accuracy [2].

In this work we discuss the algorithm [1] modified to account for the nonsphericity of aerosol particles through their approximation by randomly oriented spheroids. We comparatively analyzed the aerosol parameters retrieved with and without taking into the account the particle nonsphericity. The accuracy of the retrieving the optical and microphysical characteristics taking and without taking into account the field measurements errors is estimated with the help of numerical experiments. The algorithm is tested with the use of data on the photometric measurements performed under the conditions of the arid climate of Southeastern Kazakhstan.

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Features of Double-Frequency Sounding of Polydisperse Medium with Ellipsoidal Drops

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At present, much attention is paid to the development of remote sensing of precipitations to study processes in atmosphere, as well as various application problems. At that double-frequency sounding is widely used and based on the calculation of the differential value of radar cross section (DRCS), which improves the reliability of data compared with single-frequency method. However, most published works [1] are based on the assumption of spherical form of drops, although the majority of cases show that particle shape differs from spherical due to the interaction of forces of gravity, surface tension and aerodynamic resistance. The Pruppaher model [2] describes a drop shape in the steady fall mode by biaxial ellipsoid with the horizontal axis – $2b$, the vertical – $2a$. This greatly affects on scattering characteristics, and therefore, the solution of the electromagnetic energy scattering on ellipsoidal water drops in the case of double-frequency sounding is of significant interest.

In general, double-frequency sounding of precipitation is based on measuring of DRCS as the ratio of the specific values of radar cross sections (RCS), measured at two frequencies. Therefore, in the paper, the scattering characteristics of polydisperse medium with ellipsoidal raindrops at double-frequency sounding at orthogonal polarizations were calculated. Dependences of the drops RCS from their form and elevation angle of radar antenna have been determined and it is shown, that the ellipsoid eccentricity at double-frequency sounding significantly weaker effects on data soundings than in the case of single-frequency sounding [3].

As a result of the study the following conclusions can be made:

- the approximate solution of the double-frequency scattering of a plane electromagnetic wave in a polydisperse medium with ellipsoidal drops was obtained;
- it was shown that the drops form-factor has a small influence on the results of double-frequency sounding in contrast to a single-frequency sounding;
- to avoid the multiple values in the recovery procedure of rain intensity the special inequality was proposed.
- at horizontal polarization of the incident field, RCS of ellipsoidal drop does not depend on the viewing angle, that is essential for remote sensing of precipitations.

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Numerical Statistical Simulation of Lidar Remote Sensing of Atmospheric Aerosol and Cloudiness in Visible and Terahertz Range

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Under real atmospheric conditions the microphysical properties of the scattering medium are subjected to randomly-inhomogeneous fluctuations in time and space. Therefore direct and inverse problems of laser sensing should be considered in a stochastic formulation. In this case the initial optical parameters of the transfer equation that describes multiple scattering are defined in the form of random functions of space and time. Obviously, statement of direct and inverse problems of laser sensing theory under these conditions should be based upon the analysis of functional and correlation relations which define informativeness and interdependence of the estimated and measured parameters for the given experiment.

In this paper the light haze of a ground-based pulse LIDAR in an altitude-wise optically inhomogeneous cloud-free atmosphere and the correlations between aerosol scattering coefficients and echo-signal time distribution were computed for various optical-geometrical parameters of the experiment using the Monte-Carlo method. Modeling of the LIDAR echo-signal reflected from the lower boundary of a liquid droplet cloud for a ground-based LIDAR was also completed in the visible and the terahertz range. A feature of these calculations is the choice of a model with altitude-wise statistically inhomogeneous structure of aerosol scattering parameters for a cloudless atmosphere. The vertical stratification of molecular and aerosol scattering coefficients, aerosol scattering indicatrix in the atmosphere and cloud scattering indicatrix in the visible range are presented in [1], the corresponding data for the terahertz range may be found in [2]. The echo-signals from clouds were computed in the assumption of statistical variation of the altitude of the lower cloudiness boundary. The vertical stratification of the attenuation coefficiens in stratiform clouds was obtained from [3]. In the calculations local estimates [4] and their new effective modification [5] were employed.

Note that maximum correlation values between the echo-signal and the lower cloudiness boundary are significant (over 0.4) and increase when the attenuation coefficient decreases both in the visible and in the terahertz range. In the case of a combined radiation source and receiver single scattering makes the main contribution to the echo-signal (averaged over the cloud's lower boundary altitude) in terahertz range.

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An Apparatus and Programmatic System of Hyper-Spectral Airspace Imagery Processing

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Methods, algorithms and computational programs of natural and anthropogenic objects recognition using airspace images of high spectral and spatial resolution are elaborated within the created apparatus and programmatic system. The apparatus part is based on the registration of the hyper-spectral images which are formed by hundreds of spectral channels in visible and near infrared region. The recognition is based on the joint use of spectral and texture features of the observed objects while employing the supervising procedures of a selected classifier with test sampling. A step up method is applied for the channels optimization using data under processing for the analysis of the objective function characterizing the accuracy of the objects recognition by the spectral features for the particular classifier. The high spatial resolution of the hyper-spectral images demands understanding contextual information (the context is characterized by the influence of neighboring pixels, for example, the forest vegetation object is related to a particular class unless a boundary with any other object appears, the account of the context leads to an enhancement of the accuracy of such recognition).

New approaches are accounted for while considering sites and labels in the objects pattern recognition procedures. A mathematical formalism is used of finding the maximum posteriori probability for Markov random fields to have in mind the influence of the neighboring pixels for a given class of the objects on the processed image. Standard procedures of smoothness of any distorted image due to the instrument noise and other effects are considered together with the segmentation procedure of separate classes, i.e. the smoothness only inside the selected contours ("spatial regions") of the objects. Examples are also demonstrated of the perceptual grouping appearance where the test sites with the segmenting features (points, lines, regions) are irregular distributed and the matching problem of these features has emerged. The neighborhood system has just become essential for the pixels of a particular class and the cliques between these pixels as a measure of their inter-relations. The higher level of this recognition combines such computational procedures, in which the site denotes a given matching and the label represents any acceptable transformation (orthogonal, affine or any other).

Examples are shown of the airborne hyper-spectral imagery processing where the forest canopy has a characteristic texture given by the intermediate illuminated and shaded parts of the tree crowns as well as the inter-crown space. The registered radiances of the illuminated parts are mainly determined by the optical properties of these crowns, the current atmospheric conditions and the Sun height at the moment of survey. The used hyper-spectral instrument ensures high values of the signal to noise ratio in this case. The reflection of the solar radiation by the shaded parts of the crowns of the same class of the "pure" forest species occurs in a more complicated way. Multiple sunlight scattering inside the crowns and the spectral properties of the underlying surface has just emerged important. The instrument signal level is much lower in this case than for the illuminated phyto-elements of the forest vegetation. The effect of the internal instrument noise is enhanced while forming the related radiances.

Based on the airborne hyper-spectral remote sensing, examples are revealed of the information layers selection formed on a particular test site using the collected ensembles of spectra depending on the age of the coniferous and deciduous species. The automation prospects are opened up of the recognition for such complex objects as the forest ecosystems with different species and age using the hyper-spectral images while employing the proposed apparatus and programmatic system of data processing.

Remote Sensing Technique of Near Surface Wind by Optical Images of Roughed Water Surface

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The principles of remote sensing of near surface winds by its manifestations on the waved surface under grazing angles were developed. The model of the waved water surface intensity based on expansion of surface intensity on wave's slopes taking into account wave's shadowing was developed. The analytical dependence of intensity of water surface on wave's slope dispersion permitting to restore velocity of near surface wind was received.

The technique for monitoring of wind's fields by optical RTI images (range-time-intensity images) constructed from optical profiles of sea surface was developed. The RTI image is an optical analog of side-looking radar image of sea surface but having higher spatial resolution and some possibility for remote sensing of sea roughness. It is possible to form RTI images with range from some tens meters to kilometers depending on spatial resolution needed and height of optical device above sea level.

The complex of original optical devices for recoding of RTI images using the linear array of CCD-photodiodes is created. Complex consists of four synchronized optical devices operated under various spectral diapasons, polarization of light and directions of observations. The optical complex can be installed on a shore, ship and aerial carrier. The optical device specifications:

- Swath width: from 50 m to tens of kilometers;
- Resolution (geometrical): from 3 cm and more depending on swath width;
- Frame repetition: 18.7 Hz;
- ADC frequency: 38 KHz;
- Number of points in swath: 2000;
- Spectral range of light: 0.46–0.6 microns;
- Polarization of light: vertical and horizontal.

Processing of signals, which are optical cross sections of the surface image, consists in correction of perspective distortion and construction of spatially-temporal images of the surface in the coordinates: range – time – intensity (RTI images), and in joint analysis of obtained images.

The principles of retrieval of wind field's characteristics such as spatial structure, velocity of wind's outbursts and wind velocity by its manifestations on water surface under grazing angles were developed. The investigations of near surface wind fields features in internal reservoirs and various regions of seas during last years were conducted by optical complex. The structure of near surface wind fields, eddies, wind fronts, katabatic wind flows for ranges from hundreds meters to some tens kilometers were recorded and analyzed. Derived data of optical monitoring of water surface may serve for future investigations of near surface wind features.

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Methods and Code for Processing of Multispectral and Hyperspectral Images of Remote Sensing

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The report presents methods, algorithms and software for processing of multispectral and hyperspectral imagery to improve the efficiency of data analysis in a wide range of applications. The processing of hyperspectral images is usual produced on the basis of the analysis of the spectra. Therefore it is extremely important that the spectra could be recorded without distortion. However there are the spatial distortions caused by influence of mechanical and temperature impacts on the equipment which lead to the displacement of the pictures of different bands (channels), and hence to the distortion of spectra. One way to increase the efficiency of the analysis is the correction of spatial distortion of images of different bands by means of digital computer processing.

The report presents a method, which estimates the parallel displacement of fragments of images and then corrects spatial distortion. For displacement's definition for a case of images of various bands the way of transformation of the image on similarity to a sample is used. The using of large amount of samples and a set of local characteristics of image's pixels (the brightness, gradient, textural, etc.) allows to reach the subpixel accuracy of definition of displacement and to estimate an error of its definition. Definition of displacement is carried out completely automatically. It is possible to increase efficiency of the analysis, having prepared basic data for performance of a specific task. It can be done, having presented visually basic data so that objects of interest would be allocated, and insignificant objects are imperceptible.

The new version the program of target visualization – "GSI Visualization", intended for computer processing of hyper spectral pictures is developed. The program allows representing a set of hyperspectral pictures in the form of one image in gray gradation according to similarity of the current pixel (spectrum) to a sample. Besides, there is a possibility of synthesis of the color image in pseudo-color using several samples (the quantity of samples is not limited). In the program various measures of the similarity, which choice is defined by applied task, can be used. Samples of spectra used by the program, can be chosen viewing initial images, and can be taken from in advance prepared spectral library.

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Remote Sounding of Ionospheric Disturbances Caused by Exhaust Streams of "Progress" Cargo Spacecraft

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Space launches have turned the ionosphere into a natural laboratory for examining plasma in conditions unavailable for ground-based laboratory experiments. Active space experiments in controlled local modifications of the ionosphere are of particular interest. Since 2007, such space experiments have been made using "Progress" cargo spacecraft (CSC). A source of the ionosphere modification is the exhaust stream of CSC engines. The CSC engines were being activated for 5–10 s during its flight in the field of view of the ground-based radio sounding tools. A small amount of exhaust product with the known composition is injected into the ionosphere resulting from the combustion of 5–10 kg of rocket fuel in the ~ 80 km CSC orbit arc. Artificial ionospheric disturbances caused by high-velocity exhaust streams are similar to natural ones. Studying the formation, evolution, and dynamic characteristics of such artificial disturb-ances at the defined time and place is of utmost importance. Experimental results are used for de-veloping theoretical and mathematical models of generation and evolution of plasma irregularities in the ionosphere.

The goal of space experiments is to determine space-time dependences of density, temperature, and ionic composition of local ionospheric irregularities arising from CSC engine running. The main ground-based radio sounding tool is the Irkutsk Incoherent Scatter Radar (ISR). An auxiliary device is the digital ionosonde DPS-4 operating in the vertical sounding mode. To determine sizes and location of plasma irregularities, we deployed an interference system with multi-channel digital VHF receiver that receives signals from an on-board transmitter. The space experiments were conducted under various helio-geophysical conditions. The direction of exhaust stream velocity was selected from the following options: toward and against the CSC motion; toward an ISR beam; and northward.

The experimental results may be formulated as follows. A slight exhaust stream impact on the ionosphere results in an area ("hole") of strong negative disturbances. The radar characteristics of CSC and the ionospheric "hole" parameters depend on helio-geophysical conditions, the background ionospheric characteristics, and the exhaust stream directions relative to geomagnetic field and ISR beam. When exhaust steams directions were toward ISR, we observed the strongest ionospheric disturbances (electron density decreased by 20–30 %) and the most dramatic changes in the radar characteristics of CSC. The lifetime of the "holes" was 10–20 min. With the engine running, the phase difference between VHF signals received by adjacent antennae increased.

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Effective Interpretation of Weak Lidar Signals

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Lidar probing of weak scattering atmosphere includes the solution of the problem of the interpretation of echo signals. Advantages of the linearization of the inverse problem in the case of small extinction coefficient value were recently analyzed. From the other hand, the linearization of the inverse problem leads to the additional error.

The method of the interpretation of echo signals in the case of small extinction coefficient value without using the linearization of the inverse problem is considered in this paper. The specific features of the effective interpretation of weak lidar signals without using the linearization procedure are considered. The interpretation of atmospheric aerosols lidar probing data is based on the inversion of the lidar equation. This equation connects the backscattering signal with the optical characteristics of atmospheric aerosols. The power of the background light is to be taken into account. The interpretation of lidar information was carried out here inverting the backscattering signals returned from a homogeneous atmosphere where atmospheric parameters are constant in space. The solution of the lidar equation was used to determine the extinction coefficient and the lidar constant using the preliminary calculated background light. Preliminary calculations of the background light were carried out using the symmetric scheme of date processing. The relative error in the power of the background light does not depend essentially on the scheme.

The error analysis was carried out for known experimental data. The statistical error of the extinction coefficient can be diminished using the effective beam-path averaging procedure. Errors of the extinction coefficient for different minimizing procedures depending on weighting coefficients are considered. A comparison shows that the errors found when they are analyzed can differ by almost a factor of 3 for different minimizing procedures. So, the problem of weighting coefficients is rather important. The method is developed in the paper to determine weighting coefficients.

Radar Sounding of Convective Clouds with Reference to Forecasting of the Dangerous Phenomena

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Using two-wave MRL, parameters of convective clouds in the early stage on the Black Sea Coast from the moment of occurrence of the first radioecho up to a maximum are investigated. Dynamic parameters of growing cells which characterize rate of change in time of maximum radar reflectivity of the cloud height and zone of increased water content inside are defined. The size of a hail depends on time of growth of the specified parameters. Use of the offered complex of criteria allows to reduce by 1/3 the quantity of experiments and to reduce expense of a reagent on them for a season to 25–30%.

The Satellite Navigation Systems Applying for the Investigation of the Mesoscale Structure Diurnal Variations in Troposphere

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With the development of satellite navigation systems (SNS) the ability for using their signals for remote sensing of the troposphere arose, and the problem of estimating the effect of mesoscale and other irregularities in the troposphere in GPS radio propagation can be solved. The report describes the principles of radio measurements for atmospheric research network GLONASS-GPS. The network of receivers spaced from 1 to 35 km has been constracted. This spatial resolution allows estimating the structure of the troposphere in the mesoscale processes. Radio waves refraction index is the indicator of atmospheric inhomogeneous structure. In the Kazan Federal University a network of GPS receiving stations accumulated a unique database of long-term (2007-2012) measurements with high time-frequency, which allowed to study inhomogeneous structure of the radio waves refractive index in the troposphere.

The methodology of calculation of structural function of tropospheric delays received from remote sensing by GLONASS and GPS signals is developed. It is shown that the structure function of the radio signals tropospheric delay and its power approximation are the quantitative characteristic of the troposphere inhomogeneous structure. The value of the structure functions of tropospheric delay is highest in the afternoon. Index of the power function in the daytime maximum equals to 0.7. For morning and evening measurements of the power index is 0.1–0.2. A comparison of characteristics of tropospheric irregularities obtained by calculating the structure functions from measurements GLONASS-GPS signals with the results of long-term ground-based meteorological parameters measurements in the same range of irregularities scales showed a great their similarity.

Variability of Aerosol Optical Depth in the Center of Eurasia

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Measurement results of the aerosol optical depth (AOD) obtained at the wave length of 500 nm since 1984 to 2013 at the Issyk Kul monitoring station (42°37'20" N, 76°59'08" E, 1650 m above the sea level) are presented.The automatically-controlled solar photometers, the calibration procedure and the process of data processing described in [1] were used. The analysis of the data obtained made it possible to determine the basic laws of the AOD variability: seasonal variations, linear trend and a noticeable increase of the AOD at volcanic eruptions. A mean annual value of the

AOD for the period from 1984 to 2012 decreased by about ~ 3.8%. The negative linear trend was about – 0.13% per year. During the last several years (1995–2012) the negative trend turned into the positive one 0.16% per year. Minimal seasonal AOD variations were registered in December, maximal values – in April and August, and an average amplitude of seasonal variations made (0.011 ± 0.004) or (9 ± 4)%.

The analysis of statistical indices of the atmospheric optical depth has shown that the AOD has differences in mean monthly means from the normal mode: the mode, median and the average value do not coincide.The distribution is an asymmetric one with double-peaks, the median and the main mode are shifted from the average value towards the lower values. The distribution of mean annual values is practically normal.

The simple statistical model of aerosol optical depth proposed in the paper is in satisfactory agreement with the mean annual values and is a little worse than the mean monthly values. Due to the complex linear trend this model is inapplicable for detailed forecasting of the variability of mean monthly AOD values.Thus, the analysis of the AOD monitoring results for 28 years of observations revealed a complex character of its temporal variability: seasonal and anomalous variations in the annual cycle, anomalous annual changes and long-period trends induced by various not always known helio-geophysical and anthropogenic factors.

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Observations of Nitrogen Dioxide in the Stratosphere by Passive Sensing Method at the Siberian Lidar Station IAO SB RAS in Tomsk (56.5° N, 85.1° E)

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From January 1996 to the present, Siberian Lidar Station at Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences in Tomsk (56.5° deg.N, 85.1° deg.E) performs observations of nitrogen dioxide content in the atmosphere by the passive sensing method. The measurements are performed at twilight time of the day during morning and evening with the help of the automatic spectrophotometer assembled on the basis of MDR-23 monochromator. The spectrophotometer records the spectrum of solar radiation, scattered in zenith, in the visible wavelength range (430–450 nm), when the solar zenith angle varied from 83° to 96°. The deformation of the spectrum relative to the reference spectrum is used to determine the nitrogen dioxide content along the trajectory of propagation of thr solar ray. Through solution of inverse problem, data on the oblique nitrogen dioxide content in the atmosphere are used to retrieve the vertical distribution of nitrogen dioxide in 10 layers, each 5 km in thickness, in the altitude range from 0 to 50 km. Then, we calculated the total columnar content (TCC) of nitrogen dioxide as a sum over all layers and the NO_2 content in stratospheric column in the altitude region of 10–50 km.

In the report, we will present the twilight spectrophotometer observations of the total NO_2 content for the period from 1996 to 2012 for morning and evening NO_2 observations. Analysis of time series shows that the morning TCC values of NO_2 are systematically smaller than the evening values due to night-time conversion of nitrogen oxides NO and NO_2 to “long-lived” reservoir molecules N_2O_5. The time series show the annual behavior, with maximum values during summer and minimum values during winter. The TCC values of NO_2 during the summer maximum are a factor of 4–5 larger than those during winter minimum. The annual behavior of NO_2 TCC matches the behavior of the solar insolation, which has strong effect on the photochemical processes in the stratosphere. In addition, NO_2 TCC depends not only on the ozone content in the stratosphere, but also on other admixtures of trace gas constituents of the atmosphere. The short-term variations in NO_2 TCC are also associated with the circulation processes in the atmosphere.

In the course of analysis of time series, it was found that anomalously high NO_2 TCC occurs during winter, primarily because of the transport of cold Arctic air masses, which contain the reservoir molecules of odd nitrogen and chloronitrous acid, from weakly illuminated polar regions to midlatitudes, where reservoir molecules photolize to form nitrogen dioxide. The linear regression method was used to analyze the trend of the time series of total NO_2 content for morning and evening observations. Preliminary, the time series were deseasonalized and divided into two time periods. The first time interval, from 1996 to 2006, is considered as long-term volcanically quiescent period, characterized by 23rd eleven-year cycle of solar activity. Trends for this period have values of – 2.93% per year for morning observations and – 8.3% per year for evening observations. The second time interval is from 2007 to the present, with a few volcanic eruptions occurred during it. They favored the formation of volcanic aerosol in the stratosphere, which had effect on nitrogen dioxide TCC, but the trends still have positive values.

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Atmospheric Aerosols Measurements and the Reliability Problem: New Results

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This paper analyses new methods of monoposition probing and multiposition probing. The optical thickness of the atmosphere was determined by methods of multiposition probing without numerical integrating. More accurate simulations of the errors were performed for multiposition schemes of lidar probing with realistic parameters of lidar and atmosphere. We take into account the relationship between the lidar signals and the integral terms of the Klett equations. The purpose of this paper is also to discuss the lidar equation solutions developed for weak signal processing and the results of the analysis of the effectiveness of these solutions. There are considered the errors of the extinction coefficient for different minimizing procedures depending on weighting coefficients. The method is developed to determine weighting coefficients. The preliminary calculated parameters were used for more accurate linearization of the inverse problem. We take into account in this paper previously obtained for results [1] of aerosol measurements.

The new model of a spherical particle with the radially variable refractive index was proposed. The effectiveness of the proposed model is based on the possibility of choosing the thickness of inhomogeneous coating depending on the particle size. The proposed model can explain the significant discrepancy found in the St. Petersburg region between the photoelectric and filter aspiration results and can be used to minimize the error of particle size optical determination.

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Modification of Module to Simulate Sun-Radiometer Signals in Synergetic Method of Processing Complex Lidar&Radiometer Measurements

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Lately, on the basis of European lidar network EARLINET and global sun-photometric network AERONET a new technology of the atmosphere study, which is complex lidar&radiometric sounding of the aerosol layer, starts to develop. The idea to unite measurements by lidar and sun-photometer was worked out by researchers from Laboratory of scattering media optics of the Institute of Physics (IPh) of National Academy of Sciences of Belarus, Laboratory of Optics of Atmosphere (LOA) of Lille Scientific-Technological University and NASA Centre, and realized in the integration of lidar and radiometric observations on the ten EARLINET combined stations. The method to retrieve vertical distributions of aerosol fractions concentrations was elaborated, and a program package based on this method was designed to be used at the combined stations. Simultaneously, the synergetic method to process data of co-located lidar and radiometric observations was offered, parameters of aerosol model being computed there in parallel in a single inversion procedure for totality of measurements by two systems. This method is expected to enhance aerosol characterization.

A new algorithm and code for processing complex multi-wavelength lidar and spectral-angular radiometric measurements have been recently developed in cooperation of the researchers from LOA (Lille, France) and IPh (Minsk, Belarus). Presently, the code is upgraded to make a new program package for the complex lidar&radiometric experiment. The new algorithm has flexible modular structure. Among main modules is the «forward modeling» block designed to evaluate characteristics (radiance, polarization) of scattered radiation in the atmosphere based on solutions of the vector transfer equations to simulate signals of a background radiometer.

The report presents our results on improvement of the procedure of parallel processing of complex lidar and radiometric measurements data, namely, the results of «forward modeling» block modification. Processing of data bulk obtained in regular measurements involves a lot of calculations. Therefore, it is important to create fast analytical techniques to compute functions modeling measurements and its derivatives. The report describes analytical technique to simulate propagation and scattering of radiation through the atmosphere and its adaptation to compute signals of a background radiometer in the new algorithm version. Large attention is given to inclusion of the intricate model of bi-directional reflection by the earth surface into the analytical technique.

Mobile Measurements of Tropospheric NO_2 over Encircling Highway Round the City of St. Petersburg

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The results of mobile spectroscopic measurements of tropospheric NO_2 columns onboard motor car, on a closed ring road round St. Petersburg in august 2012 are presented. The observations were carried out with the use of compact automatic high-resolution spectrometer (OceanOptics HR4000) in the wavelength range 398–607 nm, ~ 0.6 nm spectral resolution. To perform mobile measurements, the optical fiber is installed on the car roof, making possible continuous registration of zenith-sky scattered sunlight. Location of the car is determined with the help of GPS-sensor, to attribute the measurement results to the map of the route. Exposure time of individual spectra measurement is set by the processing software depending on illumination conditions, being ~ 60 ms on the average (daytime observations close to local noon – at high sun). The measurements are recorded each 30 seconds, with individual spectra averaged within that period. The route distance was ~ 140 km, within duration of ~ 1.5 hour.

The measured spatial distribution of NO_2 over the car route display reasonable agreement with a results of simulated urban pollution dispersion (HYSPLIT model). Based on a predominant wind direction during observations, total NO_2 emission (flux) from all the sources encircled with a ring road, is estimated.

These studies were performed using the equipment of the SPbSU Resource center "Geomodel".

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Variations of CO Total Column in Atmosphere of Megapolisis Moscow and Beijing

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The results of analysis of long-term CO total column (CO TC) spectroscopic measurements over Moscow (site IAP, Obukhov Institute of Atmospheric Physics) and over Zvenigorod (site ZSS, Zvenigorod Scientific Station, 53 km West from Moscow) are presented. Using the trajectory analysis the average ("model") seasonal rural CO TC variations for all years of measurements (i.e., all events of Moscow emissions impact upon "rural" CO TC and another events of atmospheric pollutions were excluded from these retrievals) were calculated. The effect of Moscow pollution sources influence upon the CO rural TC was estimated to be small: the percentage of days with ZSS CO TC exceeding average seasonal rural means more than 10% (i. e., typical STD of diurnal TC in the "rural" area) was found ~ 5%. This procedure allows using ZSS-data of CO TC as regional rural ones.

The rate of decrease of CO TC urban part (urban TC minus rural TC) over Moscow and CO TC over Zvenigorod for 2001–2012 is 2–3% per year for different assessment techniques. Trend of CO TC over Beijing for 1992–2012 years was estimate as statistically insignificant. The atmospheric CO pollution level in Beijing was found as 2–3 times stronger comparing with Moscow ones. The average annual CO emissions in Moscow are estimated as 2.7 ± 0.9 Tg/year. It confirms similar estimates for another cities (Mexico and Sankt-Petersburg), in considering of different numbers of auto vehicles and populations.

There is no increase in the CO TC over ZSS and over Moscow for 1970–2012 years in spite of multiple increase of the motor vehicles number in Moscow. The number of high values of CO TC urban, or emission part over Moscow was decreased simultaneously with increase of number CO TC low values for 2006–2012 years. The similar tendency was observed in analyzing of aerosol pollution of Moscow atmosphere.

Gas Concentration Measurements in Gas Mixtures by IR Spectroscopic Method

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Detected changes of atmospheric gas composition stimulated the activities for high-accuracy monitoring of concentrations of atmospheric trace gases (ATG). The application of IR spectroscopic method to the problem of quantitative spectral analysis of gas mixtures has been considered. The aim of the work was the derivation of optimal parameters for concentration measurements of several ATG in atmospheric air samples using Fourier spectrometer IFS125HR and multi-path cell.

In the course of the study concentrations of CO in calibrated gas mixtures have been measured, and quantitative analysis of atmospheric air samples has been done. The results of processing and interpretation of spectra of calibrated CO and N_2 mixture and of spectra of various ATG are presented. The procedure of the elimination of sinusoidal modulation of spectrum has been developed in order to increase the measurement accuracy. The optimal spectral intervals, instrument line shape function and spectral resolution have been obtained for the analysis of the considered calibrated mixtures.

These studies were performed using the equipment of the SPbSU Resource center "Geomodel".

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Ground-Based MW Temperature-Humidity Sounding of the Troposphere

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Regular measurements of the intensity of downwelling microwave (MW) radiation were performed with high temporal resolution in 2012–2013 at the Faculty of Physics of St.Petersburg State University (St.Petersburg, Petrodvorets) using ground-based microwave instrument RPG-HATPRO (Humidity And Temperature PROfiler, manufactured by Radiometer Physics Gmbh) functioning in the spectral region of oxygen band 0.5 cm and water vapor line 1.35 cm. The inverse problem of the retrieval of temperature and humidity vertical profiles from the values of brightness temperature of downwelling MW radiation was solved using two different methods: (1) regression (the algorithm has been developed and implemented by the manufacturer of the instrument); (2) complex multiparameter method based on optimal estimation [1]. The retrieved temperature and humidity profiles were compared with radiosonde data (Voejkovo station, the distance from MW measurement site is 50 km). The discrepancies between the radiosonde data and the results obtained by regression method were 1–2 K for temperature and 5–10% for relative humidity in the lower 3-4 km layer (seasonal dependence was detected, summer and autumn of 2012 and winter of 2012–2013 were considered). Above 3–4 km altitude the regression method is characterized by noticeable systematic errors which reach 8 K at 10 km altitude. Complex multiparameter method is characterized by the absence of noticeable seasonal dependence and provides the accuracy of 1–3 K for temperature and 10% for relative humidity up to 5–6 km. Taking into account the possibility to perform MW measurements continuously, during long time periods with high temporal resolution (several minutes) and almost independently from weather conditions, one can recommend to use the data of MW temperature-humidity sounding for synchronous validation of satellite measurements. Functioning of MW instrument RPG-HATPRO was maintained by Resource center "Geomodel" of St.Petersburg State University.

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Moscow Heat Island and Thermal Anomalies into Blocking Anticyclone in Summer 2010

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Analysis of thermal sounding data [1] in the atmospheric boundary layer (Moscow and Moscow region) in summer 2010 has shown that the vertical profile temporal variability of the air temperature is conditioned by the urban heat island effect and the thermal anticyclonic anomaly in the lower atmosphere [2]. Microwave sounding data in Lomonosov Moscow State University (MSU), in Central Aerological Observatory (CAO) and at Zvenigorod Scientific Station (ZSS) of A.M. Obukhov Institute of Atmospheric Physics and also temperature measurements results in the surface layer (Moscow region) at “Mosecomonitoring” stations were used.

The urban island heat effect in the surface layer comprised an average (0.9–4.1)° C (22–29.07.2010), 1.5–5.0° C (1–10.08.2010) in the smoky atmosphere. At height 25 m the urban island heat effect (MSU) achieved 4.3° C in non-smoky atmosphere and 5.8° C in smoky atmosphere. Minimal effect (0.6–2.5)° C was seen at heights 200–400 m.

Air temperature departures of the diurnal amplitudes in the upper part of the sounding layer (300–600 m) constituted in MSU (0.8–2.3)° C (height 600 m) and (1.2–3.1)° C in CAO (height 600 m) from the diurnal amplitude at ZSS. They were determined by the thermal anticyclonic anomaly [2].

The most intensive inversions of temperature were seen at ZSS from the surface to heights 300–350 m: (2.4–3.3)° C in the non-smoky and weekly smoky atmosphere and (4.6–5.9)°C in the heavily smoky atmosphere.

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Analytical Solution of the Cloud Inverse Problem on the Base of Airborne Observation of Diffuse Solar Radiance

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The analytical approach of the inverse asymptotic formulas of the transfer theory with taking into account cloud horizontal heterogeneity is applied to the solution of the cloud optics inverse problem. The approach is free from a priori restrictions and links to desired parameters those were used by many other authors and prevented the realization of true value of cloud characteristics.

Radiance observation is accomplished at viewing zenith angles from 0° till 180° in 1° interval and repeated several times at every altitudinal level in 8 spectral channels from UV till near IR. The procedure of processing data obtained above, below and at 16 levels within cloud is based on data at a multiplicity viewing directions. The instability of solution over viewing directions is revealed for the processing radiance as distinct from irradiance. For this reason the regularization of the solution with taking into account observational and retrieval errors is performed. Final values of the single scattering albedo appear practically the same for observation above and below the cloud and for summation the optical thickness between all levels within cloud. The correction to horizontal cloud heterogeneity is applied and the new approach to ground albedo retrieval from radiance measurement is proposed and used in the algorithm. The vertical profiles of the volume scattering and absorption coefficients are presented, which reveals a significant cloud heterogeneity of cloud optical characteristics over altitude.

FTIR Measurements of CH_4 Total Column at the Peterhof Station (59.88° N, 29.83° E)

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Methane is the second most important greenhouse gas of the Earth’s atmosphere. At present CH_4 accounted for about 10–15% of all greenhouse gas emissions from human activities. Methane’s main anthropogenic sources are as follows: industry, leakage from natural gas systems, agriculture, and waste management activities. Permafrost and methane hydrates are one of the greatest natural reservoirs of CH_4 at high latitudes which could be released as a result of global warming processes.

Current study is devoted to CH_4 total column observations in Peterhof (suburb of Saint-Petersburg, about 35 km to the west from the megacity center), 59.88° N, 29.83° E, 20 m asl. Ground-based FTIR (Fourier transform IR) measurements have been carried out by Bruker IFS125 HR instrument at the Dept. of Atmospheric Physics (SPbU) from 2009 [1]. Observations are performed under a cloudless sky, or in large enough cloud cover breaks. Interferograms are recorded by an InSb detector for the optical path differences of 180 cm (corresponds to the spectral resolution of 0.005 cm^{-1}). Spectrum registration time including accumulation and averaging of ten scans is about 12 minutes. Retrievals of CH4 total column in the atmosphere from the FTIR spectrometry are performed using the standard software SFIT2 v 3.92 [2, 3, 4] designed for the NDACC (Network for the Detection of Atmospheric Composition Change). According to NDACC recommendations, we have used for retrievals following three microwindows: 2613.7–2615.4, 2835.5–2835.8 and 2921.0–2921.6 cm^{-1} [5]. Mean signal-to-noise ratios for these spectral intervals are of ~ 800. HITRAN 2000 [6] is used as a spectroscopic line parameters database. Random relative error of single CH_4 total column measurement does not exceed 0.3% (according to error matrix calculations realized in the SFIT2). Under stable atmospheric conditions, daily variations of total CH_4 do not usually exceed 1.5%.

We take this opportunity to thank NDACC network for help and Dr. James Hannigan from the University of Denver for providing the SFIT2 program and WACCM data.

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Comparison of Ground-Based IR Spectroscopic Total Column Water Vapor Measurements and Radiosonde Data

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Ground-based IR spectroscopic total column water vapor measurements with aim Bruker 125HR spectrometer were performed from May 2009 to March 2012 near Saint-Petersburg. The measurements were compared with radiosonde data from Voeikovo (50 km apart). Spectral resolution was about 0.005 cm^{-1}. Interpretation of spectral data was performed using PROFFIT program.

During the analyzed period the total column water vapor changed by about an order. Mean value from IR and radiosonde measurements are very close – 1.12 and 1.06 g/cm^2. Minimal and maximum values for Petergof and Voeikovo were 0.248 /3.48 g/cm^2 and 0.166/ 2.97 g/cm^2. The correlation coefficient between two set data is 0.963, the mean difference is 11.2%, RMS difference – 24.1%, standard deviation – 9.51%. After excluding extreme deviation (more than 40%) caused by atmosphere nonstationarity and horizontal inhomogenity the difference decreases significantly.

These studies were performed using the equipment of the SPbSU Resource center "Geomodel".

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Numerical Simulation of Solar Light Reflection by a Vertical Wall of a Snowpack

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The information on the snow microphysical parameters and snow pollution is obtained from the near infrared (NIR) measurements (in the spectral range 865–1240 nm) of intensity of solar light reflected from flat snow layers. The retrieval algorithm is based upon enhancement of light absorption by larger ice grains. However only upper snow layers (up to 5cm or so in depth) can be observed via this method due to high absorption. To avoid this problem recently measurements along the vertical snow walls are used to retrieve snow properties of deeper layers.

Mathematical model to simulate reflection of solar light by a vertical wall is presented. It is based upon the 2D transport equation and takes into account real conditions of measurements in a wide pit covered with a sheer film from above to convert direcrt solar ligh into diffusive. The numerical technique treats the forward-peaked phase function for both aerosole and snow with high accuracy. Simulation results for homogeneous snowpacks and snowpacks with the inserted cleaner or more dirty layer are presented. Influence of a inserted layer on reflected light intensity is studed. It is shown the 1D transport equation can not be used to modelling such experiments even for homogeneous snowpacks.

The Constructive Theory of the Characteristic Equation of the Radiative Transfer Theory for a Case of Arbitrary Phase Function

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For the first time the characteristic equation corresponding to the azimuth-averaged scattering phase function was formulated by V.A. Ambartsumian in 1941. Basic results on the qualitative mathematical theory of the characteristic equation and reduced characteristic equations corresponding to the scalar radiative transfer equation (SRTE) under the assumption of square-integrable phase function and the phase-out of the consideration of the continuous spectrum SRTE were presented by M.V. Maslennikov in his monograph [1] in 1968. The sufficient conditions under which the discrete spectra of the characteristic equations for SRTE are finite or infinite sets were stated by D.H. Sattinger [2], I.A. Fel`dman I.A. [3, 4], T.A. Germogenova and D.A. Shulaya [5]. In addition T.A. Germogenova and D.A. Shulaya [5] and T.A. Germogenova [6] developed the qualitative mathematical theory of a characteristic equations for SRTE taking into account the discrete and continuous spectra for such equations and assuming different assumptions about the classes to which the phase function belong. Moreover the general formal solutions of homogeneous and heterogeneous characteristic equations for SRTE were obtained in these papers. It should be emphasized that the completeness theorems which are the foundation of Case's method [7] were proved by T.A. Germogenova and D.A. Shulaya too. Then important results in the qualitative mathematical theory of the characteristic equation for the vector radiative transfer equation (VRTE) were obtained by T.A. Germogenova and N.V. Konovalov [8], T.A. Germogenova, N.V. Konovalov and M.G. Kuz`mina [9] and N.V. Konovalov [10].

The characteristic equations of radiative transfer theory (RTT) is one of the basic equations of this theory and properties of their solutions to a large extent determine the properties of solutions of various boundary-value problems for SRTE and VRTE. In studying the radiation transfer in real turbid media, which are often characterized by very complex phase functions and normalized phase matrices, in a number of practically important cases it is impossible to obtain the correct solutions of the above boundary-value problems on the basis of the qualitative mathematical theory of the characteristic equations and the standard numerical methods used in RTT. In particular, cases of highly anisotropic phase functions, which require the use of thousands of members in their expansions in Legendre polynomials for their correct description, and are these kind of situation mentioned above. The reason for this state of things lies partly in an incomplete account of all the main constructive features of the fundamental equations of RTT. For effective and correct solutions of the characteristic equations and boundary-value problems of RTT it should be taken into account as much as possible the structure of these equations and problems and as well as used theoretical constructs that are adequate to the properties of computer arithmetic. The constructive theory of characteristic equations for SRTE developed in [11, 12] almost fully satisfies to such requirements. In these works the use of constructive procedures allowed one not only to obtain the main results of the qualitative mathematical theory of characteristic equations for SRTE, but to construct analytical solutions of these equations for arbitrary phase functions. There were also given the application of this constructive theory to the determination of the reflection function for a semi-infinite turbid medium. The use of this theory and the general invariance relations reduction method (GIRRM) (a general summary and applications of this method were given in [13]) allows us to solve boundary-value problems RTT for turbid media of complex configurations.

Further investigation showed that on the basis of the results of [11, 12] one can obtain even more simple in form and in substance effective analytical and numerical results, which are almost completely reduces the solution of the characteristic equations for SRTE to the calculation of the same type of infinite continued fractions and associated Legendre functions normalized in some way. It should be noted that the calculation of these fractions and the expansion coefficients of the required solutions in associated Legendre functions involves only the use of two-term recurrence relations. We especially emphasize that the use of these recursions allow one to correctly and efficiently obtain numerical values for the required quantities in the case of arbitrary single scattering albedo and almost arbitrary phase function. One of the most important results of the constructive theory developed here is the presentation of the required solutions of the characteristic equation in the form of a sum of series uniformly convergent on the unit sphere and in the form of known functions that are directly expressed in terms of the phase function.

In the report the main statements of the new version of the constructive theory of characteristic equations for SRTE and the information on its possible application will be presented.

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Using of the General Invariance Relations Reduction Method for Obtaining the Radiative Field Characteristics for the Case of Plane-Parallel Media

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The general invariance relations reduction method (GIRRM), which was proposed in [1–6], and the essence of which was explained in detail in [7, 8], is one of the universal common methods of radiative transfer theory (RTT). It can be effectively used for solving boundary-value problems of radiative transfer equation for the cases of almost arbitrary phase functions and scattering, absorbing media of different configurations. Under a configuration is meant a form of the medium and the geometry of the radiation sources. On the basis of GIRRM the most meaningful results can be obtained when the turbid medium has a canonical form. Such media, in particular, include dispersion medium, which have the shape of infinite, semi-infinite and finite plane-parallel layers, a sphere, an infinite circular cylinder, a disk, regular polyhedrons and spheroids. However the substantially deepest information of radiative field characteristics can be obtained using GIRRM in the case of any phase function and turbid media of a plane-parallel configuration. This report describes the constructive scheme of using GIRRM to solve various boundary-value problems for RTE when the phase function is almost no restrictions. In particular, we can effectively solve this kind of problem, when for the correct presentation of a phase function it is necessary to use several thousand members in its expansion in Legendre polynomials.

As an illustration to the above, we present a list of problems that have been solved or can be solved with the help of GIRRM. Firstly, the exact analytic expressions for the volume Green function for the RTE in the case of an infinite plane-parallel macroscopically homogeneous dispersion medium is obtained. Secondly the correct analytical and numerical algorithms for finding the surface Green function for the RTE and the reflection function for the case of a plane semi-infinite macroscopically homogeneous dispersion medium that is not limited by an underlying surface are carried out. Thirdly, the correct analytical algorithm for finding the volume Green function for the RTE for the same semi-infinite medium. Fourthly, the efficient algorithm allowing to take into account the presence of the underlying surface (with an arbitrary reflection law), which limits the semi-infinite dispersion medium is rigorously substantiated. Fifthly, the algorithm for finding the reflection and transmission functions for a macroscopically homogeneous turbid layer of any optical thickness is proposed. Sixthly, the multi-term asymptotics for the reflection and transmission functions of optically thick layers (single scattering albedo should belong to the half-interval (0, 1]) are obtained. Seventhly, the correct procedure for finding the volume Green function for the RTE when conservative or not conservative scattering plane-parallel layer has any optical thickness is carried out.

It should be emphasized that on the basis GIRRM one can obtain the basic relations and equations of invariant embedding method, even for the case of dispersion media, which do not have a plane-parallel, spherical or cylindrical symmetry. In particular, in [9] for a boundary -value problem for RTE for the case of inhomogeneous turbid cylindrical medium exposed to unidirected infinitely narrow beam of radiation was reduced to the solution of the Cauchy problem. Using

GIRRM, in a number of situations one can also reduce the non-linear boundary value problems for integro-differential equations to the solution of the Cauchy problem (see, eg., [10]).

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The New Method to Find the Small Angle Approximation to the Transport Equation under Peak-Forward Phase Functions

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The small angle (SA) technique is often used to obtain the approximation to the transport equation solution in high peak-forward scattering media illuminated by a monodirectional beam. SA approximation takes into account scattering of the source radiation at small angles only. It presents the singular component of the solution and can be considered as simple approximation to the solution being sought. The rest regular component depends weakly on angles and can be found with no great computational expenses. For instance, a coarse angular mesh can be used.

The new method to obtain SA approximation to the transport equation solution in a slab is presented. The method is based upon mesh approximation of the transport equation and does not include a analytical solutions. The numerical results by some refining angular meshs for the slab with the Heney-Greenstein phase function with asymmetry parameters $g = 0.85$ and $g = 0.93$ are given. They correspond to the phase functions of the clouds and sea water. One shows preliminary calculation of the SA approximation permits to find the regular component on coarse angular meshes and reduce full calculation time.

Specific Features of Different Types of Time-Dependent Diffusion Models Employed for the Radiation Transport Description in Scattering Media

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The interaction of pulsed laser radiation with scattering matter can be generally described by the time-dependent radiative transfer equation (RTE). The radiative transfer means the combination of two different independent physical processes that corresponds to the radiation absorption and scattering. The initial optical characteristics (the absorption coefficient and the scattering phase function) are to be determined from this initial integro-differential RTE. However, RTE can not be solved analytically in its initial form due to its complexity, so there are commonly used various approximations in order to simplify the RTE by some additional assumptions. The diffusion approximation is the most widely used today. This relatively simple approximation converts RTE to the time-dependent diffusion equation and the initial optical characteristics are replaced by the absorption coefficient and reduced scattering coefficient.

In the present work three various time-dependent diffusion models (classical, refined and extrapolated) of the radiative transport are investigated in the case of the scattering slab geometry. The general limitations of the diffusion approximation and the particular drawbacks of each diffusion model are outlined. Employing these models the absorption and reduced scattering coefficients of the homogeneous scattering medium are determined in the case of the transmission geometry. The scattering phantoms were made from water-lipid solutions. These coefficients are determined from experimental temporal distributions of transmitted photons at different slab thickness (from 10 to 110 mm) with original fitting procedure. The specific nonlinear dependencies of the scattering and absorption coefficients on the slab thickness were obtained for each of the examined models, although it is physically impossible for the same substance. Two separate parts can be clearly distinguished on the obtained graphs, where the first one corresponds to the rapid decrease of the reduced scattering coefficient at small slab thickness (at $l < 30$ mm) and on the second part of the curve at $40 < l < 90$ mm these values are decreasing smoothly (the plateau part). In general, the observed effect is caused by the fact that the significant features of the scattering indicatrix are lost when the diffusion approximation has been applied to the time-dependent RTE. This explanation was confirmed by Monte Carlo simulation, where the similar dependencies were obtained. Nevertheless, the existed diffusion models could be successfully employed within the plateau part of the respective curves of absorption and scattering coefficients where the determined values are supposed to be close enough to the true ones. Thus, novel models are strongly required which take into account the scattering indicatrix specific features more adequately in order to improve the accuracy of the determined values in real experiments.

On the Use of Method of Synthetic Iterations in Problems of Atmospheric Optics

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For the solution of the radiative transfer equation (RTE) by any numerical method the scattering integral is replaced by a finite sum. The physical basis of the radiative transfer theory is the ray approximation that inevitably generates singularities in the radiance angular distribution and makes it impossible to replace the integral with the sum. Therefore, singularities should be eliminated though approximately, but necessarily analytically. This allows us to reformulate the boundary value problem for the smooth solution regular part with the residual of the solution anisotropic part as the source function. RTE for the solution regular part allows the discretization. The resulting discrete RTE for the homogeneous slab is reduced to a two-point boundary value problem of the system of the ordinary differential equations. This system has an analytic solution as a matrix expression in the form of scatterers that expresses the radiation emitted from the slab through the incident radiation and the source function of the residuals of the solution anisotropic part.

All matrix operations today are standardized and optimized for a specific processor. Therefore, it is possible only one implementation of the algorithm in principle. Differences between the various programs associated with various methods of the approximate elimination of the solution anisotropic part. It can be shown that the best way to eliminate the anisotropic part is based on the analysis of the angular spectrum of the radiance distribution (expansion in spherical

harmonics): slow monotonic decrease in the index of the spectrum – small-angle modification of spherical harmonics method (MSH). This approach MDOM can significantly reduce the number of ordinates *N* and azimuthal harmonics *M* due to the accurate elimination of the solution anisotropic part. This provides for the specified algorithm the fastest count rate at the same accuracy.
This approach has an average convergence in power. The angular distribution of the regular part is close to isotropic, but saves all the angular details of the phase function. For the radiance angular distribution is characteristic the ratio that is equivalent to the Nyquist theorem. Therefore, the convergence of all methods of the anisotropic part elimination is about the same for the small errors in the uniform metric.

The modern signal processing algorithms of remote sensing from space require the accuracy better than 1% in the uniform metric and the computation time should be not more than 1 second on a standard PC for a single wavelength. As one can see, numerical methods at the traditional approach do not allow it to achieve. However, in neutron physics was developed the method of synthetic iterations (SI) that can significantly accelerate the convergence of the RTE solutions. At the SI the procedure of iteration calculation is divided into two steps. At the first step it is found the approximate RTE solution describing the exact one enough well in the mean-square metric in power. At the second step the ordinary iteration of the approximate solutions is calculated.

The numerical RTE solution by the algorithm MDOM satisfies conditions of the first SI step. However, a further calculation of the ordinary iteration is difficult, because the form of the scatterers expression does not give the value of the radiance field inside the medium. If we use the obtained solution, the two-point RTE boundary value problem converted into two independent one-point problems with initial conditions on the upper or lower boundaries of the slab. This allows finding the field in the medium in the form of solutions of each problem in the form of a linear combination of exponents on the optical thickness. Each solution contains both positive and negative exponents, making them unstable at the large slab depth. Selecting the individual solutions for the up- and downstream, and combining them, one can get a stable solution containing only the negative exponents. The calculation of the iteration is reduced to the exponent integration over the optical thickness. Numerical calculations showed a significant acceleration of convergence by almost two orders of magnitude, due to the essential reduction of *N* and *M*.

Numerical Study of Rainbows, Glories, and Coronas

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Phase functions of light scattering in water-drop clouds for various distributions of a droplet size are studied in this paper. Conditions of forming glories, rainbows and coronas are considered. The hypothesis proposed by A.N. Nevzorov is discussed, which states that a considerable amount of water in cold clouds can exist in a specific phase state with refractive index 1.8 (the so-called A-water). Polarization and angular distributions are investigated numerically for the radiation reflected by cloud layers with drops of water and hypothetical A-water. The multiple light scattering is simulated by the Monte Carlo method. The numerical results obtained enable one to develop procedures for the analysis of a microphysical structure of clouds and existence of A-water [1]. The numerical software has been developed in the Ludwig-Maximilian University of Munich and in the Institute of Computational Mathematics and Mathematical Geophysics of Siberian Branch of Russian Academy of Sciences (Novosibirsk). The research was supported by RFBR (project 12-05-00169).

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An Efficient Code for Transmittance and Radiance in IR Atmospheric Windows

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A large number of applied problems in atmospheric optics is connected with a definition of optical characteristics of the atmospheric transmittance windows. Transmittance and radiance of atmospheric paths required for the estimation of the signal-noise relation on application of IR-devices in real atmosphere are of prime interest. As it is known, various ways of IR-radiation extinction are to be taken into account in calculating the transmittance in IR atmospheric windows. The molecular absorption and scattering by atmospheric gases, the extinction by aerosols, the absorption in the water vapor continuum and the absorption induced by nitrogen pressure are among these. The developed (by now) algorithms for calculating the input of these processes in the general radiation extinction are also well known. At the same time, the selection or design of the most effective algorithms, combining the high accuracy with a reasonable calculating speed are still remain an intricate problem.

A comparative analysis of the contribution of various IR-radiation extinction to the total error in determining the slant atmospheric path transmittance is made in this paper. That information has been used in selecting the specific calculation algorithms of one or another extinction factor. Thus, the model MTCD2.5 [1] is used to calculate the water vapor continuum in all IR-atmospheric windows. A specially developed procedure is used to estimate the contribution of aerosol components in the bottom layer. The molecular absorption calculated with the method [2] that combines a high accuracy with a high speed. Notice, that this method allows one to change easily the spectral resolution in the range from 0.2 cm and more without evident changes in the calculating speed. A comparison between the calculated transmittance and radiance of the atmospheric paths and the results, obtained from the widely used calculating methods (line-by-line method [4], MODTRAN[5]) is presented in the report.

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The Pulse Characteristics of the Traces "Terra-Space" in the Presence of Clouds

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The pulse characteristic (PC) of the trace $J(t)$ is the response of the trace on the δ-pulse of source. The PC is the most important concept in non-stationary problems of radiative transfer. Full time integral of PC is the attenuation coefficient of the radiation. The mathematical convolution with a source function is the signal generated at the point in space. The function of the upper limit, referred to the attenuation coefficient, is the trace transfer function $P(t)$.

In this paper the PC was calculated using the Monte Carlo method for the trace "Terra-Space" in the presence continuous stratiform clouds in the atmosphere. Point isotropic source of optical radiation is located between the cloud layer and the underlying ground surface. The observer is in the near-space at the zenith angle of sight υ relative to the source. The main variable parameter is the cloud optical thickness τ. The wavelength range corresponds to the visible and near-infrared part of the spectrum.

The results of calculations show that with the increase τ the fraction of photons with low travel times decreases, and the effective domain of the $J(t)$ is localized to the increasingly distant from zero intervals of the time. The modal time (t_{mod}) of the function $J(t)$ is on the increase and for $\upsilon = 0°$ equals, respectively, to $1.3{\cdot}10^{-6}$ s for $\tau = 5$; $3{\cdot}10^{-6}$ c – for $\tau = 10$; $2.3{\cdot}10^{-5}$ c – for $\tau = 60$ and $2.8{\cdot}10^{-5}$ c – for $\tau = 100$. The increasing of the viewing angle υ leads to the growth of the modal time. For example, for $\tau = 60$ and $\upsilon = 60°$ the modal time is $2.7{\cdot}10^{-5}$ s, i.e. increases by almost 15%. Dependence of the PC modal time on the optical thickness is almost linear, and for $\upsilon = 0°$ is given approximately by $\tau = 3{\cdot}10^{6}\, t_{\text{mod}}$. The error of this ratio for the computer models do not go beyond 10%.

The slope k of the transfer function $P(t)$ in the range of its change from P_1 to P_2 is in a stable relationship with an optical thickness. In particular, for $\upsilon = 0°$ this relationship can be expressed as the inversely proportional function $\tau = 2.23{\cdot}10^{10}\, k^{-2}$, where in the slope $k = [P(t_2)–P(t_1)]/(t_2–t_1)$, the values of the transfer function $P(t_1) = 0.2$, $P(t_2) = 0.4$, and corresponding times t_2 and t_1 ($t_2 > t_1$) are determined by the particular type of function $P(t,\tau)$. The error in determining τ by the slope of the front of the function $P(t)$ is within 20%. The established relationship between τ and the parameters of the functions $J(t)$ and $P(t)$ suggests the possibility of remote determination of the optical thickness of clouds from space vehicles.

Model Image of the Pulse Characteristic of the Light Scattering Medium

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The pulse characteristic (PC) of the scattering medium from the phenomenological reasons and from results of analysis numerical experiments is established as a logarithmic normal distribution of the parameter $x = \ln\sigma ct$, wherein σ is the scattering index of the medium, c is the light velocity, and t is time. It is showed the "long" signals in the intense scattering medium are distorted like this distortion of the "short" signals in the weakly scattering medium. The logarithmic normal distribution is proof as for directed source (laser) as for the point isotropic source. Permissible it is ensured so for sources another tip.

The comparison of the numerical calculated PC and its model shows that the difference of the results is not more 8% on the level more 0.1 of maximum PC. The maximal difference not more 20% there is on the edges of the logarithmic normal distribution. It is showed that the half-width of the PC decreases with the growth of the medium optical thickness. This thesis is proofed by the calculations of the variation factor.

For the practical aim the formulae are given in the natural shape: $t_i = f(a_i, b_i, D, \sigma D)$ (1), wherein $t_1 = t_{\text{cp}}$ is the mean time of the PC, $t_2 = t_{\text{med}}$ is the median of the PC, and $t_3 = t_{\text{mod}}$ is the modal time (the time of the PC maximum). Numerical values of the dimensionless factors a_i and b_i for the point isotropic source are given. With the growth of the medium optical thickness all t_i approaches to each other. It follows from here that the PC to had been symmetric more and more when the optical thickness growth, to had been logarithmic normally by this.

As the main conclusion of the investigations is the analytical image of the PC by the logarithmic normal distribution permits to get connection the parameters of PC with the parameters of the trace in the forms by eq. (1). From this equations it is possible to determine the trace parameters solving the inverse problem.

The (O$_2$) Zeeman Effect in Planetary Atmospheric Microwave Radiative Transfer Models

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Atmospheric satellite microwave sensors (e.g.\ Odin Sub-Millimeter Radiometer) and ground-based microwave sensors (e.g.\ Tempera in Bern) are build to retrieve atmospheric parameters from the radiation they observe, often by method of best-fit between data and modeled expectations. Since the Zeeman effect can be safely ignored at larger pressures and for most species, it is quite common to not include the effect in line-by-line radiative transfer simulations. However, at low pressures the Zeeman-splitting of O$_2$ in the microwave region becomes so large that retrieved atmospheric parameters can no longer be trusted without a radiative transfer model that accounts for this magnetic effect on the signal.

To properly describe the Zeeman effect is therefore of high importance from a simulators point of view, in order to facilitate, e.g., temperature retrievals at high altitudes. Re-usability of code helps to ease understanding and makes the general work-flow easier on the programmer. The discussion in the work will therefore focus on this part of the implementation, rather than on the physics of the Zeeman effect. I discuss how to turn unpolarized line-by-line cross-sectional computations without Zeeman perturbations into Zeeman-ready software. In the process I will try to divide the general Implementation into several separate problems. The subdivisions will be: frequency perturbation, relative line-strength, polarization rotation, line-shape, and input of special line parameters.

I describe the implementation of the Zeeman effect in the open-source and freely available Atmospheric Radiative Transfer Simulator (ARTS). A comparison of the implementation with previous models is then discussed, as well as comparisons with O$_2$ data from Odin/SMR at 487 GHz, and with Tempera at 53 GHz. I have found that ARTS handle line-by-line Zeeman effect in a satisfactory manner. Since the problem seems well described for O$_2$, it should also be quite straightforward for additional molecules and/or atoms to be simulated in the Zeeman module. However, I am presently lacking good descriptions of theoretical models for half-spin particles and, most importantly, data for comparison.

Open Questions and Mathematical Subtleties in Vectorial Radiative Transfer Theory

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The transversal polarization of natural light is commonly represented in the Stokes/Mueller formalism. Combined with the equation of transfer this leads to the Vectorial Radiative Transfer Equation (VRTE). The polarization altering effects of a medium are encoded in this equation by the 4x4 extinction and phase matrices. These matrices can be regarded as the infinitesimal generators of an unknown Mueller matrix for the underlying medium, which describes the change in Stokes vector after propagation over a finite distance and thus represents the finite model of the medium.

Currently, we do not know the full mathematical structure (i.e., the algebra) of these generators. The reason for this is our incomplete knowledge of the full structure of Mueller matrices. We need to know the mathematical structure of the extinction and phase matrices for the following reasons.

(i) To accurately represent a given medium in the VRTE, based on measurements of its Mueller matrix.

(ii) To understand when the infinitesimal VRTE model cannot represent a given finite model. Failure to do so can result in obtaining the wrong solution (even without realizing it).

(iii) To be able to increase the efficiency of numerical VRTE algorithms.

The subset of Mueller matrices corresponding to reciprocal media form a Lie group. Subtleties such as (ii) are related to the topology of this group. It is already known that one of its subgroups has non-trivial topology. This fact implies that the infinitesimal VRTE is not an equivalent description of the finite model of a medium. In other words, solving the VRTE for certain media will produce the wrong finite model. It will be discussed, when and how this arises and how we can deal with it.

Depolarization Coefficients of Light in Multiple Scattering Media

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Information on the depolarization coefficients of linearly (ε_L) and circularly (ε_C) polarized light is of great interest to application of polarization techniques for remote sensing of highly scattering media (aerosols, sea water, biological tissues etc.). These coefficients govern the depth dependence of the degree of polarization and are sensitive to optical properties of the medium. Of prime importance is to obtain analytical relations that could establish direct interrelation between the depolarization coefficients of light and the characteristics of the medium (the phase function, the scattering matrix elements and etc.) [1–3].

In this report, the coefficients of depolarization of multiply scattered linearly and circularly polarized light are calculated. For the model media [4] and aqueous suspensions of polystyrene particles), the calculations are carried out both with numerical solving the vector radiative transfer equation and analytically, within the polarization mode approximation [5]. In the latter case the depolarization coefficients are explicitly expressed in terms of the scattering (σ) and absorption coefficients, and the diagonal elements of the scattering matrix of the medium. The range of applicability of the polarization mode approximation is established. For most practically important cases, this method is shown to provide a satisfactory degree of accuracy. We also calculate the fundamental coefficients of depolarization of light in the medium composed of the Rayleigh particles (for the medium with no absorption $\varepsilon_L = 0.745 \cdot \sigma$, $\varepsilon_C = 0.852 \cdot \sigma$). The obtained values correct the results [1–3]. The phenomenological approach [1–3] to calculations without resorting to the vector radiative transfer equation overestimates essentially the values of the depolarization coefficients in the Rayleigh medium (the depolarization lengths prove to be less than the mean free path).

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Radiative Transfer in Sea Ice

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Up to melting season arctic sea ice is covered by snow as a rule. During the melting season the part of ice surface is drained and ice field is covered by small (of several mm) pieces of ice (so cold white ice). This layer is quite optically thick and can be considered as a mixture of ice and air. It is analogous to snow but in contrast to snow this layer is characterized by a greater typical grain size and greater physical density. This layer provides the stable high reflectance. In the summer melting multi-year ice (MYI) three characteristic sub-layers may be distinguished: ‘white ice’ (drained surface), above water and underwater parts of an ice sheet. Scattering in ice itself is due to brine and air inclusions, above-water part of ice contains more air inclusions while in-water part is saturated by water. Drained surface is a part of ice surface, free of water, which has flown down, producing melt ponds.

Up to now the only empirical theory of optical properties of sea ice has existed. To describe theoretically optical properties of this medium we use the model of sea ice as the statistically homogeneous random mixture. Optical characteristics of such a mixture are completely defined by the length distribution of a random chord. Coupling of the recently developed version of the Raleigh-Hans approximation for arbitrary shaped inclusions (brines) and optics of a stochastic mixture ensures description of the optical properties of sea ice in various situations. This theory provides optical characteristics of all layers of sea ice (the extinction coefficient, single scattering albedo and scattering phase function in optical range).

Developed modeling of melt pond reflection is based on the following suggestions: the melt ponds depth is much smaller than their width, therefore, the sidelong reflection is neglected; reflection by the pond bottom is described by the Lambert law. The melt pond reflection includes Fresnel reflection by the pond surface and reflection of a system water layer + ice bottom, including multiple reflections between the pond bottom and surface with regard to attenuation of light propagating through a water layer. Thus, the radiance coefficient of light reflected by a melt pond depends on the directions of illumination and observation, on the bottom albedo and on the pond optical thickness. The analytical formulas for the melt pond reflection were obtained. Thus all optical characteristics of Arctic summer sea ice, which makes the input to the radiative transfer code, are defined.

Software *Ice Reflectance Simulator* (IRS) to compute radiation transfer in the Arctic ice during the summer time has been developed on the base of the fast and accurate RT code RAY and was deployed to study radiative properties of arctic ice with regard to its multi-layers composition, a possible snow cover, melt ponds, waters in polynyas and leaks, as well as the ocean water under ice sheets. Particularly good agreement of this modeling with the field data provided by Dr. Polashenski and Prof. Perovich (CRREL Lab., USA) was obtained.

Влияние формы ледяного пластинчатого кристалла на поведение элементов матрицы рассеяния света на примере гексагона, усеченного дроксталла и «неидеальной» гексагональной пластинки, наиболее характерных для состава перистых облаков при учете горизонтальной/преимущественной ориентациях в пространстве

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Рассмотрено взаимодействие видимого излучения и с наиболее характерными геометрическими формами ледяных пластинчатых кристаллических частиц, которые чаще всего встречаются в перистых облаках, с учетом их горизонтальной/преимущественной ориентациях в пространстве. Были рассмотрены следующие геометрические формы: гексагон, усеченный дроксталл, "неидеальная" гексагональная пластинка. Показано, что как индикатриса рассеяния света, так и поляризацонные элементы матрицы рассеяния света в случае рассеяния света на усеченном дроксталле значительно отличаются от рассения света на пластинчатых кристаллах с другой рассматриваемой геометрией. В частности, в индикатрисе становится возможным идентифицировать новые гало, например, гало, которое получается при падении света на гексагональную грань и далее происходит взаимодействие с одой из скошенных граней ледяного кристалла. При углах падения вблизи зенита данное гало может заключать в себе до 70–80% рассеянной энергии. Также проанализировано поведение элементов матрицы рассеяния света. Установлено, что, несмотря на различные геометрические формы кристаллов, наибольшая часть рассеянной энергии и идентификацию особенностей в поведении элементов матрицы Мюллера следует проводить в гало, которые образуются траекториями с небольшим числом внутренних столкновений с гранями рассматриваемых кристаллов.

Asymptotic Regularities of Phase Scattering Function at Light Scattering by Water Droplets

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An analysis of mechanisms responsible for the formation of a pattern of radiation scattered in the range of angles θ from 0 to 180^0 is made for a sphere with the refraction index of m=4/3 by comparing the phase scattering functions calculated with the Mie theory and interference formulae with the use of the diffraction p_d and partial rays p = 0, 1, 2 and 3 of geometric optics (GO). In view of these refinements it appeared that large-scale oscillation regularities of the exact phase scattering function at high parameters of x equal to the ratio of a sphere circumference length to the radiation wave length corresponded to the interference pattern of two or three rays mentioned above. Depending on the composition of interference rays all the range of the phase scattering function angles is subdivided into 6 ranges. The first (diffraction) range is characterized by the prevailing contribution of ray p_d, the amplitude of which at zero-th angles is proportional to $(x+x^{1/3})$. The interference of this ray with the rays p = 0 and 1 gives a pattern qualitatively similar to the real one. For integral characteristics a computation error with the interference formulae in the range of angles $0–10^0$ does not exceed units of percent for x > 10 and within the large x values it tends to zero.

For other regions the relationships for oscillation periods are given, from which the tendencies of oscillation periods over the angle $\Delta\theta$ to zero are the following: according to the laws of x^{-1} (10–80° – region p = 0.1), $x^{-1/2}$ (80–110° and 165–180° – the regions with p = 0.3 and 0.2) and $x^{-2/3}$ (110–129° and 138–165° – rainbow regions p = 3 and 2) is seen. In the range of angles $30–60^0$ an effect of rainbows 4 and 5 is found in the form of modulations, typical of these rainbows. In the above-mentioned regions the span of the interference phase scattering functions and the oscillation period Δx at large value of x depends only on θ and does not depend on x. Note that an interference structure is superimposed a resonance structure with period ≈ 1.1/m.

From the analysis it follows that in all the above-mentioned regions there are interference oscillation structures with the periods of several degrees. From this it follows that minimal ranges of scattering over a scattering angle should be no less than 10^0, and over the parameter x they should be divisible by the resonance structure period. The present paper describes the results of the phase scattering function averaging over the chosen parameters of θ from 10 to 15^0 and δ = 0.82 for the refractive index m = 4/3 given as the approximation dependences on $\langle x \rangle$ with three parameters. One of these parameters is equal to an average value of the phase scattering function in GO. A set of these coefficients is given in the form of a table. It covers the angles from 10 to 180^0 and makes it possible to calculate for the visible spectrum range the drop spectra with the radii over 2 micrometers.

Self- and Foreign Water Vapor Continuum Absorption Coefficient in the 8–12 and 3–5 μm Transmission Windows and Cooling Rates in the MLS Atmosphere

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The nature of the water vapor continuum absorption has been a widely debated topic in the last few years. This is mainly due to the fact that an extensive literature on laboratory measurements of .self and foreign water vapor continuum absorption in the 8–12 and 3–5 μm atmospheric windows [NIST, CAVIAR] has evolved. The accuracy of the data discussed is reasonably high to allow for comparison with theoretical calculations. Even so, the investigations performed thus far have failed to provide an unambiguous answer to the question as to what fraction of monomer and dimer absorption is involved in the continuum absorption between water vapor bands. In this connection development of the monomer and dimer absorption hypotheses may contribute to our understanding of absorption processes of interest.

According to asymptotic line wing theory elaborated by our research team, absorption in the atmospheric windows results from a combined effect of far wings of strong lines of the neighboring monomer absorption bands. The basic approximation to be used in solving a complete quantum problem of interaction of absorbing and broadening molecules is based on the semiclassical representation method that considers separately the centers of mass motion regarded later as the classical motion. Asymptotic evaluation of the time integral is made for the case of large frequency detunings. The resulting expression for the line shape includes parameters of the classical and quantum intermolecular interaction potentials found from the comparison of experimental and calculated absorption coefficients. The asymptotic line wing theory states that the description of the absorption involves all the interactions between colliding molecular pairs except those responsible for the formation of new molecules that, in principle, can be interpreted as the absorption by metastable and “free” pair states.

The calculation results for spectral and temperature dependence of the self and foreign continuum absorption in the 8–12 and 3–5 μm atmospheric windows are presented to show good agreement with measured values. Expressions for line shapes are used to calculate the cooling rates in the IR region within a 33-layer radiation model. A computer program employs the parallelization code. Self- and nitrogen-broadening contributions and those from central and line wing parts into the cooling rates as functions of height are examined.

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Implementation of the Method of Synthetic Iterations in the Solution of the Radiative Transfer Equation on the Basis of the Two-Stream Approximation

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Synthetic iteration (SI) accelerates significantly the convergence of the methods of solving the radiative transfer equation (RTE). The essence lies in the division of iteration in two steps. In the first step one finds an approximate solution that describes well enough the solution in power. In the second step the usual iteration is calculated. In paper [1] the RTE solutions was investigated by SI, where as a first approximation one took the RTE solution by the discrete ordinate method with the anisotropic part elimination by the small-angle modification of spherical harmonics method (MSH). The advantage of MSH is a fairly accurate calculation of the solution anisotropic part that results in close to the isotropic angular distribution of the radiance. It allows hoping for the possibility of using two-stream approximation for finding the approximate RTE solution at the first step.

The two-stream approximation is based on the view that the radiance angular distribution is in shaped close to isotropic. This approach is similar to the discrete ordinate method with two ordinates only, but with different weights, which are calculated so as to satisfy the normalization of the phase function already for two streams. The resulting system of two ordinary differential equations with the MSH residual as the source function has an analytical solution in the matrix form.

The implementation of the method and numerical calculations shows that the algorithm allows calculating the radiance angular distribution with an accuracy of less than 1%, significantly exceeding the calculations speed of all the others. The accuracy is reduced for the sighting angles close to the sliding angle reaching 5%. It seems that the decrease of accuracy is not an obstacle for the use of the algorithm for the interpretation of the remote sensing data, since sliding sighting angles are not used. MSH and the two-stream approximation allow the simple analytical solution for the arbitrary medium geometry. This opens up the possibility of transition to the solution of transfer problems for the turbid medium volume of arbitrary geometry.

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The Mathematical Model of Daylight Sky Luminance Distribution

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We propose a new approach in daylighting calculations based on the realistic modeling of radiative transfer in atmosphere [1]. That could be reached by using the new model of radiative transfer in turbid medium slab with abstraction of anisotropic scattering. This model appeared to be sufficiently fast and exact, because of the effective approach in calculation methods of anisotropic and smooth parts of the luminance angular distribution. And so its application could be supposed in daylighting design calculations. The main advantages are seen not only in completion with standards, but in creating a realistic picture of the lighting scene in the given time and environment conditions. This model gives opportunities to predict the sky luminance distribution for the given physical parameters of atmosphere. Slabs stratifications, the real scattering indicatrix and their models can be taken into account. For daylighting calculations we approach to modeling real situations. Thus became the transition from calculations of relative lighting parameters (such as daylight factor), to absolute ones, like luminance and illuminance distributions in the given scene. This, in turn, opens possibilities of principally new analysis of daylighting. We can take into account, estimate and see the distribution of lighting parameters based on calculations in the environment with natural lighting sources of the Sun and atmosphere.

We have analyzed the new model in the point of application in daylighting design calculations in rooms. For this purpose the standard sky luminance distribution models of International Commission on Illumination (CIE) [2] have been approximated. The combination of the models of Rayleigh and Henyey-Greenstein scattering phase function was included in the model of radiative transfer. The approximation was based not on the common methods of mean deviation or mean square root deviation, but on the sum of the mean deviation (by modules of deviations) and module of maximum deviation. Thus the minimum in the point with the maximum deviation and also minimum in other deviations could be reached, and surfaces become one nearer to another. We have achieved good results in the approximations for the clear sky models (the deviations sum below 15%).

We have created the MATLAB program for calculating daylight factor distribution in rooms. There were used models of the CIE standard sky and the radiative transfer model in turbid medium slab. These sky models also were created in the Lightscape 3.2. lighting calculation program for 3D scenes. A strong influence of sky luminance distribution on the illuminance in the room was identified in comparison of the results. The analysis shows the relevance of the application of this model for the daylight calculations.

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Aerosol Radiative Characteristics During Smoke Mist in Siberia

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Forests from massive forest and peat fires, in addition to volcanic eruptions, influence substantially the radiation regime and ecological state of large regions for duration of up to 1–2 months. The situations with anomalous smoke mist in European part of Russia in 2002 and 2010 are best elucidated in the scientific literature. This report addresses the characteristics of smoke mist, which was observed in Siberia during summer of 2012.

The photometric measurements in the region of Tomsk (Akademgorodok and “Background” observatory) have been conducted in year-round regime with the use of SP and CE 318 sun photometers (AERONET; http://aeronet.gsfc.nasa.gov). The observation results are used to determine: the aerosol optical depth (AOD) and moisture content of the atmosphere, as well as (under the clear-sky conditions) the single scattering albedo (SSA) and asymmetry factor of scattering phase function (AFSPF) of aerosol. The two latter characteristics were retrieved applying the standard AERONET approach [1] and using the original algorithms [2]. The aerosol radiative characteristics were analyzed employing the measurements of direct, diffuse, and total solar radiation, performed using MS-802 pyranometer and MS-53 pyrheliometer.

The data obtained indicate that the smoke situations spanned the period from mid-June to early August. Two waves of the highest smoke turbidities, with AOD larger than 3–5, were observed in early and late July, with the monthly average value exceeding 1 (for comparison, the multiyear average AOD in July is 0.16). AOD deviated most strongly from the background conditions in UV spectral range; and in the relative value, AOD increased nearly identically, i.e., by a factor of 7–9, across the entire spectral range.

The aerosol AFSPF and SSA retrievals, performed using different methods, are discussed; we compare the average characteristics under background conditions, in July 2012, and during separate smoke situations. Based on the data obtained, we present the estimates of the aerosol radiative forcing, and compare the fluxes of direct, total, and diffuse solar radiation during smoke mist against average data under the conditions usual for the region of Tomsk.

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Optical-Microphysical Properties of Smoke Haze from Siberian Forest Fires in Summer 2012

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The interest to study of the influence exerted by smokes from Siberian forest fires on the dynamics of aerosol composition of the atmosphere and climate changes in Arctic has increased drastically in the recent years. A stable anticyclone has formed in the Siberian region in summer 2012 under conditions of the flat high-pressure gradient, and extensive forest fires occurred due to long-term hot weather.

In June–August 2012, we conducted the round-the-clock measurements of the directed aerosol scattering coefficient of the dry content of particles $\mu(45°)$ ($Mm^{-1}sr^{-1}$) (FAN nephelometer) and the mass concentration of black carbon M_{BC} (μg/m^3) (MDA aethalometer) at the Aerosol Station of IAO SB RAS and Fonovaya (Background) observatory (forest zone 70 km to the west from Tomsk). The particle size distributions in the size range 0.3–20 μm was measured with a GRIMM Model 1.108 photoelectric particle counter. The data obtained have allowed us to determine the mass concentration of submicron aerosol M_A (μg/м^3), relative content of black carbon in particles (BC fraction) $P = M_{BC}/M_A$, single scattering albedo ω, imaginary part of the refractive index of particles χ, and total volume of particles with diameters of 0.3–1.6 μm. Angular and polarization components of scattered radiation in the visible spectral region at three wavelengths were measured by another FAN spectronephelometer-polarimeter. These data were used to estimate the size spectrum and refractive index of submicron particles through solution of the inverse problem. The dependence of the directed aerosol scattering coefficient at an angle of 45° on the relative humidity RH of air was recorded at artificial humidification of particles, and the parameter of condensation activity was determined.

Four episodes of smoke haze outbreak were observed in summer 2012: June 17–July 7, July 15–22, July 25–29 and August 1–4. The highest smoke level of air was observed on July 27. The achieved mass concentrations of submicron aerosol of 1505.6 μg/m^3 (three times higher than the maximum permissible level) and black carbon of 38.8 μg/m^3 many times exceeded the background summer levels. The air smoke level was comparable with the smoke haze from peat-forest fires in the Moscow Region in summer 2010. The black carbon fraction P in smoke haze was low (1.5–2%), that is, smoke particles were slightly absorbing. The imaginary part of the complex refractive index of particles determined by the rule of the volume mixing of black carbon with nonabsorbing aerosol substance with regard for the value of P was low: $\chi < 0.02$. The single scattering albedo in the visible spectral region in smokes was high ~ 0.95–0.98. This fact indicates that smokes of forest fires behave as a cooling factor in the radiative-climatic effect.

As the smoke haze becomes denser, the volume concentration of particles increases all over the size spectrum as compared to the background level. The increase is the largest (by 100 and more times) in the diameter range 0.4–0.6 μm. From the results of solution of the inverse problem, the volume size distribution of smoke particles was characterized by the narrow medium-disperse fraction with a mean diameter of 0.4–0.5 μm and refractive index ~ 1.4–1.5. Under background summer conditions, the mean value of the modal diameter of particles is 0.2–0.3 μm, that is, particles in smokes become larger. The degree of linear polarization of the radiation scattered at an angle of 90° in smoke haze was usually negative and decreased down to – 0.1, whereas under background conditions it is most often equal to 0.3–0.4. The condensation activity of smoke particles appeared to be low: the parameter of condensation activity varied within 0.05–0.1.

The linear correlations between of the black carbon and aerosol concentrations, total volume of submicron particles, and the coefficient of directed scattering at an angle of 45° in the smoke haze were increased as compared to the background conditions. The correlation coefficients achieved the high level of 0.97–0.99. This counts in favor of applicability of the single-parameter model of atmospheric hazes for the smoke haze.

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Influence of Large-Scale Forest Fires on Aerosol Characteristics of Lower Atmosphere

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Large-scale forest fires in central Yakutia in 2002 were studied on remote sensing data of MODIS/Terra and AVHRR/NOAA and data of meteorological stations. Spatial-temporal distribution of aerosol optical thickness (AOT) and aerosol index (AI) are analyzed. The forward trajectories of aerosol plumes movement were calculated. There were two main movement directions of biomass burning products: north- and south-east. However, in some cases, aerosol plumes moved north-west to distances up to 3000 km.

Total emissions of CO_2 in the atmosphere were 68–171 Mt (0.9–2.4% of global CO_2 emissions from fires); CO – 3.5–9.7 Mt (0.9–2.5%); CH_4 – 0.13–0.52 Mt (0.6–2.4%). The amount of CO_2 emissions compared to global annual volcanic emissions.

Empirical Model of the Vertical Profiles of Aerosol Optical Parameters in the Troposphere of West Siberia Taking into account Light Absorption and Hygroscopic Properties

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The approach we develop to radiative calculations using empirical models of optical properties of tropospheric aerosol in West Siberia is discussed. The empirical model of the aerosol optical characteristics in the 5 km high layer of the atmosphere, based on the data of long-term airborne sensing of the vertical profiles of aerosol scattering and absorption parameters, is presented. The model provides retrieval of the needed set of parameters for calculation of the optical characteristics and short-wave radiative budget. The input parameters of the model are the mean values of the angular scattering coefficient, particle size distribution function, concentration of the absorbing substance (“soot”), parameter of condensation activity and relative humidity of air at different heights for different seasons, type of air mass, and time of day. Statistical reliability of the experimental data is confirmed by comparison of the synoptic features and meteorological parameters with the data of long-term observations in the West Siberian region. At the first stage, the empirical model of the aerosol scattering parameters in the lower 5-km high layer of the atmosphere of West Siberia was created [1]. At the present stage of developing the model, the data array of monthly airborne sensing (1997–2012) was included, that enabled us to estimate the imaginary part of the complex refractive index on the basis of the experimental data on the concentration of absorbing particles [2].

Aerosol was modeled as a sum of submicron and coarse lognormal fractions at zero relative humidity. Parameters of the fractions (median radii, half-widths of the distributions and volume concentrations) were selected so that the total (of both fractions) angular scattering coefficient at the angle of 45° and wavelength of 0.51 μm matched the experimental mean value at this height under corresponding conditions (season, type of air mass, time of the day).

Taking into account the experimental data on size distribution of soot particles [3], we assumed the basic hypothesis that 90% of the absorbing substance is located in the submicron fraction, and 10% is in the coarse fraction. Real and imaginary parts of the refractive index were estimated using the “mixture rule”. Then the obtained parameters of the fractions (median radii, volume concentrations, refractive indices) were recalculated to the respective value of relative humidity (its seasonal mean values were taken) using the seasonal mean parameter of condensation activity at each height. At the final stage, the scattering matrix, single scattering albedo and aerosol optical thickness for different seasons were calculated. Good agreement (within 5%) of the seasonal mean values of the columnar single scattering albedo and asymmetry factor of the scattering phase function obtained with the presented model and the original techniques for solving the inverse problem based on the AERONET data in Tomsk is observed.

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Simulation of Vertical Profiles of Solar Radiative Fluxes in the Clear-Sky Atmosphere Taking into Account the Regional Features of the Western Siberia

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The aerosol models (OPAC, WCP, etc.) had long been the only complete source of data on the wavelength variations (0.2–4 μm) and vertical profiles of the radiatively significant optical characteristics of aerosol, namely, the extinction coefficient, the albedo, and the scattering phase function. However, the coarse spatio-temporal resolution, characteristic for these models, may be the reason for the inaccuracy in the estimates of the radiation effects for specific aerosol types or climatic zones (regions). The uncertainty of the model estimates of the radiative effect is reduced by refining both the proper radiation codes and the complex of input parameters.

The report presents the calculations of broadband fluxes of solar radiation with the use of the empirical model of the vertical profiles of the aerosol optical characteristics in the altitude range of 0–5 km for the Western Siberia [1]. The empirical model was created on the basis of aircraft studies of vertical profile of the angular scattering coefficients and disperse composition of atmospheric aerosol, as well as on the basis of real measurements of the content of absorbing particles, which made it possible to estimate the imaginary part of the refractive index. The broadband fluxes in the molecular-aerosol plane-parallel atmosphere were calculated using the algorithms of the Monte Carlo method, developed earlier. The transmission function was calculated using the k-distribution method (HITRAN2008) on the basis of regional model of the profiles of temperature, pressure, and water vapor taking into account the absorption by all atmospheric gases, the information on which is presented in the AFGL meteorological model. The total columnar moisture content and the aerosol optical depth corresponded to the multiyear average values, observed during summer and winter periods in Tomsk. The total carbon dioxide content in the atmosphere was 380 ppm. The surface albedo was specified using the measurements of the MODIS satellite scanner for the region of Tomsk.

The used empirical model correctly describes the aerosol optical characteristics (extinction coefficient, single scattering albedo (SSA), and asymmetry factor (AF) of the scattering phase function) in the spectral interval (0.44–0.87 μm). We discuss how these data can be used for the radiation calculations in a wider (0.2–4 μm) wavelength range. The effects of the vertical variations in the extinction coefficient, SSA, and AF upon the solar radiative fluxes at the different atmospheric levels are estimated. It is shown that, under mean summer conditions, the neglect of the stratification of the optical characteristics causes no more than 3–5 W/m^2 difference in the diffuse radiative fluxes at the top and bottom of the atmosphere; however, the flux difference may reach several tens of W/m^2 at other atmospheric levels within the troposphere. We compared the solar radiative fluxes, calculated taking into account the seasonal variations (winter, summer) in the optical characteristics of aerosol, atmospheric moisture content, and other atmospheric parameters, surface albedo, and illumination conditions.

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Retrieval of Radiative and Microphysical Parameters of the Atmospheric Aerosol from the Data of Three-Wavelength Integrating Nephelometer

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The single scattering albedo and asymmetry factor of the scattering phase function are among the most significant radiative characteristics of the atmospheric aerosol. Their retrieval from the observational data needs the solution of ill-posed inversion problems and simultaneous measurements of several optical parameters. At the present time, the integrating nephelometer TSI 3563, capable of measuring the scattering coefficient and its component due to scattering in a backward hemisphere at three wavelengths – 450, 550 and 700 nm is widely used for these purposes along with other instruments. The ratio of forward to backward scattering is closely related to the asymmetry factor, and comparison of the scattering coefficient with independently determined absorption (or extinction) coefficient makes it possible to estimate the single scattering albedo. However, the nephelometric data require correction due, in particular, to the limited to 7–170º integration range. This problem was considered e.g. in [1, 2]. It was proposed to use the relation between the Angstrom exponent and correction factor as one of the ways to solve it.

In the present paper, the possibility to retrieve the aerosol microstructure directly from six parameters measured by integrating nephelometer is analyzed, and a new approach to the data correction is suggested. Numerical simulations with bimodal aerosol models showed that microstructure of the fine fraction can be reliably retrieved from the data on the scattering intensity integrated over 7–170º and 90–170º at three wavelengths. So, in cases when fine fraction is predominant in scattering, the microphysical extrapolation is applicable in assessment of the scattering coefficients. In general, the more productive approach was found to be based on the statistics of the size spectra retrieved in a wide particle size range (the data from Zvenigorod AERONET site were used). The scattering coefficients and measured by nephelometer parameters were recalculated for these size distributions. Then by means of multiple regression technique, relations between measured and retrievable parameters were constructed. This approach provides a standard deviation of about 1%. Results of measurements with nepehelometer, operating in the St. Petersburg State University since the fall of 2012, and solving the inverse problem are also presented in the paper.

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On the Spectral Polarization of the Radiation Flux as a Global Characterization of Air Pollution and Radiative Forcing of Earth's Climate

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The present report focuses on the application of the theory of the polarized radiation in space projects aimed at research climate system. The polarization state of the Earth's radiation is the most informative indicator of air pollution: the degree of polarization in terms of pure molecular atmosphere of the order of 70–80%, and with the aerosol pollution is reduced to 2–12%. Throughout the '90s layer of tropospheric aerosols on average decreased significantly, i.e. the atmosphere of our planet has become more transparent. If this result is true, it means that global warming is caused not only by the greenhouse effect, but kind and tropospheric aerosols – is a slurry containing black carbon, such as soot, absorb sunlight, warming the atmosphere.

Currently, one of the pressing problems of remote sensing is the study of aerosols – the most uncertain factor in the radiative forcing of the climate. A particularly acute problem of their studies of the structure and the most effective approach is polarimetry – a method of research on the characteristics of aerosols scattered sunlight.

In work spherical models of spectral radiation fluxes with polarization are formulated and their information content as a radiative forcing characteristic is studied.

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Transfer Process Investigation in Windsand Flux: New Results

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Windsand flux mineral aerosol elevated from the underlying surface in the atmosphere can influence greatly on the radiative regime of the atmosphere. Therefore transfer processes into windsand flux needs to study throghly to estimate characteristics of the mineral aerosol generated on the surface. The subject under discussion is the results of studying the mineral aerosol lift-off from the desertified areas and attendant processes peculiarities. It is known the saltation is the crucial factor into the windsand flux. The saltation study using high-speed video-recording [1] was shown that the availability of the quasiperiodic variation of height on the sandy surface provides initiation of the resonant saltation.

Very high electrization of the windsand flux has been investigated [2, 3]. Statistical characteristics of the electric current variations were calculated. Due to the necessity of accounting the windsand flux electrization during the saltation, estimates of a specific charge of sand grains are received taking into account the sign charge variation. It has been shown that the aerosol particle concentration fluctuations correlate with the saltating send concentration variations.

Inverse problem of the saltating sand grain dynamics has been solved [1] using the high-speed video-recording data in the windsand flux. The rate of the mineral aerosol lift-off from the underlying surface over desertified area was determined.

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Long-term Variations of Soot and Submicrometer Aerosol Content in the Regions with Different Anthropogenic Aerosol Loading

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The analysis of temporal and spatial variability of the submicrometer aerosol and Black Carbon (BC) in regions of the cities of Moscow, Beijing and the North Caucasus was carried out. One of the main objectives of the work is the studying of the long-term time-series of the aerosol constituents in the atmosphere to assess the level of background air pollution in the region and the influence of anthropogenic sources of pollution on the characteristics of the urban atmosphere. Last 20 years, the rapid economic growth in Chine has resulted in extremely urbanized population due to the accretion of adjacent to Beijing agglomerations. Moscow is also waiting for further expanding agglomeration, the first phase of which consists of a significant increase in Moscow's territory. In the region of the North Caucasus an actual fusion of the resort towns of Kislovodsk, Yessentuki, Pyatigorsk, Zheleznovodsk and Mineral`nyye Vody occurred.

The features of trends of the near-ground fine aerosol concentrations in these regions are discussed. The results of synchronous measurements of polluting admixtures in the surface layer and in the atmospheric column are summarized. To analyze the characteristics of the spatial distribution of the aerosol characteristics, data from the satellite instrument MODIS, in conjunction with ground-based data, including that from AERONET network were used. Important to identify the contribution of cities is the ability to use the data from scientific stations located in regional background points: Kislovodsk High-Mountain Research Station and Zvenigorod Scientific Station of A.M.Obuhov IAP RAS and Xinglong observatory of the Chinese Academy of Sciences. All measurements were performed by a uniform technique, therefore it is possible to consider the comparison of the results of measurements in different regions as correct. Despite the significant difference in the fine aerosol and BC content in Beijing compared with Caucasian resorts and Moscow, these differences are mainly due to significantly higher number concentration of particles at similar ranges of the variations of effective particles radii. Moreover, for all the regions with increasing fine aerosol concentration, the refractive index and the relative content of BC in the aerosol decrease. This fact indicates a predominance of coagulation and heterogeneous condensation in the processes of the aerosol transformation.

Measurements in all cities confirmed the regional character of aerosol pollution – there is a significant correlation between quantitative characteristics of both BC and fine aerosol components in the cities and at background stations. However, spatial BC concentration inhomogeneity in all regions is considerably higher than for submicron aerosol. In Kislovodsk in the winter time there is no significant correlation between the concentration of aerosol at the surface and in the atmospheric column. In Beijing and Moscow, high levels of concentration in the surface layer in the majority of cases correspond to high values of the aerosol optical depth.

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Estimation of Columnar Mineral Dust, Organic and Inorganic Carbon Volume Content under the Conditions of the Western Siberia

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Mineral dust and carbon-containing atmospheric particles are the key light absorbing aerosols in the Earth's atmosphere. The complete understanding of their volume content and mass concentration is required for improving the estimates and predicting the radiation-climatic effects of aerosol. To date, the main part of this information is accumulated on the basis of the methods for the physical-chemical analysis in the local volume, as well as on the basis of direct measurements in the near-ground atmospheric layer. The continuous monitoring of the troposphere by means of aircraft sensing is expensive; therefore, the data on the vertical distribution of aerosol characteristics are obtained only for separate regions around the globe and pertain to time-limited observation periods. First steps toward estimating the mass concentration of elemental carbon during continuous-mode sensing of the total atmospheric depth from the Earth's surface (by example of AERONET data) were undertaken in work [1].

In this work, a modified Schuster's approach [1] is used to estimate the volume content of aerosol chemical components like mineral dust, organic and inorganic carbon according to data of passive remote sensing from the ground. The input parameters for estimating the desired characteristics are the aerosol optical depth, the volume concentration of aerosol particles, and the spectral values of the single scattering albedo and complex refractive index in the total atmospheric column. The density of the estimated components and their optical constants are assumed to be a priori known. The approach is implemented by introducing a new aerosol model composed of mineral dust (DU), organic carbon (BrC) and inorganic carbon (BC) as well as the predominately scattering components, namely, ammonium sulfate and water. The aerosol medium is approximated by internal mixture of these particles. The effective refractive index of the medium is formed on the basis of the Maxwell-Garnett effective medium approximation. The optimal values of volume content of the aerosol components are determined by the minimum of the optical residual. Considering that the optical and microphysical characteristics of aerosol, which are used as input parameters, are the result of solution of incorrect inverse problem, we discuss the results of studying the sensitivity of the method to retrieval errors of these characteristics, as well as to uncertainties in the a priori information on the optical constants of DU, BrC, and BC.

We present the results of testing the method with the use of the aerosol optical and microphysical characteristics retrieved by the method of Dubovik and King [2] from measurements at AERONET station in Tomsk under the conditions of extreme turbidity of the atmosphere (2012 forest fires) and under the background conditions. The obtained estimates of the volume content of DU, BrC, and BC, as well as the mass concentration of BC, are compared with data presented in the literature for other AERONET sites. We analyze the correlation of BC mass concentration estimates with measurements of BC mass concentration in the near-ground atmospheric layer.

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Assessment of Influence of the Aerosol of the Atmospheric Surface Layer on Results of Aerosol Optical Depth Measurements over the City Yekaterinburg

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Results of pair measurements of the aerosol optical depth (AOD) of the atmosphere in the Middle Urals obtained from sun photometers during 2010–2012 in urban zone and background region, including measurements at different heights are analyzed. The background point is in forest area 65 km away the city Yekaterinburg on a platform of Kourovka Astronomical Observatory. The measurements were made by sun photometer of Cimel CE318 used in the Aerosol Robotic Network (AERONET (http://aeronet.fsfc.nasa.gov)). The urban point is located in the central part of the city Yekaterinburg on a platform of Institute of Industrial Ecology of the Urals Branch of Russian Academy of Sciences. Measurements were carried out by means of sun photometer of the SP-9.

Comparative analysis of hourly average values of aerosol optical depth has shown that values of AOD measured in urban zone are mainly higher of the corresponding values in the background region. Relative changes of AOD in urban and background regions are made of 60–90% for different wavelengths and seasons of year. Besides AOD in the two regions are statistically significant.

Results of AOT measurements at different heights performed during summer 2012 in city Yekaterinburg are presented as well. The measurements made by the portable sun photometer SPM-2008 and SPM-2011 at different heights: 1 м and 186 м over earth level. Statistically significant distinction of AOD at different heights was revealed (range from 0.01 to 0.07 for different wavelengths). Thus, the received results show that the increased value of AOD over the large industrial city is caused by the higher content of aerosol in a surface layer of the atmosphere.

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The Retrieval of Aerosol Complex Refractive Index and Extinction Coefficient Contribution Analyses in Urban City of China

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The aerosol complex refractive index is one of the most fundamental optical parameter and can directly affect scattering and absorption characteristics of aerosol. However the aerosol complex refractive index is difficult to be measured directly. In this paper the aerosol complex refractive index is retrieved by taking use of the Lorenz-Mie scattering theory and with observational data of aerosol number concentrations from 0.2 μm to 32 μm, the aerosol scattering and absorption coefficients in the urban city Tianjin of China. The retrieved equivalent complex refractive index of aerosol at 0.55 μm in Tianjin is 1.649–0.0257i in this work. During the observational period, the averaged extinction coefficient is 0.465 km^{-1} and scattering coefficient, absorption coefficient and NO^2 absorption contributed it by 85.7%, 9.2% and 2.1%, respectively. We calculated the contribution to extinction coefficient by different size aerosols in urban Tianjin by using the above complex refractive index result. The results indicated that aerosol particles smaller than 0.5 μm have the largest contribution to scattering coefficient with the value of about 73%, those between 0.5 to 1 μm and larger than 1 μm account for 15% and 12%, respectively. Whereas the aerosol particles smaller than 0.5 μm contribute 33% to absorption coefficient, those between 0.5 to 1 μm, between 1 to 10 μm and larger than 10 μm account for 8%, 44% and 14%, respectively.

The Possibility for the Basic Optical and Radiative Characteristics Parameterization of Cloud Layers with the Mixed Phase Structure

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Basic optical characteristics of light scattering in a mixed-phase cloud layer (asymmetry parameter of the scattering phase function μ, single-scattering albedo a, scattering, absorption and extinction efficiencies factors and coefficients) for separate wavelengths in a range from 0.6 to 12.0 µ are considered. At theoretical studying the model of the mixed-phase cloud layer containing ice crystals and water drops mixed on volume was used [1]. Calculations of above-mentioned characteristics for crystal fraction of the mixed-phase cloud layer are spent by means of the approached methods [2] developed by us earlier for calculations of characteristics of light scattering by the particles with the sizes, exceeding length of a wave of incident radiation, and for drop fraction of this cloud by a technique received with use of known theory Mie-Lorentz .

On the basis of the calculations detailed parameterization of the above-mentioned characteristics depending on average temperature of cloud layer T, the average sizes of cloudy particles of various forms and the relation of their concentration was received. Applying separate experimental data concerning the possible sizes of ice particles and their concentration at some temperatures, the parameterization of optical characteristics of elementary volume of the cloudy medium in dependence only from T was defined. Nevertheless the results of calculations of these characteristics show the basic possibility of construction of their statistically reliable parameterization depending on T only in the presence of true information about temperature dependence of the characteristic sizes of particles of various fractions and their concentration in a cloud.

With use of the calculated optical characteristics of the mixed clouds the estimation of their influence on the basic radiative characteristics (a cloud layer albedo A; and transmission factor S) was executed. The specified radiative characteristics were defined by means of approach delta-Eddington. The cloud layers with optical thickness less than 10 and zenith angle of the sun less than 45° were considered. Calculations of basic radiative characteristics of clouds at optical thickness less than 10 were executed by us with use of the received optical characteristics on a delta-Eddington approximation [3].

It is shown that at wavelengths more than 6µ and $275 > T > 250$ K the variation of values A and S an order of 35 % that is connected with possible dependence of values μ and a on a variation of modal radius of the overcooled water drops in an interval $r_m = 1–4$ µ at the fixed temperature of the mixed-phase cloud. Decreasing of the specified dispersion and, accordingly, the obtaining with a rather high accuracy of parameterization of radiating characteristics of cloud layers with known optical thickness as cloud layer average temperature under certain conditions supervision are possible only at acquisition of reliable experimental data about temperature dependence of the average sizes of cloudy particles of different shapes and their concentrations.

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Ice Water Content Profiles of High-Level Clouds: Classification, Statistics, and Radiative Effects

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About 40% of all clouds on Earth are high-level clouds (< 440 hPa), which have a noticeable effect on the energetic budget of the atmosphere: optically thick clouds reflect the incoming solar radiation while thinner clouds act as “greenhouse films” preventing escape of the Earth’s infrared radiation to space. Accurate modelling of the radiative properties of high-level clouds is essential both for estimating their energetic effects and for the retrieval of bulk microphysical properties from infrared observations. It requires knowing the scattering and absorbing characteristics of cloud particles, amount of ice in the cloud, and variation of these parameters if the cloud is extended. In this work, we concentrate on vertical distribution of ice water content (IWC) in the high-level ice clouds.

For the analysis, we used a synergy of the active and passive sounders of the A-Train satellite constellation. Relatively high spectral resolution of the Atmospheric InfraRed Sounder (AIRS) allows the identification of cirrus clouds and the retrieval of their physical and bulk microphysical properties as well as their horizontal extent. Active sounders, the CALIPSO lidar and the CloudSat radar, provide the vertical structure of the clouds: the radar-lidar GEOPROF dataset [1] contains the vertical extent and position of each cloud layer while the liDARraDAR dataset [2] gives the IWC profiles and effective ice crystal sizes. In addition, we use environmental parameters from ERA Interim reanalyses.

We have studied IWC vertical distributions for the period of 2007–2009 and classified them in accordance with their profile shape. The analysis shows that a) there are four main types of IWC vertical distributions; b) profile type mainly depends on the integrated IWC of the cloud (ice water path); c) there is a weak correlation between vertical wind and dominating profile type.

We discuss an impact of different IWC profiles on the radiative properties of a cloud layer and the energetic budget of the atmosphere using the calculations performed with the 4A/OP+DISORT radiative transfer code (http://4aop.noveltis.com/).

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Experimental Studies of Cloud Motion Parameters at Different Troposphere Altitudes in the Range 8–13 μm

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The report presents the research results of clouds direction and speed at different altitudes in the troposphere, obtained with a high-speed high-sensitivity equipment based on a multi-element matrices and with automated scanning system for cloud types parameterization and recognition [1, 2, 3]. Working model was made consisting of a multi-element matrix, with spherical (convex) mirror located at its entrance. Threshold sensitivity in the range of 8–13 μm for radiance is $\approx 10^{-5}$•cm^{-2}•sr^{-1}, for temperature is ≈ 0.1 K, the spatial resolution is 10×10 minutes of arc, the frequency of image capture is 50 frames/s, the resolution of clouds image is 190×190 pixels. The method and cloud movement parameters at day and night, was also reported in [4].

Here we present the motion parameters of complex cloudforms with multi-layered structure at day and night, recorded simultaneously at different altitudes in the troposphere by radiation characteristics (radiation energy and brightness temperature). It has been experimentally found that the cloudforms at different altitudes are moving at different speeds and can move both in the same and in different directions. Also, these movements change in velocity and have linear and sometimes nonlinear (vortex) motions. Constant velocity motions and fluctuating motions – in the form of wave patterns with different frequency spectra of velocity fluctuations – were detected. The information about the random motion of small-scale (cellular) cloudforms is presented. The results are presented in the form of image frames describing the continuous movement of clouds, in tabular and graphical forms with detailed explanations of the random motions of small-scale clouds inhomogeneities.

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On Analytic Representation of Cloud Drop Spectra

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Two-parameter Gamma distribution (with parameters, α and r_0) and three-parameter modified (with an additional parameter, γ) Gamma distribution (if $\gamma = 1$, the second distribution moves to the first distribution) are currently the most commonly used in cloud spectra approximations. In particular, the most popular cloud model, C1, has the following parameters: $\alpha = 6$, $\gamma = 1$. The adequacy of the real spectra description using these and other well-known distributions is not currently questioned. On the one hand, this is due to poor progress in the development of measurement equipment. On the other hand, current level of computer technology allows direct cloud spectra modeling within cloud physics tasks [1]. It is noteworthy that modeling of radiation interaction with clouds requires analytic representation of cloud spectra.

Experimental measurements of cloud spectra conducted in a cloud chamber of RPA Typhoon using cloud drops meter FIROK showed a qualitative difference between the measured spectra with Gamma distributions. It comprised the difference in the sign of skewness, k_{as} – negative for experimental and positive for Gamma distribution. Negative k_{as} values were observed in fog and stratus cloud spectra measured by the authors. Selection of parameters of the modified Gamma distribution for $\gamma > 3$ with negative skewness based on experimental data is not possible because of huge uncertainties in the relation between parameters α and γ. Note that the $\gamma > 3$' area is not used in the literature. To determine other suitable analytical expressions for the real spectra, a series of calculation studies using a numerical condensation model of cloud spectra formation and evolution, based on Sedunov monograph [2], has been conducted. The studies confirmed the fact of negative k_{as} values for calculated spectra as well. The same situation was also obtained theoretically [3] when solving the set of differential equations of drop growth and moisture exchange between the growing and the evaporating drops during their evolution at a constant temperature.

The studies have shown that, at each of formation and evolution stages, the calculated spectra can be described by one of the three analytical distributions: modified Gamma with constant parameter $\alpha = 3$, mirror Gamma and mirror Smirnov. The two latters can be considered preferable for stationary clouds, as their structure is more consistent with analytical solutions of Lifshitz and Slezov. Selection of appropriate parameters shall be performed based on the maximum value of the approximated functions and the position of such maximum value, using the relations described herein. Parameters can be also selected based on a combination of the maximum value position and the relative spectrum width. The available experimental cloud spectra are also well approximated by the above analytical distributions. Selection of the optimal distribution form can be done based on the maximum concordance of skewness values.

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Evaluation of Aerosol Optical Thickness (AOT) Influence on the Insolation from Direct Ground Observations at the ARG Station, Kishinev (Moldova)

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Data from direct measurements of global solar radiation on a horizontal surface (daily totals Q_d) and daily mean values of aerosol optical thickness <AOT@500> are used to show relationship between these parameters and to obtain quantitative estimates. All measurements were performed at the ground-based solar radiation monitoring station at the Institute of Applied Physics (IAP) of ASM, Kishinev (Moldova). Radiometric sensor CM-11 (300–2800 nm) was used to measure global solar radiation. AOT data at wavelength of 500 nm, AOT@500, were derived from measurements of direct solar radiation by using sunphotometer Cimel CE 318. These measurements of AOT are carrying out within the framework of the international program AERONET, NASA/GSFC since 1999. More detail information about the ground station, instrumentation used, measurement procedures and time series of measured parameters in graphical form is presented at the Atmospheric Research Group(ARG) site http://arg.phys.asm.md.

The evaluation procedure takes into account the simultaneous measurements of global solar radiation Q_d and AOT@500, which were made under cloud-free atmosphere conditions for the period from 2004 to 2007. This was done to minimize the effect of clouds on measurement results. Data from a multiyear observations were grouped by months. A linear approximation of the dependence between the amount of daily total of global radiation Q_d (MJ/m^2) and daily mean of <AOT@500> is presented as follows: $Q_d = a + b$ <AOT@500>, where (a, b) are the approximation coefficients; for daily totals of global radiation value $b < 0$. It was shown that with increasing values of <AOT@500>, as a parameter describing turbidity of the atmosphere, it was observed a reduction of insolation on the Earth’s surface.

In the course of period of observation daily mean values of <AOT@500> ranged from 0.06 to 0.35, depending on the season. For example, in February daily mean values of <AOT@500> ranged as 0.06 -> 0.16 (case of transparent atmosphere), that corresponded to variation of daily insolation Q_d in the range 13 MJ/m^2 -> 10 MJ/m^2; in July daily mean values of <AOT@500> ranged as 0.06 -> 0.34 (case of turbid atmosphere) and it corresponded to variation of daily insolation Q_d in the range 30 MJ/m^2 -> 26 MJ/m^2. It should be mentioned that multiyear (1999–2011) mean value of AOT@500 at the IAP ASM ground-based station equals to ~ 0.21. The corresponding approximation coefficients b [MJ/(m^2* unit-of-AOT)] for February and July were equal to ~ –24.4 and – 10.6, respectively. Thus, increasing of the contribution of the aerosol component (as the growth of AOT@500) in the atmosphere leads to a reduction of incoming global solar radiation on the Earth's surface, which was observed under the cloud-free conditions.

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Results of Measurements of Optical and Microphysical Characteristics of Aerosol in the Arctic Region: Spitsbergen -2012

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The arctic region is an indicator of global climate changes on the Earth. An important role in dynamics of radiation balance is played by atmospheric aerosol coming to the Arctic through long-range transport from the continent due to numerous anthropogenic and natural pollution sources. In the spring and summer seasons of 2012, investigators of the Institute of Atmospheric Optics SB RAS and the Arctic and Antarctic Scientific Research Institute have continued the study of atmospheric aerosol characteristics near the Barentsburg Zonal Hydrometeorological Observatory (ZHMO) (78.1°N, 14.2° E) at the Svalbard archipelago (Spitsbergen). As in 2011, the following aerosol characteristics were measured in the atmospheric column and in the surface layer: aerosol optical thickness (AOT) of the atmospheric column in the wavelength range 0.34–2.14 µm, parameters α and β of the Angstrom’s formula, fine and coarse AOT components, mass concentrations of aerosol M_A (µg·m^{-3}) and black carbon M_{BC} (µg·m^{-3}), number density N_A (cm^{-3}) and particle size distribution in the range 0.3–20 µm. The measurements were conducted with the measurement system including an SPM portable sun photometer and an aerosol station consisting of MDA three-wavelength aethalometer and GRIMM Model 1.108 photoelectric particle counter.

In this paper, we analyze the results of measurements in spring (April 21–June 12) and summer (July 21–August 28) of 2012, estimate the seasonal mean values and standard deviations of the characteristics under study, compare the obtained data with the data of 2011 and literature data, and discuss peculiarities of the seasonal and annual variability of the parameters.

The whole measurement period of 2012 (spring–summer) was characterized by the high transparency of the atmosphere (low aerosol turbidity). The mean value of AOT (0.5 µm) was $\overline{\tau}_{0.5}$ = 0.095 at variations from 0.057 to 0.166. The value of the Angstrom index α characterizing the selectivity of the spectral dependence of AOT in the spectral range 0.44–0.87 µm varied from 0.8 to 1.48 at the mean value $\overline{\alpha}$ = 1.25. A characteristic feature of the spectral dependence in 2012 as compared to 2011 was the longer power-law decrease of AOT values up to 2.14 µm due to the higher content of the fine aerosol at the simultaneous decrease of the contribution from coarse particles. No significant seasonal trend in the mean AOT values was observed in 2012 in contrast to the pronounced tendency of decrease from spring to summer (from 0.101 to 0.065) observed in 2011. Year-to-year differences in the seasonal variability of AOT can be caused by particular weather and circulation conditions of every year.

The results of measurements in the surface air layer are indicative of the low content of aerosol and black carbon, which is in agreement with AOT estimates from sun photometry data. The mean values of concentrations and standard deviations for the entire measurement period of 2012 (spring-summer) were the following: the mass aerosol concentration $M_A = 1.53 \pm 2.05$ µg·m^{-3}, number density $M_A = 1.53 \pm 2.05$ cm^{-3}, mass concentration of black carbon $M_{BC} = 0.12 \pm 0.19$ µg·m^{-3}.

An “anomalous” tendency of increase of the mean mass concentrations of aerosol (1.41–1.93 µg·m^{-3}) and black carbon (0.10–0.15 µg·m^{-3}) from spring to summer was observed. However, the average value of N_A decreased three times. This anomalous dynamics is presumably caused by the increased influence of local sources in summer. The year-to-year variability in comparison with the data of 2011 showed itself identically for the both seasons in the increased concentration of aerosol and the decreased concentration of black carbon. For the spring season, M_A and N_A increased 1.5 and 2.4 times as compared with 2011, while M_{BC} decreased 1.5 times. In summer, the change was even greater: M_A increased 2.5 times as compared with 2011, while M_{BC} decreased 3 times. Peculiarities of the particle size distribution are discussed as well.

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Spatial and Seasonal Features of the Aerosol Optical Thickness Distribution over Russia from the Data of Ground-Based and Satellite Observations

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Spatial distribution of the monthly mean values of aerosol optical thickness at 550 nm (AOT550) with a spatial step 1x1° over Russia was retrieved using MODIS satellite data (collection 5.1) for the period from 2000 to 2012. Satellite sounding of AOT fails over the territories with a high surface albedo. In such situations we used data from the Russian actinometric network stations and international AERONET network. They were also used for a validation of the satellite observations over other regions. Due to the sparseness of the ground-based networks their data were averaged through homogeneous climatic regions. Finally, composite maps of the monthly averaged AOT550 distributions over Russia were created, combining the data of ground-based and satellite measurements. In conjunction with climate maps of the IRI / LDEO, Climate Data Library (maps of the average monthly precipitations and of the general wind direction at 925 hPa for the period 1961-1990) [2], the main features of the AOT550 spatial distribution were revealed. Peculiarities of intra-annual variability of AOT550 monthly mean have been identified in homogeneous climatic regions.

This work was supported by RFBR under Project #13-05-00956.

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The Analysis of the Inter-Annual Variability of Fogs in European Airports

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The presence of aerosols in the environment remains a major problem in meteorology due to the fact that it is necessary to confront the negative effects on health, on the radiation balance, on the Earth's surface temperature. The main element in the atmosphere, which absorbs Earth radiation and sends a counter-radiation, is water vapor. Water vapor provides the strongest positive feedback. In the presence of aerosol absorption of radiation there is a direct "pumping" of energy in the atmosphere. Thus "anti-greenhouse" effect appears. However, since the absorbing aerosol is an infrared radiator, at the same time it should take place the opposite effect – the increase in the greenhouse effect of the atmosphere. The assessment of effects of the interaction of tropospheric aerosols with solar radiation is a complex problem of the theory of radiation transfer.

Radiation fog is formed by radiation cooling of the earth's surface at cloudless nights as a result the surface air layer is cooling. It is typical for regions with continental climate. Radiation fog is also formed in the centers of areas with high pressure, which is characterized by light winds and clear skies. In a relatively stable air, radiation fog, arisen in the evening or at night, can hold for the entire day.

The purpose of this study is to establish inter-annual changes in the number of fogs in 5 European airports. To make an assessment of statistical trends in the observing changes in the radiation climate during the current global warming (since 1988) in comparison with the previous (15–30-year) period. To make assessment findings about the change in cloudiness in these areas based on the characteristics of indirect. In this work is used published historical data of meteorological observations over the period from 1958 to 2012. According to climate scientists, one of the foggiest cities in the world is Rio de Janeiro – on average during a year there are 164 days with fogs. Second place is the capital of Ecuador, Quito – 92 foggy days a year. It is followed with a big difference by Helsinki – 60 days, Bucharest – 55 days, London – 46 days, 44 days in Berlin, in St. Petersburg and Moscow the number of foggy days during a year for about 30, in Rome – 23 days. In Stockholm, the fog can be observed 13 days in a year and, for example, in Dublin and Reykjavik only 5–7 days. For this study popular airports of Europe – Helsinki, London, Kishinev, Rimini and St. Petersburg – have been selected. The study of inter-annual variations in the number of fogs in Europe identified the tendency towards the increase in the number of fogs for the last 10 years.

Chemical Composition and Hygroscopic Properties of Aerosol Particles from Siberian Boreal Area

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Organic aerosols (OA) along with the elemental carbon (EC) and ions strongly contribute to direct and indirect aerosol effects on climate. Boreal forests in Eurasia are a major source of primary organic aerosols (POA) directly emitted from the surface to the atmosphere and secondary organic aerosols (SOA) formed from gaseous precursors in the atmosphere. In order to evaluate and understand the influence of aerosols on climate change in the Artic and Northern Eurasia, long-term observations of the OC, EC and ion content of aerosols in the boreal zone are needed.

In this work we present continuous measurements from April 2010 to June 2012 conducted at Zotino Tall Tower Observatory in Central Siberia (ZOTTO, 60º N, 89º E), Russia. The quartz fiber filters were analyzed for organic and elemental carbon by thermal-optical instrument (SunSet lab.). The Nuclepore filters were analyzed for ions by ion chromatography (Dionex, ICS-1100). With help from high time resolution CO and light absorption results and HYSPLIT back trajectories calculations, the filter samples were separate to episode and non-episode samples.

The aerosols chemical composition were clearly different between episode and non-episode samples, and between winter and other three seasons. The winter episodes associated with elevated concentrations for most of species were usually related to anthropogenic pollution, the air masses during such episodes had passed over the central Siberian region around Omsk and Novosibirsk – a heavily industrialized area. During spring and fall, a number of samples exhibited high K+, and oxalate levels, indicating an impact from biomass burning. In addition a notable episode with extreme high Na, Cl, and Mg were observed for the samples collected between 20 to 24 December 2010, which may result from long range transport of sea salt. In the aerosol chemical mass closure calculations, six aerosol types were considered. Organic matter (OM) contributed by far the most to the PM mass; it accounted for about 60–70% of the average PM mass. Followed by Secondary Inorganic Aerosols species (SO_4, NH_4, and NO_3), more than 30% of PM mass. OM contribution to PM mass was lower in winter than that in the other three seasons, while EC, Ammonium and Nitrite show higher contribution in winter. The mean PM mass attribution to the different aerosol types Zotto during non-episodes periods were similar to those for the 2007 campaign at the forested site of Hyytiälä, Finland. EC and Nitrate were more important and Ammonium was clearly less important at Zotto, though.

Key issues are the hygroscopic growth of boreal aerosol particles and their activation as cloud condensation nuclei (CCN). Water soluble organic carbon compounds typically account for ~ 50% or more of total OC [1] but their impact on aerosol water uptake and cloud formation are not fully characterized. In this study the mass-based hygroscopicity measurements under sub-saturated conditions at 5–99% RH [2] were used to characterize CCN and hygroscopic properties of the boreal aerosols. It was shown that aerosol water uptake is basically controlled by concentration of inorganic ions in the particles.

This work was supported by St. Petersburg state University under grant 11.38.650.2013 and Russian Foundation for Basic Research, under grant 12-05-00620.

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Photophoretic Interaction of Aerosol Particles in the Earth's Atmosphere and Its Effect on Coagulation

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A computational experiment demonstrated a new form of interaction between aerosol particles absorbing solar radiation–a photophoretic interaction [1]. Interaction is of gas-kinetic nature and can be classified as photophoretic phenomena. Photophoretic forces were calculated on the basis of a free molecular flow regime approximation and a previously developed Monte Carlo algorithm [2]. Under the effect of light, the temperature of particles changes from the temperature of ambient gas and, under the effect of other particles in the gas medium, upsets the uniformity of accommodation of molecular energy and momentum over the surface of these particles to bring forth forces affecting the particles. The photophoretic interaction depends on a particles' altitude in the Earth's atmosphere (atmospheric pressure), the particles sizes and a distance between them. Calculations showed that when submicron particles that are soot-like in their optical properties are radiated with solar light, considerable repulsive forces arising between them are by orders of magnitude higher than gravity, and these forces decrease approximately as the inverse square of the distance between the particles.

Due to the fact that the distance dependence of photophoretic interaction force is of the Coulomb type, we can use the analogy with the electrostatic interaction and evaluate the effect of photophoretic interaction on coagulation of aerosol particles. A solution to the problem of Brownian coagulation for like-charged aerosol particles of the same sizes is well-known [3]. Using this result we calculated the ratio of the coagulation constants with and without photophoretic interaction taken into account. The calculations showed that for particles in the stratosphere with radius less than 0.05 µm, the photophoretic interaction influence on coagulation constant is unimportant. With particles size growth the photophoretic interaction was shown to decrease the coagulation constant of submicron particles strongly absorbing radiation by orders of magnitude compared to the constant in darkness, at an intensity of radiation equal to solar light intensity. The significant effect of photophoretic interaction on coagulation has been demonstrated. The ratio of coagulation constants varies slightly up to 75 km.

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Cloud Optical Parameters from Radiative Experiments Accomplished in USSR (LGU) and USA (NASA) in Different Geographical Regions

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Results of retrieving optical parameters of cloud atmosphere from airborne data are compared. Airborne experiments are taken in Goddard Space Flight Center during last two decades. Measurement of the diffuse solar radiance in eight spectral channels (0.340; 0.381; 0.472; 0.682; 0.870; 1.035; 1.219; 1.273 µm) at viewing zenith angles from 0° till 180° in 1° interval are accomplished above the Atlantic Ocean close to West-South Africa coast. The approach and algorithms of NASA data processing is in the presentation at section 2. Spectral semispherical solar irradiance in the spectral diapason 0.35–0.96 µm in 0.002 µm interval has been measured in the end of the last century in different geographical sites in ranges of international complex programs: GATE (tropical latitudes), CAENEX (mid-latitudes), POLEX (polar latitudes).

Results of cloud optics inverse problem (retrieving optical parameters of extended clouds from different observations shows the single scattering albedo is not variable at different latitudes, but volume scattering and absorption coefficients are significantly changeable from Polar regions to Tropics. Obtained parameters (the ground albedo, optical thickness, single scattering albedo, volume scattering and absorption coefficients) provide the cloud optical model for estimation radiative divergence, heating rate and water content.

Measurements of Soot and Submicronic Aerosol Content Near-Water in the Atmospheric in the Northern and Southern Hemispheres

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Results of measurements of soot concentration and submicron aerosol in the near-water layer in the two Russian Antarctic expeditions (55th and 57th cruises "Akademik Fedorov") from November 4, 2009 to February 18, 2010 and November 10, 2011 on February 16, 2012 are presented. Measurements were carried out from St. Petersburg, across the Atlantic to Antarctica, then the Southern Ocean along the coast and on the way back from Antarctica to Cape Town.

In the northern hemisphere, the soot concentration during the 55th and 57th cruises is 80–810 ng/m^3 and 120–760 ng/m^3, accordingly. From 20º north latitude to the equator on the average received 410 ng/m^3 and 360 ng/m3, and in the South Atlantic – an average 150 ng/m^3 in both expeditions. In the Southern Ocean variations of the soot concentration 10–180 ng/m^3 and on average 75 ng/m^3. During the measurement, parked near the station Progress in cruise 57th were received the lowest levels of soot and submicron aerosol: 6–84 ng/m^3 and 0.4–0.8 mg/m^3, accordingly. The analysis of the variability of the soot concentration and submicron aerosol from the directions of the air mass arrive has been carried out. It is shown that the increase in the soot concentrations and submicron aerosol is connected with the arrival of air masses from the continents and on the contrary there is a decrease in the concentrations in the air masses coming from remote areas of the ocean.

Expedition 59th "Akademik Mstislav Keldysh" in the White, Barents and Kara seas carried out September 12–October 7, 2011. In background regions of the soot concentration varied in the range 10–470 ng/m^3. Low levels of soot on the 2 sections of the route at the northern latitude 73–75º in the Kara Sea is an average of 23 ng/m^{3}and 32 ng/m^3 and an average – 115 ng/m^3 in the higher latitudes (76–78º). The level of soot in the air depends on the direction of arrive of air mass: low, if the transfer from the Central Arctic and high – from the industrial area. The resulting levels of soot pollution in the Arctic correspond to the results of [1].

Around the clock measurements of soot and submicron aerosol in the near-water have been carried out of the coast of in the Black Sea (Gelendzhik) in 2007–2009 (September). The average the soot concentration and submicron aerosol is 0.9–1.5 mg/m^3 and 21.4–42.5 mg/m^3. A fairly close correlation between the mass soot concentrations and submicron aerosol was showed (R = 0.7–0.8). The share of soot in the submicron aerosol is 2.6–7.0%. When arrive from the sea, and in the storm, the proportion of soot in aerosol is lower than in the aerosol with a land. In the day the content of the soot and submicron aerosol is low, and in the morning and evening are peaks. The influence of meteorological parameters (speed, wind direction, temperature, etc.) on the soot concentration and submicron aerosol were investigated.

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On the Long- and Short-Period Variations of Mass Concentration of Near-Ground Aerosol

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Continuous observations of the near-surface aerosol characteristics are conducted since 1991 at Zvenigorod Research Station of IAP RAS. Started by V.N. Sidorov by means of nephelometer with air flow, they were supplemented in 2000 by measurements with the help of spectropolarimeter and a commercially available nephelometer PhAN. The system of registration of the latter instrument provided a continuous record by averaging through a minute interval that made it possible to follow not only the variations with periods of several days, but at much higher frequencies. Here we consider two aspects of variations – the variations of the mass concentration values obtained in 2012, and those obtained for the entire observation period 1991 to 2012. In the latter case we analyze the variability of mean annual near-ground aerosol mass concentration. All the instruments have the ability to measure the angular scattering coefficient at a wavelength of 0.52-0.54 um and at a scattering angle of 45 degrees. The aerosol mass concentration was estimated under the relation M = D11(0.54 мкм,45°)*3000, where D11 in $km^{-1}sr^{-1}$, M – in $\mu g/m^3$.

The time series of M for 2012, its Fourier spectrum, and the annual means for 22 years of observations are presented in the paper. The entire time series for 2012 reveals a monotonic (which have began approximately in 2008) reduction of M both in the average value, and in the number and amplitude of individual short peaks with periods of several days. In the Fourier spectrum of the temporal behavior of M, the distinct maxima are observed at periods of 7, 20 and 85 days, the latter can be seen in time series even without the use of spectral analysis. It is interesting that the 50-days and daily periods of variations are very weakly expressed. The dependence of the average annual values – since about 2000 – are distinctly bell shaped – the decrease of the average values of M to 2000 up to $M = 20\ \mu g/m^3$, was followed by a monotonous and rapid growth, continuing until reaching values of $M = 64\ \mu g/m^3$ in 2007. A monotonous and rapid decrease in the values of M begins after this maximum. The last value for the year 2012 – $33 \mu g/m^3$. It is interesting to note that this relationship for twelve years has been strictly in antiphase with an index of solar activity, the data of which (according to the intensity of solar radiation at a frequency of 2800 MHz) were taken from the site of NOAA. Because approximately 80% of the variance of M is associated with the long-range transport, it is possible that solar activity can cause changes in the atmospheric circulation.

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Radiation and Temperature Effects of Dust Aerosol

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Radiation and temperature effects of dust aerosol are estimated from measurements at the AERONET station in Nigeria (Ilorin) during dusty storms from the Sahara desert between January 28 and February 6, 2000. Two dust aerosol models were used, including the semi-empirical model based on the continental model [1] with aerosol particles less than 15 µm (as in the AERONET). The second model was also used with large particles taking into account and with spectral distribution for imaginary part of refractive index [2]. Integral radiation fluxes for longwave and shortwave spectral ranges were calculated with the use of integral transmittance functions for cloudless atmosphere (H_2O, CO_2, O_3, O_2, aerosol). Longwave fluxes with the aerosol contribution were calculated using integral absorption coefficient normalized by the corresponding extinction coefficient at 550 nm.

According to simulations the dust aerosol optical thickness and asymmetry factor increase and single scattering albedo decreases due to contribution of large particles (larger than 15 µm). Dust aerosol leads to the shortwave cooling of the surface and surface-atmosphere system without the contribution of large aerosol particles. The surface shortwave cooling with the contribution of large particles is stronger, while the surface-atmosphere system can be cooling or heating, when large particles are taken into account. The longwave heating of the surface and surface-atmosphere system with contribution of large dust particles is stronger.

Shortwave cooling rate of aerosol layer near surface was estimated in the range $-(0.3\div1.5)^oC$/hour without taking into account of large particles and in the range $-(0.4\div3.0)^oC$/hour with contribution of large particles. The longwave heating rate of aerosol layer near surface without large particles was less than 0.2^oC/hour, while with contribution of large particles it was between 0.2 and 0.4°C/hour. The obtained estimates for radiation and temperature effects of dusty storms indicate a need to take into account aerosol particles with radius larger than 15 μm.

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Effect of Hygroscopic Growth on Aerosol Light Scattering: First Measurements in the Suburb of St. Petersburg

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Atmospheric aerosols have a considerable impact on the radiative transfer and global climate. However there is an immense uncertainty of aerosol forcimg estimation, caused by the wide range variability of aerosols properties. The key factor of the variability is the effect of water uptake on the aerosol light scattering. The aerosol particle scattering coefficient strongly depends upon the aerosol size and chemical composition and ambient relative humidity. Therefore the knowledge of scattering coefficient as function of relative humidity (RH) is of great importance for aerosol forcing estimation and remote sounding methods validation. A humidified nephelometer is used recently to follow the aerosol light scattering dependence on RH [1]. Comparative analysis of data obtained from five European sites displays the difference in RH behavior of aerosol scattering coefficient. The fact makes worthwhile to increase the number of measuring sites.

This work presents the first results of similar measurements initiated this spring in the department of Atmospheric Physics of Physics Institute of St.Petersburg university in Peterhof near St. Petersburg. The key employed equipment is AURORA 5000 (ECOTECH, Australia) which consists of two polar nephelometers AURORA 4000 combined with the aerosol conditioning system. The input aerosol flow is split into two identical ones. The first flow is kept dry and the second is kept under controlled RH in 30–90% range. These flows passed through the separate nephelometers which simultaneously measured scattering coefficients of dry and humidified aerosol for three wavelength (425 nm, 525 nm and 635 nm). Thus we *in situ* obtained humidogram of scattering enhancement factor. First results show that mineral poor hygroscopic aerosol particles prevail in St.Petersburg with mean scattering enhancement factor 1.3–1.4 under 85% RH.

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Objective Recognition of Cloud Types by the Spatial and Temporal Structure of its Thermal Radiation in the Range of 8–13 microns

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Currently practiced cloudforms meteorological visual classificatio, developed by scientists and experts from many countries for almost two centuries, is used mainly in the daytime and is based on the eye perception of cloud inhomogeneities brightness contrasts, that reflect and scatter solar radiation. This information is obtained by the observer and is subjective, i.e. consumers are receiving certain errors in determination of the cloud coverage and cloud shape. Very often these errors occur in the evaluation of top tier cloudforms and mixed forms with multi-layered structure. RPA 'Typhoon' researches the clouds spatial-temporal patterns for many years for the tasks of vision systems development for various purposes in the optical range [1–5]. In the recent years, the association develops meteorological radiation classification, which utilizes many stable parameters of cloud thermal radiation.

This report examines the issues of cloud fields radiation parameterization and their objective (automated) recognition at daytime and nightime. Set of statistical parameters of the cloudforms radiation fields in the range of 8–13 microns is presented, which reliably recognize single-leyered cloudforms in 80–88% of cases. For a more reliable recognition of complex multi-tier forms, and besides the known features [5], the additional recognitial features are applied, which were also used in satellite remote sensing methods: the cloud coverage ratio of the sky (coverage), multilayer index, connectivity and streakiness of the cloud field. Three-dimensional images of cloudforms and information in tabular and graphical form are presented.

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SESSION 5. "RADIATIVE CLIMATOLOGY AND ALGORITHMS IN MODELS FOR WEATHER AND CLIMATE FORECASTING"

Chairman: Prof. **O.M. Pokrovsky** (MGO, SPb)
Co-chairmen: Ass. of RAS **I.I. Mokhov** (IFA RAS, Moscow), Prof. **L.R. Dmitrieva** (RHMC, Moscow), Prof. **N.E. Chubarova** (MSU, Moscow), Prof. **B.A. Fomin** (Kurchatov Institute, Moscow), Prof. **N. Jacquinet** (Ecole Polytechnique, France)

The Earth-Atmosphere System Radiative Energetics with Influence of the Cloud Properties and Modern Tendency of the Cloud Cover Evolution

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The tendency to the cloud cover variations during last two decades in the different regions of the Russia (1990–2000, 2001–2010) has been revealed by many scientists. This process may produces the seriously meteorological consequences for the Earth weather and climate taking into consideration the great influence of the cloud cover on the radiative and heat balance of the Earth. Some characteristic feature of the cloud cover variations tendency is contained in its regional character and seasonal pecularities.

The results of the cloud cover variations analysis based on the surface observations data in the regions around the internal seas of Russia is received during the programme Climeseas (Ref. n.247521 People 2009 JRSES) of the seventh Framework Program of the European Union. The analysis of the data for 1990–2000 and 2001–2010 years shows the variations of the 10 years mean value of the cloud cover in the limits of – 0.05 ÷ + 0.05. The tendency for 20 years period is the increasing of the cloud cover in the Caspian Sea region and its decreasing in the around regions. Such kind of the cloud situation reconstruction may lead to increasing of the horizontal surface temperature gradients in the region and meteorological consequences. In particular this may promote the convective activity in the region and the increasing of the number of the cases with convective form of clouds.

The main process that regulates the system energetics and meteorological phenomena is the absorption of the solar radiation fluxes by the Earth surface. The numerical experiments were conducted to evaluate the radiative characteristics of the earth-atmosphere system under cloud properties variations. The solar and longwave radiation fluxes were calculated taking into account the cloud cover tendency. The variations of the solar components of the radiation characteristics are greater than longwave. Under the one-layer cloudness the variation of the surface radiation balance in solar spectra is near 50–60 wt/m² under the cloud cover changing 0–0.2 and surface albedo 0.2. The radiation balance at the upper boundary of the system is variated in the limits of 150–180 wt/m². In the longwave spectra under the same cloud conditions the effective radiation variation at the surface is much smaller, approximately 10 wt/m². These variations in the surface radiance balance may cause the surface temperature variations in the limits of 1–2º.

The presented approximate evaluations show the complexity and importance of the discussed processes for the weather prediction and climate change problem.

The Relationship between Air Temperature and Radiative Balance at the Surface and at the Top of Atmosphere over the Asian Territory of Russia using Reanalysis and Satellite Data

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Over the Asian territory of Russia (ATR) for the period of 1975–2012 the estimates of spatial-temporal variability of major climatic parameters such as temperature, pressure and precipitation were calculated using daily observational data at stations, located to the east from Urals and in contiguous regions.

The validation of initial data was done before calculations:

– characteristics of radiative balance elements at the top of atmosphere, obtained by reanalysis data JRA-25 and MERRA, were compared with satellite data: CERES (2000–2012), PATMOS-x (1982–2009), MODIS (2000–2012), ISCCP (1983–2007);

– characteristics of cloudiness, obtained by reanalysis data JRA-25 and MERRA, were compared with observational data from stations and with satellite data: CERES (2000–2011), PATMOS-x (1982–2009), ISCCP (1983–2007).

It was obtained that for all datasets there is a similar situation in interannual variability of total cloudiness: it decreases before 1992 and it increases after this year. The difference in data is approximately 20% (from 50 to 73%). Among these data time series from JRA-25 have a good agreement with PATMOS-x data: correlation coefficient is 0.5 for 1983–1996.

Different level clouds have different influence on the temperature regime over the territory. From the analysis of cloud characteristics, discussed in this study, it follows that data presented in mentioned above datasets do not allow to select each cloud level with necessary reliability, that is why it is difficult to find its greenhouse effects which influence on surface temperature change.

The comparison of radiative balance at the top of atmosphere, shortwave radiation at the surface, effective radiation and total cloudiness has shown that there are two subintervals in the interannual variability of these elements. In the first subinterval over ATR the decrease of total cloudiness and the corresponding increase of downward shortwave radiation at the surface are observed. In the second subinterval the decrease of mentioned elements is accompanied with total cloudiness increase.

Two regression models related surface temperature anomalies with anomalies of radiative fluxes at the top of atmosphere and total cloudiness anomalies using reanalysis data (model “A”) and using satellite data (model “B”) were constructed. Global circulation characteristics were included in both models. Obtained regression models allow describing in cold season from 67 to 87% of temperature variability, from 18 to 60% of pressure variability and from 18 to 58% of precipitation variability.

The Features of the Space-Time Variability of Radiation Balance Components in Eurasia

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The studies of space-time variability of solar radiation incident at the Earth’s surface become of particular importance due to the climate change problem. This study presents results of analyzing the climatologically series of global radiation seasonal and annual means using the data of 171 actinometrical stations in Eurasia for 1964–1989 and 186 stations for 1990–2010, as well as the diffuse and direct solar radiation from data of 88 stations for 1990–2010. To study the space-time variability of radiation balance components the information on global (Q) and diffuse (D) radiation was used from the World Radiation Data Center and the Operation-Reference Data Bank

"Actinometry" of Roshydromet. Values of direct solar radiation on the horizontal surface (*S'*) for each station were calculated as the difference between the global and diffuse radiation values. To estimate the tendencies of solar radiation long-term changes the technique for approximating the series by linear function was used.

In the period of 1964–1989 the tendency to the decrease of the global radiation incident at the Earth's surface is observed at most of stations in Europe and Asia on the average by 1–3% per decade. The most appreciable decrease of *Q* is observed in north-west Europe, in Mediterranean Sea region and on Japan Islands where at some stations it is 5–7% per decade. The highest number of negative trends of *Q* is observed during the spring and summer seasons. During the next twenty-year period the negative tendency of *Q* is observed only in the Iceland Minimum area and on the Indo-Chinese and Hindustan Peninsulas. On the prevailing territory of Eurasia the increase of *Q* annual means is observed to be by 2–3% on the average, for a season the average values increased by up to 4–5% per decade autumn and winter season. In the first decade of XXI century in most Eurasia areas the value of global radiation reached the level the 60-es of the past century, and at some stations they exceeded this level. The most considerable changes of Q is observed in the west and central Europe and in the Pacific Ocean region where at some stations the increase of *Q* annual values reached 8% per decade.

The increase of global radiation measured at actinometrical stations is related basically with the increase of direct solar radiation. In 1990–2010 the annual mean values of S' increased on the average by 8–9%, up to 14–16% per decade in the winter season. Against the increase of direct solar and global radiation in the recent twenty-year period the diffuse radiation in Eurasia decrease on the average by 3–5% per decade. The opposite tendency in the change of *S'* and *D* is observed only in India and at the most of actinometrical stations in China.

These tendencies of long-term change in short-wave solar radiation in Eurasia for 1964–2010 evidence the large-scale effect of some factors related, first of all, to the change of cloud cover and atmospheric transparency.

The Influence of Anthropogenic and Natural Radiative Forcing on the Climate in Russia as Estimated with an Ensemble of Global Climate Models of the New Generation (CMIP5)

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The presentation examines the evolution of the climate in Russia in the 20th–early 21st century according to observations and simulations taking separately into account the influence of external radiation forcings. Model simulations are presented by three ensembles of experiments with global atmosphere-ocean general circulation models (AOGCMs) participated in the international project CMIP5. In the frame of the CMIP5 project, special experiments were performed to simulate the evolution of the climate of the 19th–21st centuries (1850–2005) taking into account both natural and anthropogenic external forcings (ensemble Hist). Anthropogenic external forcings, in particular, include the observed changes in the atmospheric concentrations of the main greenhouse gases and anthropogenic aerosols, and the changes in land use. But natural forcings include changes in the structure of the incoming solar radiation at the top of the atmosphere, and changes in the concentration of aerosols of natural origin, for example, aerosols associated with major volcanic eruptions. In addition, a number of AOGCMs performed separate experiments designed to identify the causes of observed climate change, in which the influence of external factors were taken into account separately.

The presentation examines two ensembles of such experiments: in the first ensemble all external factors were fixed except for changes in the concentration of the main greenhouse gases (ensemble Hist-GHG), and in the second ensemble, only the natural external factors were taken into account (ensemble Hist-Nat). Analysis of the model reproducing of the temporal evolution of the surface temperature made for a number of large regions in Russia has shown, in particular, that the ensemble Hist, on average, well enough reproduce the temporal evolution of temperature changes for the whole territory of Russia as well as for a number of large regions. Significant part of the variance of interannual changes (from 20% to 40%) can be reproduced in the model experiments. The main contribution to the observed increase in temperature on the territory of Russia is made by the impact of changes in the concentration of greenhouse gases. However, the natural effects significantly manifest themselves in interannual variations in temperature. Their influence is especially high in the summer when the impact of aerosols of natural origin on the incoming solar radiation flux at the surface is significant, but the interannual variability of temperature is relatively small.

Analysis of the spatial correspondence of model simulations with observations showed that only temperature changes obtained in the ensemble Hist are in good agreement with that observed. The results of the other two ensembles are different from the observational data. Thus, the temperature changes can neither be explained by natural causes nor by the influence of rising atmospheric concentrations of greenhouse gases alone.

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Solar Radiative Fluxes in the Clear-Sky Atmosphere: Comparison of Simulations and Ground-Based Measurements

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The considerable spatio-temporal variations and the variety of aerosol properties are the reasons for the insufficient level of the present-day understanding of both the aerosol optical characteristics, and for the uncertainty during simulation of radiation effects. The calculations and measurements of broadband solar radiative fluxes can be reconciled by refining the radiation models, what include the proper radiation codes and a complex of the input parameters for specific types of aerosol or climatic zones.

The purpose of this work is to analyze the results of closed radiation experiments (CREs), which were performed under the clear-sky conditions during summers of 2010–2012 near Tomsk. During CREs, we measured the fluxes of direct *S* and total *Q* radiation with the help of MS-53 pyrheliometer and MS-802 pyranometer in the wavelength range of 0.305–2.8 μm. Algorithm of the Monte Carlo method was used to calculate the broadband fluxes *S*, *Q*, and of diffuse solar radiation *D* in the molecular-aerosol atmosphere. The input parameters for the radiation calculations were determined on the basis of combination of (1) data, obtained immediately during CRE; (2) empirical models, based on the results of multiyear observations in the region of Western Siberia; and (3) the widely accepted models of aerosol and gas composition of the atmosphere. Most *Q* and *D* calculations used columnar values of the single scattering albedo (SSA) and asymmetry factor of the aerosol scattering phase function, retrieved using different methods [1, 2] on the basis of ground-based measurements of the spectral aerosol optical depth (AOD) and diffuse sky radiance with CE 318 radiometer.

The experimental and calculated radiative fluxes were compared by considering the relative (δ) and absolute (Δ) differences in the *S*, *D*, and *Q* fluxes in juxtaposition with the uncertainty (Er), caused by the measurement and radiation calculation errors. The measurement errors were estimated using ratings of the MS-53 and MS-802 instruments under the assumption that every type of error (nonlinearity effects, temperature uncertainties, etc.) is independent of other error types. The uncertainties in the *S*, *D*, *Q* calculations were estimated by considering only errors in specifying the input parameters. It is shown that, under the conditions of high atmospheric transparency (AOD(0.55 μm) = 0.05), the AOD determination errors have most significant effect on the accuracy of the calculations of direct and diffuse radiation. Under the characteristic summer conditions of

Siberia (AOD(0.55 μm) = 0.15), the diffuse radiative fluxes are most sensitive to the value of aerosol SSA: δD is ~ 5% when SSA is specified with an error of 0.05.

To compare the model-based and measured radiative fluxes, we selected 28 situations which were characterized by low (< 0.2) AOD values. The comparison showed that the discrepancies (in the absolute value) in the direct radiative fluxes ΔS were in the range of 3–20 W/m^2 and were smaller or comparable with the ErS value, in most cases. The exceptions were the atmospheric situations with high atmospheric transparency; however, additional numerical experiments showed that ΔS differences are reduced by approximately a factor of two when AOD measurement error is taken into consideration. The ΔQ variability range did not exceed ~ 25 W/m^2 and was much less than the value of the uncertainty ErQ. We also note that the ΔQ values, calculated with the use of different methods for retrieving the optical characteristics and the OPAC continental aerosol models, differed insignificantly from each other.

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The Assessments of Eye-Damage Biologically Active UV Irradiance

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The UV radiation has a significant biological impact: its influence on human skin is well-known, however, it also has a noticeable eye-damage effects including acute effect (photokeratitis) and long-term effect (cataracta and eye cancer). For characterizing the UV influence on skin the biological action spectra of erythema and vitamin D are usually used. Similarly, for the assessment of eye-damage effect we can use the action spectrum proposed by [1], which also has a maximum sensitivity in UV-B spectral region. Based on the detailed studies we showed the possibility of utilizing several types of broadband pyranometers with sensitivity in UV-B spectral region for measuring the eye-damage UV radiation. Parallel measurements by the Bentham DTM-300 spectrometer and the UVB-1 YES pyranometer at the Innsbruck Medical University (Austria) provided us the calibration factor in eye-damage units for this broadband instrument.

Based on the accurate radiative transfer simulations by the DISORT method the electronic database of eye-damage biologically active radiation has been generated for a large range of atmospheric parameters and solar elevations. The quantitative effects of different atmospheric parameters on this type of radiation have been obtained and compared with their effects on erythemally-weighted irradiance. The interactive program module has been developed for effective estimations of different types of biologically active UV irradiance in various optical conditions.

While analysing the biologically active irradiance it is important to make its assessments in real conditions with account for the urban opacity. For this purpose using the experimental and model data the quantitative dependencies on urban opacity were obtained for open and screening solar disk conditions. The significant difference in attenuation of UV-B irradiance was shown compared with that for total shortwave irradiance.

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The Estimation of UV Radiation Impact on Human Health in Moscow According to the Updated Measurements at the Meteorological Observatory of Moscow State University

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The main objective of this research is to identify favorable and unfavorable periods during the year in terms of UV radiation impact on human health in Moscow, according to the updated measurements of biologically active UV radiation (BAUVR) at the Meteorological Observatory of Moscow State University (MO MSU). Two types of BAUVR were considered: erythemally-weighted UV radiation, which has a major negative impact on human health, and vitamin D UV radiation.

Measurements of erythemally-weighted UV radiation at the MO MSU have been in operation since 1999 by the UVB-1 YES pyranometers, which are widely used in the world. UVB-1 is a broadband device with a spectral sensitivity curve which is close to the erythema action spectrum. The main sources of the uncertainty of this instrument are due to the differences between the instrumental spectral curve and the spectral curve of erythemally-weighted irradiance, as well as the deviation from the cosine law. According to the WMO recommendations these uncertainties have been taken into account in UV radiation database version 2 [1]. To eliminate the temperature dependence the UVB-1 device is equipped with temperature stabilization system at 45 °C. However, the comparisons between the routine measurements and reference devices of a new generation has detected the residual temperature dependence in routine UV measurements. Based on the obtained dependence on air temperature, as well as on the relationship between the reference and routine measurements, the correction of the database version 2 was carried out and a new database version 3 was generated. The difference between the monthly sum of UV radiation between version 2 and version 3 databases varies from 0-1% in summer to 20–30% in winter.

Threshold values of BAUVR should be known to assess the effect of UV radiation on human health. In the monthly newsletter of the MO MSU threshold is 25% of MED for 25% of the human body [2] is used as a UV threshold to produce vitamin D. In the updated recommendation [3], this threshold for vitamin D production is 20% of MED for 20% of the human body. However, the open body fraction can vary depending on the air temperature, therefore a threshold which takes into account this dependence was proposed [4].

Using the database version 3 over the 1999–2012 year period, it was found that vitamin D is generated in the human skin in Moscow from 22.10 till 13.02 according to threshold by [3], from 16.10 till 17.02 according to the threshold which is used in the monthly newsletter of the MO MSU, and from 11.10 till 13.03 according to the proposed threshold which takes into account the open body fraction. The regular increasing of vitamin D deficiency period is revealed if the database version 2 is used.

Protection from harmful effects of UV radiation as recommended [5] is necessary for a person with the second type of skin when UV index greater than 3. Dangerous levels of BAUVR in Moscow are observed in the midday time from 22.04 till 25.08 according to databases version 3 and version 2.

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Research of Cloudiness Trends Impact on Radiation Budget Based on International Satellite Cloud Climatology Project Data

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Results of a comprehensive analysis of the global and regional cloudiness for 1983-2009 have been presented. The monthly data obtained in frame of the International Satellite Cloud Climatology Project (ISCCP) were used in this study. The aproach based on imlementation an original smoothing technique and the wavelet analysis was imlemented in this research. Both techniques are approriate to be applied to non-stationary time series. It was shown that there is a decreasing trend in total cloudiness of 2–6% size for global and regional scales. Greatest decreasing tendencies were found in the tropic belt and over the oceans.Least decreasing was found over the land. The crosscorrelation coefficients between the global cloudiness on one hand and the surface air temperature and the sea surface temperature climate series on other hand have achieved the 84–86% levels for 1983–2009.

Radiation Regime under Conditions of the Intensive Drought of 2001–2010 in Ukraine

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Changes of the radiation regime in periods of intense droughts of 2001–2010, relative to the standard norms of climatological period 1961–1990 are obtained. Atmospheric and atmosphere-soil droughts of varying intensity were observed in most parts of the country 7 years of 10 in during the first decade of the XXI century. The most intense droughts occurred in 2001, 2003, 2010 during the vegetation period in the spring, summer, and autumn. They led to the deterioration and massive loss of crops. Total radiation increases, but to a lesser extent than the duration of sunshine and the direct solar radiation (by 25–85%), while reducing the scattered radiation (10–25%). Bare soil heating led to an increase in surface albedo in the spring and autumn drought events, reaching 10% in the north. The radiation balance increased during droughty periods.

Dependences in Long-Time Variations of Sunshine Duration and Air Temperature over Russia

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In an analysis of the causes of the 2010 anomalously hot summer over European Russia, it was found that the sunshine duration, cloud amount and, eventually, incoming solar radiation are modulated by lunar tides. The intensity of the modulation depends on the season of the year. The length of the Earth's (lunar) months is not a multiple of the solar year. The lunar year, which is equal to 13 sidereal or 12 synodic months, lasts 355 days. The lunar perigee distance varies with a period of 206 days. Therefore, the incoming solar radiation varies not only with a solar-year period of 365.24 days, but also with "tidal" periods of 355 and 206 days. The addition of these oscillations generates quasi-35-year and 4-year beats of meteorological elements, incoming solar radiation, the components of the radiation and heat budget in the Earth's climate system, and climate change forcing. Plots of analyzed long-time series of air temperature, cloud amount, and sunshine duration in Moscow and Kazan, incoming solar radiation over Russia, and geophysical and climate characteristics are presented that underlie these conclusions.

The Light Conditions of Megapolis During Smoky Haze

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During the period of natural illuminance observation in the meteorological observatory of the Moscow State University (since 1962) Moscow thrice was subjected to a catastrophic effect of smoky haze from burning forests and peat bogs. In 2010, it has been the most devastating by force of influence on living organisms. The objective of the study was to evaluate the light regime of Moscow – as one of the largest cities in the world – in heavy smoke conditions. Periods with a smoky haze in 1972, 2002 and 2010 were compared.

The mean values of the aerosol optical thickness at a 550 nm wavelength (AOT550) during the days with a smoky haze were: in 1972 – 0.85, in 2002 – 0.87 and 2010 – 1.50 [1]. At first the top "boundary conditions" were determined – the values of total (EQ), diffuse (ED) and direct (ES) illuminance at cloudless and clean conditions were obtained. As such "model" period of 1994–2001 were considered, wen maximum transparency of the atmosphere was observed in Moscow (the average for August P2 = 0.74, AOT550 = 0.15).

Direct illuminance is subjected to the most significant impact by smoky haze, decreasing to near zero during a particularly excessive smoke. The correspondingly increase of the ED is considerable up to three times compared to the clear-sky conditions at solar elevations more than 30 degrees. However, such increase of ED does not compensate the significant loss of direct illumination as a result the total illuminance is also reduced. On average, the total illuminance in smoky haze was less than 15–30% compared to the clear sky conditions, and decreased till 60–70% at excessive smoke. Especially catastrophic conditions were formed in August 7–9, 2010 (AOT550> 1.5), when the daily sums of EQ were only 284–429 Klux·h. Similar level of lighting in August was observed in cloudy weather, accompanied by precipitation during the hole day. As a result, in August 2010 due to a strong smoky haze the minimum of the monthly ES sum during the period of 1964–2012 was observed. At the same time, the maximum sum of ED was marked, and EQ was in the top ten of the least monthly amounts. The presence of a smoky haze leads to a significant depletion of the solar flux by visible rays.

Thus, the light equivalent (ratio of lighting sums to sums of radiation) of direct radiation at the average cloud cover in August 7–9, is 27–28 klx·h/MJ·m^{-2}, and in 2010 it did not exceed 7 klx·h/MJ·m^{-2}. The corresponding change in the light equivalent of total radiation is: 31 klx·h/MJ·m^{-2} at average climatic conditions and 25–27 klx·h/MJ·m^{-2} in 2010. So, smoky haze leads to a significant depletion of sunlight by the most physiological active rays, forming together with other factors extremely adverse living conditions for alive organisms, as was observed in Moscow in 1972, 2002 and 2010.

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The Variability of the Long-Wave Radiation Balance

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On the basis of long-term (1958–2012 years) solar radiation and atmospheric measurements in Meteorological Observatory of Moscow State University, analyse of the observed and calculated fluxes of long-wave radiation (LWR) as well as the factors, determining their variability, has been performed. As a result, regression formulas relating the effective radiation and atmospheric back radiation with cloud amount, temperature, and humidity were obtained.

The one of greatest interest is the study of long-term variability of atmospheric back radiation (E_a) because it is connected with processes determining the "greenhouse effect." The increasing tendency of the back radiation is determined by growth of cloud amount as well as the total humidity, and temperature observed in the MO MSU. Assessing the impact of cloud cover under the same temperature and humidity conditions showed that the overcast increases E_a by 40–70 W/m^2. A warming effect is minimal for continuous cloudy cover in high altitudes. Maximum E_a values are observed under low rain clouds. Winter clouds have greater warming effect.

The aerosol effect on E_a becomes noticeable starting with the aerosol optical thickness (AOT) greater than 0.6. In Moscow, such conditions were observed only during strong forest fires. During the smoky plumes, Ea increased by 20–25 W/m^2 comparable with the effect of some cloud forms. Aerosol can not influence on the trend of E_a increasing because of significant AOT reduction for the past 20 years.

According to calculations, LWR caused by growth of CO_2 concentration from 330 ppmv to modern 380 ppmv for 45 years (from 1966 to 2010) is less than 0.3 W/m^2 in summer and 0.5 W/m^2 in winter. Such Ea changes are much less accuracy of the LWR measurements and do not appear in the long-term variability in Ea MO MSU.

Multiannual Time Series of Column Transparency, 1906-2012

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Multiannual changes in atmospheric column transparency based on measurements of direct solar radiation allow us to assess aerosol load, formation of radiation regime and conditions for remote sensing.

In this work, the main parameter is the integral (broadband) transparency coefficient (p_2) transformed to a solar elevation 30°. This coefficient enables easy calculation of several other broadband parameters of column transparency and turbidity as well as transition to spectral Aerosol Optical thickness, AOT_λ.

As at the previous symposiums, ISARD-2009, ISARD-2011, we present multiannual time series of p_2 for three different European climatic locations: (1) Estonia, meteorological stations Tartu-Tõravere and Tiirikoja; (2) Moscow, Meteorological Observatory of the Moscow State University; (3) Feodosiya, Karadag Geophysical Research Observatory, Crimea, Ukraine.

The time series are updated to 2012 (incl). For comparison, historical evolution of p_2 at Pavlovsk, during 1906–1936, is given. Our new findings are as follows.

1. In 2011–2012 the p_2 annual values kept their high values, for example:
   Tartu-Tõravere, p_2(2012) = 0.807, the highest value since 1932 (from the very beginning),
   Crimea, p_2(2011) = 0.772, the highest value since 1948 (observations started in 1934),
   Moscow, p_2(2012) = 0.768, the highest value since 1955 г. (from the very beginning).
2. The period from 1994, i.e. the last 19 years, could be called “the period of brightening“, characterized by very high column transparency. Impressive clearing of the atmosphere can be seen in carpet-type figures of monthly mean p_2 values. Because no increase in column humidity was observed during this period, the improve in column transparency happened due to decrease in column aerosol content. The first reason in less aerosol load in Europe is lack of great volcanic eruptions – by 1994 the emissions of Mount Pinatubo (June 1991) have dissipated and volcanically a calm period followed. The second reason is improvement of technology in industry, power engineering and transportation. The third reason is migration of some heavy manufacturing from Europe to countries in Southeast Asia. The fourth reason is general economic decline in previous socialist countries after the collapse of the USSR in August 1991 which favored a considerable decrease in emissions from all types of stationary air pollution sources.

Concerning future extension of presented impressive time series of column transparency, we have a very sad information from Ukraine. For economy reasons, work of the Karadag meteorological station is reorganized. Most likely direct solar beam will not be measured there anymore. A 79 years (1934-2012) time series will be interrupted. During the last decades the measurements were guided by Gennady K. Gushchin, Cand. Geogr. Sc.

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Spectral Aerosol Optical Depth Prediction with Some Broadband Models. Validation with AERONET Observations

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Aerosol optical depth, AOTλ, usually presented for 500, 550, 1000 nm (AOT500, AOT550, AOT1000), is a central parameter for description of column aerosol content and column optical properties. From the 1990s, after start of US NASA programs AERONET, TerraMODIS and AquaMODIS, this parameter became very popular. On the other hand, in order to obtain a more detailed temporal and spatial overview on aerosol distribution, especially for retrospective extrapolation of AOTλ time series to pre-1990 years when the photometric network was sparse, it is necessary to use alternative methods for its calculation. Several AOTλ broadband models can be found from an extensive literature survey. Among them, the high-performance models are laborious for processing of large amounts of data or require special or very accurate input quantities. But there are also rather simple models which allow easy programming and do not need ancillary meteorological data as input. The goal of the present work is intercomparison of some simple AOTλ broadband models. Only one more complicated model was included to the intercomparison.

In total we tested six models. Three models (MU-1, MU-2, MU-3) were created in the Moscow University, two models (TU-1, TU-2) in the University of Tartu. The most complicated model (G-1) was created by Chr. Gueymard.

The Input and Output data of models are as follows.

MU-1. Input: h – solar elevation, S – direct normal broadband irradiance, W – precipitable water vapor, α – the Ångström wavelength’s exponent. Number of equations = 13. Output: AOT550. Published in 1991.

MU-2. Input: h, S, W; α = 1.0 (fixed). Number of equations = 1. Output: AOT550. A simplified version of MU-1. Published in 1991.

MU-3. Input: h, S, W; α = 1.0 (fixed). Number of equations = 2. Output: AOT500. An updated version of MU-2. Published in 2005.

TU-1. Input: p_2 – the integral (broadband) transparency coefficient transformed to a solar elevation, $m = 2$; W, α. Number of equations = 1. An updated version of MU-1. Output: AOT500. Published in 2007.

TU-2. Input: p_2, W. Number of equations = 2. Output: AOT500. Published in 2012.

G-1. Input: h, S, W, α = 1.3 (fixed), content of O_3 and NO_2. Number of equations > 30. Output: AOT1000. Published in 1998.

The direct broadband irradiance, S, was measured at Tõravere meteorological station (Estonia, 58°16’N, 26°28’E) by an actinometer AT-50. Column content of precipitable water, W, was evaluated from station water vapor pressure. The modelled AOTλ results, for outputs $\lambda \neq 500$ nm, were recalculated, using the Ångström formula, to AOT500.

The reference AOT500 values were measured at Tõravere by the AERONET Cimel photometer. Actually we compiled a table of simultaneous registration of broadband irradiance, S, and the AERONET measured AOT500. The table contains 26 091 complex observations from all seasons during 10 years, 2002–2011. Within 10 min both, broadband (AT-50) and spectral (Cimel) instruments, accomplished their measurements.

Two models (MU-1, TU-1) allow variation of the Ångström exponent. We have made runs of these models inserting $\alpha = 1.2$, 1.3, 1.4 and α = *'a priori* known' (from the AERONET observations).

However, keeping in mind either under- or overestimation of the AOT500 predictions, the best result was performed by MU-3. An average underestimation was only 0.5% (slope of the regression, 'model versus reference', was equal to 0.995). Correlation between predicted and reference values, characterized with the coefficient of determination, was, $R^2 = 0.947$. In 45 cases (from the total 26 091) the model gave negative, physically impossible results, i.e. predicting AOT500 < 0. Note that the Ångström exponent in this model is fixed, $\alpha = 1.0$.

Slightly better correlation, $R^2 = 0.957$, was achieved by TU-2, but the slope was equal to 1.013 which means an average, by 1.3%, overestimation. There were no negative predictions. Note that in this model the Ångström exponent was not considered at all.

Runs of models MU-1 and TU-1 with the use of individual, 'a priori known' Ångström exponents for each observation, did not improve predictions.

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Influence of the Stratospheric Aerosol Two-Layer and Two-Layer Antireflection Particles on Climate: the Model Estimates

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It is well known the stratospheric aerosol is important factor for both regional and global climate changes. In the model studies often the radiative and thermal regimes changes due to atmospheric aerosol are considered in common only. But aerosol particles structure and their size distribution are not taken in to account. The last circumstance leads to significant uncertainties in estimation of atmospheric radiative regime evolution which may have even different sign.

Here the impact of the two-layer particles of stratospheric aerosol on the Instantaneous Radiative Forcing (IRF) and on the stationary climate temperature regime is modeled. Aerosol particles are described by the form-factor $ff = r / r_{kern}$, where r is the radius of the particle, r_{kern} is the radius of its kernel. The lognormal size distribution r is considered. Various values of the form-factor describe the different stages of the 75% sulfate shell formation. Three models of "two-layer" aerosol particles are discussed: 1) two-layer particles are two-layer particles, which have a sharp boundary between the kernel and the shell; 2) antireflection particles are two-layer particles, which do not have sharp boundaries between the kernel and the shell; 3) quasihomogeneous particles are homogeneous particles, which have the same integral optical characteristics, as well as two-layer particles. Also the results of similar calculations with the homogeneous particles of 75% sulfate aerosol are given. The optical properties of aerosol particles are calculated according to the Mie theory. A two-dimensional zonally and annually average steady state energy balance radiative-convective equilibrium model is used. This semi-empirical model has the detailed radiation code, the parameterized energy transfer, the conservation of the relative humidity in the troposphere, and it takes into account the albedo – temperature feedback also.

The calculations of the IRF and surface temperature changes due to above stratospheric aerosol models are carried out. The stratospheric aerosol layer has optical thickness is 0.05 at a wavelength of 0.55 μm (this layer is located above the tropopause). Ensembles of aerosol particles with the following characteristics are considered: the position parameter a_g = 0,05, 0.3, 0.5 μm, the shape parameter σ_g = 1.1, 1.5, 2.0, 2.5 μm and form-factor values *ff* = 1.43, 2.057, 2.745, 3.439 respectively.

Conclusions: 1) The account of both size distribution of volcanic aerosol particles and its internal structure *ff* may exert a significant influence on the evaluation of the atmospheric radiation field changes; 2) In some cases the IRF due to the stratospheric aerosol variations is not reliable index for climate change evaluation; 3) Considered two-layer particles and two-layer antireflection particles have more efficient antigreenhouse properties (geoengineering) than the particles of 75% sulfate aerosol.

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Variations in Atmospheric Turbidity due to the Global and Regional aerosol Disturbances during 1976–2012 Years above Russia

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Radiation energy of the Earth-atmosphere system is largely determined by the atmosphere transparency. The most significant and long-term changes in the atmospheric turbidity occur under the influence of volcanic eruptions, relatively short – under the influence of a smoky haze from the forest and peat fires.

The results of the systematization and generalization of data on the spatial and temporal variation of the integral and aerosol atmospheric turbidity as above the whole territory of the Russia and so above its separate regions over the period of 1976–2012. The object of the study were the series of monthly and annual values of turbidity factor T_2 and aerosol optical depth AOD for the major Russian regions: north, center and south of the ETR, the Urals, Western Siberia, north-east, center and south ATR and the Far East. Trends T_2 and AOT were estimated. The changes of monthly and annual values of T_2 and AOT for the periods of 1976–2012 and 1994–2012 were examined. The total change of T_2 and AOT in the series of the monthly values have been received for a period of relatively high transparency of the atmosphere (1994–2012) and are presented as histograms and annual variation $\Delta(T_2)$ and Δ(AOT) (for the separate stations or for RF regions).

Basic laws of the space-time distribution of turbidity above the Russia can be summarized as follows. During the concerned period, there is a complex pattern of temporal variations of atmospheric turbidity. Changes in T_2 and AOT usually occur simultaneously as a rule, but AOT changes faster than T_2. The highest transparency of the atmosphere is typical for the northern regions of both the Asian and the European part of the Russia.

Despite of the fact that the period under review (1976–2012) is relatively short, it can be divided into separate time interval, significantly different in terms of the atmosphere turbidity. Allocation of these periods was made according to the analysis of annual and monthly series of characteristics of atmospheric turbidity. For all areas can be pointed out that in general, against the background of significant interannual variability of T_2 and AOT, the well-defined long-term time trends exist. For the most part of Russia in the last thirty years there is a trend of a decrease of T_2 and AOT. Since 1994 on the territory of Russia atmospheric turbidity consistently below normal, indicating the purification of the atmosphere from the atmospheric aerosol. In a period of relatively high transparency in certain regions of Russia the trends toward a slight increase of the integral turbidity were showed out while a relatively low level of the aerosol component existed.

The Role in Climate Change of the Solar-Geomagnetic Activity Variations

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The contribution of the main energy and natural variability of factors – the solar-geomagnetic activity to the current global warming is determined. For the first time the following data of space monitoring are used simultaneously: 1) variations on the most significant manifestations of solar-geomagnetic activity – flares in X-rays and the principal magnetic storms; 2) the global cover of total cloudiness and on changes in the radiation balance of the Earth as a stream of values reflected short-wave solar radiation and outgoing long-wave radiation flux produced since 1983.

Comparison of these data allowed us to obtain results, and qualitative and quantitative evidence of the prevailing role of the secular cycle of solar activity (with a maximum at the end of XX–beginning of XXI century) in the current global warming. The mechanism of this phenomenon is due to the contribution of the greenhouse effect on the optically thin clouds, the global cover of which is controlled by just a degree of solar-geomagnetic activity. Such clouds regulates the flow rate of the outgoing long-wave radiation of the Earth to space in such a way that the current recession phase of the secular cycle of solar activity contribute to global warming will be reduced.

The analysis of data on the flare and geomagnetic activity as a predictor of a number of climatic characteristics, allowing to suggest possible ways to use the "solar signal" in weather forecasts: a) taking into account the quasi-periods detected in 2–5.5 years in air temperature and precipitation, b) taking into account available (for example, the 23rd cycle of solar activity) correlation in the variations of the global cover of total cloudiness and low clouds to the variability of the solar constant.

The results of investigation show that:

– the main channel of influence of solar-geomagnetic activity on the climate and weather - characteristics the global cover of optically thin clouds. This give an additional amount of flow of the outgoing long-wave radiation into space from 7 Wm^{-2} in the radiation balance of the Earth during the passage of the secular maximum of solar activity;

– the contribution of the "solar signal – the factors of increased solar-geomagnetic activity" in global warming is the end of XX–beginning of XXI-century – prevails, and to man-made greenhouse effect gases contribute to 2.63 Wm^{-2} (assessment of the Intergovernmental Panel on Climate Change) plays a very minor role;

– the main anthropogenic contributions (6.3 Wm^{-2}) is associated with large-scale abiotization of dry land and deforestation in the past few decades;

– the contribution to global climate change of the solar constant values variations (around 0.1%, which is about 0.3 Wm^{-2}, taking into account the sphericity of the Earth) is insignificant.

On Additional Influx of Solar Energy in the Geosphere

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From the analysis of the results of our observations and works [1, 2] an idea crystallized about the composition of the total flux of solar radiation, sources and mechanism of coherent quantum force fields of different nature in the convection zone and the solar atmosphere. We have now considered the triumvirate of solar power fields: gravitational, electromagnetic and vortex that actively interact with the objects and subjects in the geosphere. In other words, we live in a rapidly varying composition of three surroundings: gravy-environment, EMR-environment and the vortex environment. At this stage, the focus of the report will concentrate on the solar spiral vortex environment.

When the Earth is covered by a collimated beam of spiral vortex radiation (SVR) emerging from the shadow of a large sunspot, an additional vortex flow of energy to the system "atmosphere-the underlying surface", in some cases, in periods of high solar activity reaches $\sim 5 \cdot 10^{23}$ erg/s. Comparing the flow of SVR with the influx of EMR ($1.75 \cdot 10^{17}$ W or $1.75 \cdot 10^{24}$ erg/s), we find that in the years of maximum solar activity (SA) the SVR influx to the Earth can reach 36% from the influx of integrated electromagnetic energy for the period covering. Thus, the incoming part of the radiation balance of the Earth implicitly acquires the 11-year-old SVR-component. In addition, this component is additionally imposed by the periodic component of the SVR, defined by the appearance on the solar disk during the high SA equatorial coronal holes (CH). These regions may occupy huge areas on the disk and emit a quasi-collimated streams of SVR, creating besides than immediate fluxes of vortex energy, the supersonic solar wind streams that through the magnetosphere and ionosphere of the polar regions indirectly (through the corpuscular streams) transfer to the lower layers of the atmosphere and the oceans the vortex energy emanating from the magnetic structures of the CH. Another component of the SVR is generated in the magnetic structures that limit supergranular cells of the chromospheres network, covering the latitude zone of ± 40°. The magnetic structure of the grid – vertical magnetic tubes disposed along the granulation cells. The diameter of these tubes reaches 1,000 km, and the number exceeds 10^6. Under the influence of the vortex field, plasmoids are ejected (with the period of 10–20 min, like pistons) and then passed by SVR solitons going off into the heliosphere (including the Earth). This mechanism is called spicular and ranks second in importance due to the fact that solitons (compressions) of the SVR in spicules consist of coherent fields. Among a number of less significant components of the SVR, we should pay attention to the background contribution of the many millions of photospheric granules which present always and everywhere in the photosphere. Since the background flows of SVR (carrying up to a few tenths of a percent of the energy EMR flows) that continuously intrude in the geosphere, then in the cloud layers of the atmosphere, they undergo considerable energy loss. When SVR flows are followed on the hydrosphere and lithosphere, where the efficiency of interaction with the substance of the SVR increases by an order, they are left in these parts of the geosphere to 1.5% of the received vortex energy. The accumulation of energy (at constant filling losses) obviously must lead to dynamic perturbation of the hydrosphere and the interior of the geoid with increasing solar activity (and SVR). Since the background flows of SVR (carrying up to a few tenths of a percent of the energy EMR flows) that continuously intrude in the geosphere, then in the cloud layers of the atmosphere, they undergo considerable energy loss. When streams of SVR follow further to the hydrosphere and a lithosphere where efficiency of interaction of SVR with substance increases much, they leave in these parts of a geosphere to 1.5% from the arrived vortex energy. Energy accumulation (at continuous completion of losses), obviously, has to lead to dynamic disturbances of the hydrosphere and internal areas of a geoid in process of growth of solar activity (and SVR). These tendencies are noted within the last century that doesn't contradict the violation of radiation balance between the planet and the space observed in the last decades (growth of average annual values of radiation balance of Earth). Really, our "civilization" is finally reconstructed on an ecological disruption way, and all this occurs with a continuous growth of concentration of greenhouse gases in the atmosphere, complicating return in space of surplus of internal energy collecting in a geosphere. Apparently, measures for urgent decrease in weight of greenhouse gases are necessary for fight against warming in Earth atmosphere.

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New Global Short-Wave Radiation Climatology from VOS based on Highly Accurate Parameterization

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The talk will revisit the computation of short wave radiation at sea surface using VOS observations of cloud cover and meteorological state variables. For the development of new climatology of SW radiation we used newly designed parameterization based on 4 years of in-situ observations in the Atlantic Ocean. Parameterization for the first time accounts not only for the cloud amount but also for the forms of clouds that is critical under overcast and nearly overcast conditions. New parameterization was for the first time applied to the VOS meteorological observations (available from the latest update of ICOADS collection) on individual sample basis. In order to avoid the impact of inhomogeneous distribution of observations in time (resulting in strong biases and precluding the use of similar parameterizations for climatological computations) we used multiply computations with virtually rotated time for every VOS report. Climatology of SW radiation for the period from 1950 to 2011 has been intercompared with reanalyses and satellite radiative products. Furthermore, a comparison was performed with alternative SW parameterizations. Accounting for cloud types allowed for the identification of specific features of insolation at sea surface in the eastern parts of the ocean. Generally global mean insolation in our new climatology tends to be 1 to 5 Wm^2 smaller compared to the estimates based on alternative parameterizations. Using new climatology we analysed climate variability in short wave radiation fluxes including estimates of long-term trends and oscillating shorter-term interannual modes.

The First Results of Net Radiometer Kipp & Zonen Measurements in MO MSU: Error Estimates and Comparison with Observations by Actinometric Network Devices

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In Meteorological Observatory, Department of Meteorology and Climatology, Faculty of Geography, Moscow State University (MSU MO) since 1954 the radiation balance components (RB) measurements are carried out the with standard network devices. In recent years, range of observation expands. During the 2008–2012 downward longwave radiation (DLR) was measured with precision pyrgeometer Eppley (model PIR). Since May 2012 the widely used net radiometer CNR4 by firm Kipp & Zonen has been introduced to the routine work, which measures the value of net radiation, and the radiation of the upper and lower hemisphere in the short-and longwave range of the spectrum. It is allowed not only to obtain the new data, but also provided an opportunity to compare the results of measurements of national instruments and devices that are used in many countries around the world.

The accuracy of the DLR measurement by net radiometer CNR4 based on parallel observations with pyrgeometer Eppley, which measurement error was only 2–3 W m^{-2}, have been evaluated. It is shown that the DLR measurements made by net radiometer CNR4 overestimate downward longwave radiation by approximately 9±1% or 30 Wm^{-2}. Also, there are quite significant DLR changes during atmospheric precipitation, when the measurement error by CNR4 reached 30% or more. Note that this problem can be solved by installing the fan device into this model unit. The DLR values obtained by the pyrgeometer Eppley and the DLR measurements by standard net radiometer M-10m at night time with taking into account the calculation of natural surface radiation are close (the difference between them is within a few percent). The maximum difference for the mean hourly DLR values did not exceed the accuracy of net radiometer M-10m, which is 15%. The objective of the study also was to assess the possibility of M-10m net radiometer replace by net radiometer CNR4 during further radiation budget monitoring at MSU MO.

When you change type of device it is extremely important to preserve the uniformity of observations. According to the instruction RD 52.04.562-96 the standardized RB measurements are made without direct radiation. To get the full radiation budget direct solar radiation, which is measured by heliostat mounted on the MSU MO roof, is added to RB value. Net radiometers CNR4 and M-10m were installed at the meteorological site with a natural covering at a distance of about 10 m from each other. During a day, there are periods when instruments shaded. Comparison of the measurements of shortwave fluxes has revealed an extremely important role of shadowing features of the MSU MO meteorological site. During the study, the estimation of device shading conditions during daytime was done. We compared the hourly and daily sums of shortwave radiation in winter and summer at various cloud conditions obtained by the net radiometer CNR4 and standard network devices. Under overcast sky the difference in daily amounts of shortwave radiation was 3–5 %. On a clear and partly cloudy days the difference in hourly sums reaches 50% at separate hours (under different shading device), and in diurnal sums it increases to 25%.

Climatic Solar Energy Resources in the Moscow Region

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This report summarizes the results of solar radiation monitoring in Meteorological Observatory of Moscow State University (MSU MO) during 1955−2007. Based on these observations, the climatic resources of the total integral (IR, 300−4000 nm), ultraviolet (UVR, 300-380 nm) and photosynthetically active (PAR, 380−710 nm) solar radiation were estimated, and the average climatic values of sunshine duration, surface albedo and net radiation or radiation budget (RB) were obtained. The analysis of the time variability of these characteristics and the factors determining them was done. For comparison, the results of the radiation observations in the suburbs were also used.

The empirical model of solar radiation in cloudless atmosphere was developed. A set of equations allowing to evaluate IR, UVR and PAR under different conditions (sun elevation, aerosol optical thickness, surface albedo) and for different time intervals – a month, warm (May-September) and cold (December–March with snow cover) periods – was obtained. The influence of volcanic and smoke aerosols, as well as the city's impact on the total radiation in different parts of the spectrum was analyzed. Based on the hourly cloud monitoring (since 1965), and basic standard meteorological observations every 3 hour (since 1954) the cloudiness regime was studied in detail. Considerable attention was paid to the parameterization of the integral, ultraviolet, photosynthetically active radiation in the overcast conditions. The influence of overcast sky with various cloud form on the quantity and the spectral distribution of solar radiation was evaluated.

The indirect estimation methods, which allow to define PAR and UVR in the regions where there are no direct observations of them, were developed. The shares of PAR and UVR in total integral radiation (qf, quv) were examined. A detailed analysis of qf and qufr dependence on solar elevation, aerosol optical thickness and clouds was done. The peculiarities of qufr changes in pure air and in the presence of a smoky haze have been considered. We also discuss the opportunity to evaluate total IR and PAR by sunshine duration. Using the obtained approximations, the monthly sums of PAR during the vegetation period for different regions of the European part of Russia have been calculated. The summarized data on surface albedo and reflected shortwave radiation have been represented. Daily and annual course these parameters and the statistical characteristics of their variability were analyzed.

For the first time the results of long-term observations of the surface radiation budget have been systematized and generalized. Climatic norms of RB have been calculated and their variability (daily, annual, interannual) have been evaluated. The correlations between RB main components and factors that determine their variability have been received. The probability of a daily RB sum occurrence during a year is determined.

Trends in radiation parameters of the atmosphere (including 2012), representing the modern climate change, as well as the relationships of radiation balance components on their determinants are analyzed. This is the first generalization of such prolonged and complex radiation observations in the Moscow region.

Regional Features of Climatic Changes in the Components of Surface Radiation Budget over Russia

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The long-term changes as well as decadal changes in the components of the surface radiation budget with taking account of the observational data up to 2012 are considered. In contrast to the radiation fluxes at the top of the atmosphere, which are measured by modern satellite systems, the primary source of data to monitor the components of the surface radiation budget are series of ground-based solar radiation observations. At the present time the climate monitoring system for the territory of Russia includes the regular analysis of monthly, seasonal and annual totals for both global and direct surface solar radiation which is based on the observational data from Russian actinometrical network stations.

The changes in surface solar radiation for the last five decades have certain characteristics that make unrealistic to use a linear model for the whole interval. In the late 80's–early 90's. 20c. in Russia there was a reduced income of solar radiation. In the last decade of the 20th century, a partial recovery was observed, so the values had become close to normal. These patterns of long-term changes have been also observed in other parts of the globe and are known as "global dimming and brightening". However, in recent years – in the early 21th century – in Russia some specific features in change of direct and total radiation were found.

The results of the analysis for tendencies and rates of change in radiative fluxes (direct and global radiation) over different parts of the period 1961–2012 are demonstrated. In addition to it similar results on total cloud cover change are given. The above estimates are discussed in the context of climate change in relevant characteristics at the global level.

The Relationship between Surface Temperature and Heat Balance Elements over the Territory of West Siberia

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In this study the variability of spatial and temporal distributions of temperature and atmospheric pressure is investigated for the territory of West Siberia (50–70ºN, 60–90ºE) for the period of 1975–2012 using observational data at meteorological stations.

In the beginning of XXI century the tendency of decelerate of surface temperature increase over the territory of West Siberia is observed. It was obtained that in winter months during last decade the process of warming was changed by the process of cooling, especially in the center and in the east part of West Siberia. The most important role in the weather and climate formation belongs to radiative and heat balance elements at the surface. Also clouds contribute to both heating and cooling of climatic system.

The main purpose of this study is to investigate the spatial and temporal variability of heat balance elements and cloudiness in the period of global warming 1979–2012 and to reveal the relationship between air surface temperature, cloudiness and heat fluxes for the territory of West

Siberia. The average fields of radiative and heat balance elements and clouds, the fields of their linear trends were calculated and constructed using JRA-25 and MERRA reanalysis datasets.

To determine temperature variability over West Siberia, we used a regression model, which relates surface temperature anomalies with short-wave radiation anomalies, longwave radiation anomalies, calculated for clear sky, anomalies of latent, sensible heat, heat flux into the ground, and with cloudiness anomalies. These anomalies describe from 22% to 81% of temperature variability in different months. We also estimated the role of each cloud level in temperature variability. In addition, the influence of circulation processes on temperature regime in Siberia was revealed.

Correction of Aerosol Optical Thickness Succession Under Strong Atmospheric Turbidity

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Since 1955, observations of atmospheric aerosol turbidity have been carried out by Meteorological Observatory of Moscow State University (MSU MO). The aerosol optical depth (AOD) for the effective wavelength of the solar spectrum at 550 nm is used as an indicator of atmospheric turbidity. It is calculated from measurements of direct solar radiation by standard actinometer with a 10 degree angle. For more than fifty years the climatic normals, as well as the limits of AOT variability due to natural and anthropogenic factors have been evaluated. Under high turbidity conditions, the AOT estimates are understated because of diffused solar radiation falling into an actinometer.

The goal of this study was to readjust the existing climate normals and AOT long-term climatic trends taking into account the impact of this factor. The calculations of AOT amendments were performed by the interpolation scheme developed using the AOT itself and the Sun angular height for the continental aerosol model. It is desirable to introduce such amendments with AOT value at approximately 0.5. Such values of AOT are typically observed in extreme situations, especially in smoky plumes from forest fires or under adverse meteorological conditions (inversions, calm, etc.). In Moscow for the entire period of 1955−2012 such cases amounted to just 7% of the total. The correction taking into account scattered radiation has been made for monthly and annual averaged AOT values for all the days when AOT exceeded 0.5 during the period of 1955-2012. Significant changes to the monthly totals have occurred only in the months of smoky haze in 1972, 2002 and 2010. These changes ranged from 5% in July 2010 to 45% in August 2010. Average annual values increased by 5% in 1972, by 11% in 2002, by 20% in 2010. Averaged long-term monthly values for the period of 1955-2010 changed only for the August values raising from 0.24 to 0.25. The average long-term annual value over this period remained unchanged. A significant decreasing trend in AOT continued throughout this period with the same degree of certainty.

Radiation Monitoring in the Kandalaksha Bay of the White Sea in the Winter of 2013

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The radiation budjet (RB) of the system "surface-atmosphere" − the main factor characterizing the energy exchange at the earth's surface. Its study is extremely important now in the Arctic regions, as it is evident now a close connection, for example, between the temperature in the Arctic, decreasing ice cover of the Arctic Ocean and the weather in Europe. However, the number of observation points of RB in the Arctic is small.

The results of radiation measurements during the winter expedition of Science Student Society of Meteorology and Climatology Department of MSU are discussing. They were held at the White Sea Biological Station (BBS), Faculty of Biology, MSU, located in the south-west coast of the Kindo peninsula, Kandalaksha Bay, from 28 January to 3 February 2013. Tasks of the research – the evaluation of the radiation regime of underlying surface in winter at the latitude of the Arctic Circle. The structure of the observations was included: total and reflected shortwave solar radiation (IR, 300−3000 nm, pyranometers CMP-21 by KIPP & ZONEN and M-80m), long wave fluxes from the sea surface and atmosphere (4500−42000 nm, pyrgeometers CGR-3 by KIPP & ZONEN), the visible solar radiation (PAR, 400−700 nm, quantum sensor LI-190SL by LI-COR), and the total and reflected natural illuminance of the earth's surface (NE, photometer LI-210SL by LI-COR).

During the day, there was mostly overcast weather with low level clouds, the presence of which greatly weakened the incoming solar radiation − till 70−80% of IR and 40−70% of PAR. Maximum incoming solar IR does not exceed 623 MJ/m^2. The contribution of the visible radiation to the total IR reached 60−70% with stratocumulus clouds, increasing to 75−77% with nimbostratus ones. The natural illumination at midday time varied from 3−4.5 klx, decreasing to 1−2 klx with nimbostratus clouds.

During the expedition, there was the strong inflow of warm air from the Atlantic. This resulted in the increase in air temperature from − 7° C up to + 0.8° C during the day. At the same time the long wave RB became a positive within 10 hours and has reached 3 MJ/m^2. During this period the intensive destruction of sea ice was observed. Near the BBC is located not freezing polynya, which area due to such a powerful inflow of warm air has increased more than doubled. This has led to a decrease in sea ice albedo by 14% (from 72.5% to 58.4%) and to the corresponding increase of the absorbed radiation: from 111 to 1493 MJ/m^2. Though, the snow albedo on the coast was extremely high: 82−91% for the integral radiation and 83−97% in the visible region of the spectrum. Total radiation budget (hourly sum) ranged from − 127.3 MJ/m^2 to 23.3 MJ/m^2.

Thus, moist and warm marine air entering the Arctic regions, leads to the increase of counter radiation of the atmosphere, which leads eventually to the positive values of the total net radiation, even in the middle winter season. The conditions of natural daylight close to the twilight.

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SESSION 6. "STUDIES OF RADIATIVE CHARACTERISTICS OF ATMOSPHERE AND SURFACE"

Chairman: Prof. **N.F. Elansky** (IFA RAS, Moscow)
Co-chairman: Dr. **E.I. Grechko** (IFA RAS, Moscow),
Dr. **F.V. Kashin** (RPA "Typhoon", Moscow)

A Combined Experiment on the Measurement of Atmospheric Parameters on May 22, 2012 in Tomsk

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The work is devoted to the description of the problems and the hardware- methodical maintenance of the combined experiment conducted on 22.05.2012, based on the IAO SB RAS. The main goal of the experiment is to determine the greatest possible number of atmospheric parameters with the use of the aircraft-laboratory and the ground-based complex of optical acoustic sounding and contact measurements of atmospheric characteristics. All the obtained information is accessible on demand at authors.

To investigate the vertical distribution of composition of climatically significant components of the troposphere we used the analytical complex of equipment on board of the Tu-134 "Optik" aircraft laboratory. In the measurements of vertical distribution of main greenhouse gases the precision gas-analyzer Picarro G2301-m- CO_2, CH_4 and H_2O was used. The ozone concentrations were determined with the use of UV photometric gas analyzer Thermo Environmental Instruments (TEI) Model 49C. For retrievals of the vertical structure of distribution of atmospheric aerosols we used the diffusion aerosol spectrometer (DAS) and the laser aerosol spectrometer Grimm#1.109. In the course of the experiment the measurements were made at TOR-Station, at the Basic Experimental Complex, at the observatory "Fonovaya" with the use of meteorological, gas analytical, aerosol complexes and radiosondes Vaisala R92SGP. The aeroions and gamma-background were also measured. Under regular operating conditions the measurements were made of microphysical aerosol characteristics in the ground layer at the stationary Aerosol station and the integral characteristics (aerosol optical thickness, general moisture content) were determined using the multiwave sun photometers CE 318 and SP.

Lidar measurements of vertical structure of aerosol tropospheric fields were made using the stationary multifrequency lidar "LOSA-C" at three laser wavelengths 355, 532, 1064 nm at the laser pulse repetition rate 20 Hz and the duration 10 ns. The satellite data on atmospheric characteristics were taken and processed with the use of a 2.4XLB antenna system of IAO SB RAS from the satellites Terra, Aqua and MetOP-A. The diagnostics of the atmospheric boundary layer was made using the ultrasonic meteorological stations “Meteo-2” and the three-channel acoustic Doppler sodar “Volna-4”. At the Siberian Lidar Station we measured the nitrogen peroxide content in the atmosphere at twilight. Moreover, the solar spectra were recorded with the use of the Fourier spectrometer Bruker-125M. On the base of the geophysical observatory of the Institute of Monitoring of Climatic and Ecological Systems SB RAS the instruments such as the Meteorological Observer and the Automatic Meteorological Data Measuring System and also the Multichannel mean resolution filter Radiometer NILU-UV-6T and the panoramic sky observer have been in operation.

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Preliminary Results of Sun Photometer Measurements during 58th Russian Antarctic Expedition

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The activization of research into the atmospheric aerosol optical depth (AOD) over the ocean during last decade favored the creation of maritime AERONET site [1] and the use of the portable sun photometers Microtops II [2] and SPM [3] in expedition measurements. This report addresses the measurements of AOD and atmospheric moisture content, which were performed during the 58th Russian Antarctic Expedition (RAE) along the routes of “Academician Fedorov” and “Academician Treshnikov” scientific expedition vessels (SEVs), as well as in the region of Mirny Station in Antarctica. The main attention was paid to the following questions:

1) discussion of results of intercalibration of three sun photometers (Microtops, SPM, and ABAS), performed at the Mirny Station;

2) analysis of specific features of latitude variations in AOD and atmospheric moisture content along the routes of the two SEVs (along the coasts of Africa and America);

3) comparison of the statistical characteristics of AOD, measured at the Mirny Station and onboard SEVs near the coasts of Antarctica; and

4) estimation of the interannual and seasonal variations in atmospheric AOD in Antarctica.

This study was supported by the program of basic research of the Presidium of Russian Academy of Sciences no. 23 and with the use of the unique installation, namely, the scientific expedition vessel “Academician Fedorov” under the state contract of the Ministry of Education and Science of the Russian Federation no. 16.518.11.7093.

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Variability of the Atmospheric Aerosol and Optical Parameters in the Northern and Southern Polar Regions after the Year 2000

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The paper presents the results of the analysis of the atmospheric aerosol optical depth (AOD) and Ångstrüm's exponent (α) in the Northern and Southern polar regions after the year 2000. These data were collected at the international AERONET stations. We also present the analysis of the measurements of the total optical depth (TOD) at the Russian polar stations as well as at the Russian mid-latitude background monitoring stations. We analyzed the inter-annual and intra-annual variability of AOD in the Arctic and the Antarctic. The mean monthly AOD at the Antarctic AERONET stations were not higher that 0.05 during the time period under consideration, which is in agreement with our previous results. At the Arctic stations the mean monthly AOD was usually below 0.15 except for several isolated cases.

A substantial increase in the mean monthly and mean seasonal AOD was registered at the majority of the Arctic AERONET stations in 2009. This phenomenon was not observed in the Antarctic in 2009. The mean α at the Arctic AERONET stations after the year 2000 was 1.34 ± 0.18, which corresponds to the average value for α in normal, unperturbed conditions of the atmosphere.

Measurements of TOD at Russian polar stations in the Arctic and Antarctic, collected after the year 2000, were analyzed too. Mean monthly TOD at the Antarctic stations did not surpass 0.2; at the Arctic stations the values were twice as high and reached 0.4. It was found that in a few cases, when this limit was exceeded at Arctic stations, it could be attributed to the influence of anthropogenic factors including local sources of atmospheric pollution. TOD values obtained at the Russian Arctic stations were compared with the corresponding data of the Russian mid-latitude background monitoring stations of the atmosphere. Our analysis showed the similarity of the values measured at both types of stations. Long-term variability of the relative anomalies of TOD at the stations with the longest periods of observations was also analyzed. We evaluated the influence of volcanic eruptions on the characteristics of the aerosol optical depth at the Polar Regions and on the total optical depth of the atmosphere at the mid-latitude stations. No statistically significant trends of AOD and TOD were found at both the Northern and Southern polar stations and the mid-latitude stations of background monitoring of the atmosphere during the period in question.

Behavior of Surface Ozone and Its Precursors in Obninsk in Anomalous Summer of 2010 as Compared to Summer of 2011

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Measurements of the surface ozone (one of the most important greenhouse gases) concentrations, components of nitrogen oxides ozone cycle (NOx), ozone precursors – carbon monoxide (CO) and the sum of non-methane hydrocarbons as well as the aerosol optical depth and fluxes of ultraviolet solar radiation obtained in Obninsk (55.1° N, 36.6° E) in May–September 2010 and 2011 are presented analyzed. The following instruments were used for the measurements: an automatic station of atmospheric contamination control M-28 (the data of devices F-105, K-100, P-310A and Gamma-ET were used), a Brewer-MKII spectrophotometer and an ozonometer TEC-49*i*. During the measurements the measurement complex of the High Meteorological Mast (HMM-300) was also used. The measurements were mainly performed at the HMM-300 experimental site, excluding the measurements of surface UV-radiation fluxes and aerosol depth made in the main territory of RPA "Typhoon".

The connection of the atmospheric temperature and maximal daily mean hourly surface O_3 values in May–September 2010 is characterized by a higher correlation coefficient as compared to May–September 2011 – 0.82±0.05 against 0.64±0.07. All the maximal daily mean hourly surface O_3 concentrations, except three days in August 2010 when air masses brought anomalously dense smoke from the region with forest fires, fall within 95% of the forecasting level for the connection with the surface temperature. In 2011, such a falling out of the forecasting level for the connection with the surface temperature was on 02 June, but there was no smoke at that time.

Increased surface concentrations of O_3 in Obninsk in July–August 2010 as compared to the similar period of 2011 were caused by higher concentrations of the compounds-ozone precursors. Several very high surface O_3 concentrations in August 2010 exceeding 200 microgam/m^3 and not registered during the whole observation period of 2004–2011 in Obninsk (single values of 212.5 microgram/m^3 (on 01.08.2010), 207.4 microgram/m^3 (04.08.2010) and 211.7 microgram/m^3) were caused by the arrival to Obninsk of air masses from the regions of bog and forest fires resulting in a sharp growth of NOx, CO and hydrocarbons surface concentrations. The surface CO concentration increased especially – almost by 40 times as compared with a mean value registered in May–September. Also, the solar insolation significantly decreased due to smog, did not block the generation of very high surface concentrations of O_3. Because of the smog, the correlation coefficients between mean daily (9–17 hours) concentrations of surface ozone and daily dozes of UV radiation for 2010 appeared significantly lower than in 2011 – 0.56 ± 0.07 against 0.74 ± 0.05.

It has been noted that: a) in the stable atmosphere the appearance of increased maximal daily values of surface O_3 concentrations in May–September was more likely than in the unstable atmosphere (in 2011 it was more evident: 25.3% against 23.5% in 2010 and 34.2 against 10.7% in 2011); b) the dependence of the appearance of maximal daily mean hourly concentrations of surface ozone, exceeding 160 microgram/m^3 , on the velocity of the surface wind is likely to be of a bell-shaped and not of a monotonous character; c) maximal daily mean hourly surface O_3 concentrations in May–September positively correlated with the atmospheric absolute humidity in contrast to 2011, when there was no correlation.

Features of UV Irradiance in the Conditions of Abnormal Continuous Fumigation of the Atmosphere by Forest Fires

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Results of the data analysis of ultraviolet (UV) observations carried out in the conditions of strong continuous fumigation of the atmosphere generated by vast forest fires in the Tomsk and Krasnoyarsk regions in June–August of 2012 are represented. The observations are a part of complex environmental monitoring operated in the geophysical observatory of IMCES SB RAS. UV measurements are carried out by means of multichannel moderate-bandwidth filter radiometer NILU-UV-6T. The radiometer measures UV irradiances at five channels with center wavelengths at 302, 312, 320, 340 and 380 nm. The channel bandwidths are approximately 10 nm at FWHM. In addition, a sixth channel measures photosynthetic active radiation (PAR) in the wavelength region 400–700 nm. The instrument has a built-in circular data logger with capacity of storing 3 weeks of one-minute averages of the measured irradiances and the detector temperature. A data acquisition software transfers measured raw data to the computer hard disk and can display on-line raw data as well as historical raw data. A data processing software calculates the mean and maximum dose rates and integrated daily dose of UV-A (315–400 nm), UV-B (280–315 nm), PAR, CIE- and CLW-weighted irradiance. The software also provides cloud transmission assessment at 340 or 380 nm and total ozone column.

Such strong continuous fumigation of the atmosphere in the Western Siberia was determined by abnormal weather conditions. So, during maximal fumigation observed in the end of July, 2012, when meteorological optical range decreased at times to several hundreds and even tens meters, the weather pattern in the east part of the Western Siberia has been caused by low-gradient depression. The surface temperature in Tomsk variated from 17°C at night to 29°C in the afternoon, the wind of northern direction was weak (1–3 m/s), and precipitation was absent. As have shown observations, abnormal fumigation affects on spectrum of incoming UV and PAR, reducing a radiation rate more than in two-three times in comparison with normal. And UV radiation is decayed much more strongly than PAR (by ~ 50 %).

The investigation was executed within the framework of VII.63.1.1 and VIII.77.1.1 programs of fundamental scientific researches of the Russian Academy of Sciences.

Experimental Studies of Radiation of the Atmospheric Background in the Range of 8–13 Microns

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The previous statistics for the experimental research in spatial and time structure of the atmospheric infrared-band (IR) radiation fluctuations were incomplete. These studies were carried out sporadically, for certain types of cloud amount and in accordance with measurement techniques which vary among researchers. The choice of techniques is based on the aims, equipment capabilities which are difficult to project due to considerable methodological and technical problems. For this reason a new technique of experimental research of radiance fluctuation patterns for different types of atmospheric backgrounds (AB) within infrared wavelengths of 8–13 μm was created. The research involved measurements and data processing to obtain the statistical patterns of spatial and time structure changes of the AB radiation non-stationary in space and time and the study of its properties within small-scale background fragments.

Measurements of the AB radiance fluctuation patterns were performed using a specially developed the measuring and computing complex (MCC), which involves a radiometer with an operational range of 8–13 μm as the main element. The measurements were carried out repeatedly and at regular intervals via raster scanning by radiometer axis along the azimuth and elevation with the certain sampling interval. Thus sets (packs) of background images were formed obtained from different types of clouds and cloud amounts within the range of 8–13 μm.

The processing of measurement results of AB radiance fluctuation patterns has identified new regularities: due to thermodynamic processes and turbulence atmospheric radiating, heterogeneities are formed which can change their dimensions (both horizontally and vertically) depending on the weather conditions. The regularities of radiating heterogeneities spatial variability can be described by using spatial-correlation AB radiance fluctuation functions, which have a number of specific properties:

1) spatial-correlation AB radiance fluctuation functions have considerable spatial correlation coefficients between adjacent rows / columns / AB radiation.

2) dimensions of atmospheric radiating heterogeneities in both vertical and horizontal directions are limited by the values of correlation radius of AB radiance fluctuation spatial functions (between rows/columns/ AB radiation).

3) spatial structure of AB radiating heterogeneities is not subjected to rapid changes in elevation and azimuth within the angular size limited by the values of radii (between rows / columns / AB radiation) of AB radiance fluctuation spatial correlation functions.

4) there is a general radii reduction tendency of the spatial correlation AB radiance fluctuation functions (between rows / columns / AB radiation) for all types of cloud amounts, therefore the AB radiating heterogeneities also tend to diminish in size in both vertical and horizontal directions while the observation direction is approaching the horizon.

Measurements of the spatial-temporal variability of AB radiating heterogeneities were carried out in a similar way: line-by-line scanning by radiometer axis along the azimuth at a fixed elevation value with the certain sampling intervals. Thus sets of rows, columns of AB radiation sequences (1, 2, …, k) were formed obtained from different types of clouds and cloud amounts within the range of 8–13 μm for the certain elevation (azimuth) values with the constant time sampling intervals Δt.

To process the results of the experiments one set of the rows or columns of AB sequences was chosen and then new spatial and time patterns of the AB radiating heterogeneities spatial dimensions changes were identified. The patterns can be described by spatial-temporal correlation functions of AB radiance fluctuations which have the following properties:

1) spatial-temporal correlation functions of AB radiance fluctuations have considerable spatial and time correlation coefficients between corresponding rows / columns / AB radiation sequences;
2) the radius of spatial-temporal correlation functions of AB radiance fluctuations varies according to the thermodynamic and turbulent processes velocity. These time intervals are equivalent to the lifetime of radiating heterogeneities spatial dimensions at different AB types.

During the studies of AB radiating heterogeneities time variability the radiometer axis was fixed for specified elevation value and the signal which is proportional to AB radiance heterogeneities fluctuations was recorded with the specified resolution and during the particular period of time. During the processing of the experimental results new regularities were identified which can be described by using time autocorrelation correlation functions with following properties:

1) time cross-correlation functions characterize the velocity of AB heterogeneities radiance fluctuations changes along with the specific observation direction;
2) correlation intervals of AB heterogeneities radiance fluctuations cross-correlation functions along the selected direction define the maximum AB radiation fluctuation frequency.

It can be concluded that experimental studies results of the radiance fluctuation patterns enabled to identify new spatial and time AB radiation structure. Then the features of the identified atmospheric radiation patterns were used to support the for retrieving information on existence of pinpoint artificial thermal object (ATO) principle at the atmospheric background, which states that a ATO is situated in those areas where local changes of the identified spatial and time AB radiation patterns.

Parameterizations of Short Wave Radiation at Sea Surface in the Atlantic Ocean

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The major source of uncertainties in the estimation of solar radiation at sea surface is associated with strong variability in the atmospheric transmission factor under different cloud types, even under the same total cloud cover. Existing parameterizations account mostly for the amount of clouds (quantified through the fractional cloud cover) and do not include cloud types. The latters are characterized by highly variable optical properties of clouds and can, when used, critically improve the accuracy of parameterizations of short wave radiation at sea surface. To resolve the problem of the absence of accurate parameterizations based on cloud type characteristic and to develop and advanced methodology we performed 4-year (2004–2007) experiment designed to measure the incoming shortwave radiation at the ocean surface under different could conditions. The data array includes 130 daily series of field in situ measurements of short wave radiation and simultaneous visual observations of cloud type and cloud cover in different regions of the Atlantic Ocean. Data were collected during several research cruises with the routes aligning from the sub-polar North Atlantic to Antarctica and, thus, cover most of climate conditions. Observations were used to build statistically new dependencies of the atmospheric transmission on cloud cover under different could types. Using this approach we were capable of improving the accuracy of computations of surface short wave radiation fluxes by 20% compared to the existing models using information about fractional cloud cover only. Importantly the highest improvement of the accuracy was obtained under near-overcast or overcast conditions.

Further development of this project goes along designing a system for automatic determination of cloud cover and the engagement of these estimates into calculations of the incoming short wave radiation fluxes. For the development and testing this system we used cloud cover data collected in the Atlantic Ocean during the period 2007–2011. It has been found that the automatic system provides quantitative estimation of fractional cloud cover with 20% accuracy and in case of the manual correction of records the accuracy increase up to 10%. This is equivalent to the accuracy of visual observations. Since the digital system allows for high resolution nearly operational observation of fractional cloud cover and types, further plans can be associated with the development of low-cost package for the on-line estimation of short wave incoming radiation at sea surface even at merchant vessels.

Consistency of Component Variations of Ionizing Radiation and Atmospheric-Electric Values

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The main "suppliers" of light, medium and heavy ions in the surface atmosphere over land are the radiation from radioactive substances Earth's crust and atmosphere, as well as cosmic rays. Objective: To estimate the spectral and temporal variations of the parameters agreed to ionizing radiation at a series of heights (0.1, 1, 5, 25 m) and deep (0.5, 1.5 m) with atmospheric electrical and meteorological parameters of surface atmosphere in the region with sharply-continental type of climate. Used monitoring data IMCES RAS and TPU for 2006–2012 years.

In the near-surface atmosphere β-annual variation of the background changes from year to year, in contrast to the γ-background, for which the maximum is observed in November, and the minimum in February and March, synchrony in the dynamics of β-and γ-fields recorded in the summer–autumn. On time scales from synoptic to annual variations in γ-background is closely related to changes in atmospheric pressure. It should be noted the close relationship between the change in the level of the neutron component of cosmic rays and γ-background variations of terrestrial origin. As a result, cyclonic activity and the associated changes in atmospheric pressure leads to consistent fluctuations in the background γ-terrestrial origin, and the restructuring of the atmospheric circulation over large areas associated with global climate change leads to consistent changes in the levels and variations of γ-background of natural origin.

Precipitation plays a major role in the variations of atmospheric γ-background and can lead to short-term increases in the level of background γ-radiation up to the order of magnitude. The reaction of the fields other types of ionizing radiation (β and α) on the precipitation remains poorly studied. Data Analysis 2009–2011 showed that not all cases of precipitation in the "warm" season of the year led to the appearance of bursts in the β-and γ-background in the surface layer. A number of bursts recorded in the absence of precipitation. However, in these cases, there was a rapid decrease in the atmospheric pressure or increase turbulence. The intensity of rainfall is weakly correlated with the amplitude burst of radiation.

Analysis of monitoring data revealed that there is a minimum amount of precipitation that does not affect the level of sub-surface component of radioactivity. Duration phase growth level of ionizing radiation in the soil during precipitation (from 6 to 12 hours) greatly exceeds the equivalent phase in the atmosphere. Even longer different phases of recovery levels of ionizing radiation of different components that make up a unit in the soil of the day.

Variations of α-, β- and γ-ionizing radiation in the air and soil with a daily period were in opposition. Contact meteovelichin variations of atmospheric and subsurface components of background radiation in the winter and summer conditions have fundamentally different nature: in the winter increase in pressure and a decrease in the conductivity of the atmosphere is accompanied by an increase in the sub-surface component of background radiation in the summer of this dependence is observed.

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Aircraft-Laboratory Yak-42D for Monitoring Gaseous and Aerosol Composition of the Atmosphere

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The aircraft-laboratory Yak-42D "Atmosphere" was created in Federal State Budgetary Institution Central Aerological Observatory of Russian Federal Service. The report will focus on the hardware-software complex for monitoring of changes in chemical composition, including the monitoring of pollutants and greenhouse gases in the atmosphere and the control of the stratospheric aerosol layer and the ozone layer of the atmosphere. To solve these problems, systematic airborne measurements of spatial and temporal distributions of gases and aerosols on various scales, and altitudes in the free atmosphere are needed. Airborne sensing of gaseous and aerosol composition of the atmosphere will identify as early as possible climate factors that may lead to changes in regional and global scales which are associated either with the natural fluctuations in climate-parameter, or by anthropogenic influences. The complex includes the following devices:

- Aircraft multi-wavelength aerosol lidar ML-375-A is designed to measure the backscattering coefficient and the aerosol extinction in the spectral range 355–1064 nm.
- Aircraft tunable diode laser spectrometer for measuring the concentration of greenhouse gases (water vapor, carbon dioxide, methane) and their isotopic composition in the atmosphere. Airborne spectrometer consists of the electronics module, which supports the work of six diode lasers, and 3 measuring channels for H_2O,CH_4, CO_2.
- Spectrometer in ultraviolet and visible ranges – Shamrock SR-303i for measurements of the total content of O_3, NO_2, BrO, OClO in the atmosphere.
- Ozone Analyzer Model 205.
- Greenhouse Gas Analyzer G2301-mc.
- Non-dispersive infrared analyzer SO_2/N_2O air LI-7500ADP.
- Gas chromatograph Agilent-7820A with a device for sampling air.

Whole air samples (NMHC, alkyl nitrates, long lived tracers like halocarbons), CO_2, N_2O, CO, CH_4.

Complex MR-32 for Monitoring Atmospheric Gas and Aerosol Composition. 1. Monitoring of Atmospheric Gas Composition

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Monitoring of atmospheric gas composition is made at the constantly widening network of the GAW on the basis of measuring gas concentrations (mixing ratios) in air samples taken near the ground. In continental conditions ground-based measurements are supported by measurements of gas concentrations at different heights from meteorological masts.

The instrumentation complexes used consist of gas analyzers operating on the principles of optical-acoustical or gas-chromatographical detection of the gas composition in air samples. The measurement method has a high accuracy because it is based on the comparison with the reference gas mixtures, but the results obtained characterize only the air near the ground and the atmospheric boundary layer at best.

For studies of atmospheric gas composition the method of solar absorption spectroscopy has been widely used at present. It is based on the determination of gas contents from the spectra of solar radiation that passed through the atmospheric depth. The measurement complex consists of a spectral device (a classical spectrophotometer or a Fourier-spectrometer) and a system tracking the Sun. The measurement results obtained by this method present the gas content in the atmospheric column. They are practically independent on the effect of local ground-based anthropogenic sources and characterize the troposphere and stratosphere. The simultaneous use of both methods at one and the same observation site gives more complete information on the atmospheric gas composition. The data obtained give a possibility to compare them and to study the peculiarities of the gas concentration vertical distribution in the atmosphere.

At FSBI "RPA "Typhoon" (Obninsk), an experimental prototype of an instrumentation complex has been developed for measuring gas contents and their concentrations in the atmospheric depth and in the air near the ground. The complex was put through the state acceptance tests. It is now being operated under control. The complex consists of a Fourier-spectrometer, a system tracking the Sun, an optical interface for matching the Fourier-spectrometer and the control system, an optical multipass cell and a system for sample preparation. The construction peculiarity of the complex is that it makes it possible to successively register the spectra of solar radiation that passed through the atmosphere and the absorption spectra of an artificial source radiation that passed through the optical multipass cell. Thus it is possible to simultaneously obtain information needed for determining the gas content in the atmospheric depth and its concentration in the air near the ground

Spectrometer for Monitoring of Atmospheric Ozone (Ozonometer)

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The spectrometer for the monitoring of Earth atmospheric ozone from the board of spacecraft is being designed. The aim of the spectrometer called "Ozonometer" is global and permanent monitoring of total ozone by means of measuring spectra of scattered solar radiation in near-UV and visible range of spectrum (300–500 nm). This range includes Huggins absorption band of ozone in near-UV (300–360 nm) and nitrogen dioxide NO_2 absorption bands in visible light (400–500 nm). The optical design of the spectrometer is based on the Rowland circle scheme with holographic concave diffractive grating. An off-axis parabolic mirror is used as an entrance objective. The CCD detector is linear with 2048 pixels. The spectral resolution is up to 0.3 nm. The spectrometer is supposed to provide nadir observations but there is also an additional optical entrance orientated to Sun hemisphere in order to measure pure solar spectra.

The spectrometer is being designed within Russian special federal program "Geophysics". Among the program, a group of 4 spacecrafts "Ionosphere" is to be launched in 2014–2015. They are planned to operate at a pair of circle solar-synchronous near-polar orbits (2 spacecrafts at each orbit).

Up to the present moment, the qualification model of the spectrometer has been manufactured and tested. The first performance tests were completed at optical laboratories in St. Petersburg and Moscow with the help of Hg lamps and other light sources. After that, the field atmospheric measurements have been carried out in Moscow, Orel and at Kislovodsk high-altitude atmospheric station at Caucasus. The observations have been provided at zenith direction (scattered radiation) as well as solar direct measurements. The obtained results are presented.

The research was supported by grant №11.G34.31.0074 of Ministry for Science and Education of Russian Federation.

Results of the Water Vapor Total Column Measurements in the Frame of Combined Experiment in Tomsk on May 22, 2012

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Results of the water vapor total column measurements obtained in the frame of combined experiment (the 22nd of May 2012) are presented. Ground-based observations of near IR direct solar radiation spectra were carried out by Fourier-spectrometer IFS-125M (Bruker). The set of parameters of the Fourier-spectrometer was as follows: the measurement region – 25000–8000 cm^{-1} (400–1250 nm); the spectral resolution – 0.05 cm^{-1}; the speed of scanner – 20 kHz; the diameter of aperture – 0.6 mm; single spectrum registration time – 10 min; the beamsplitter – quartz; detector – Si-diode. FTIR observations were processed using the standard software SFIT2 v3.92. Vertical profiles of atmospheric pressure and temperature required for retrievals of greenhouse gases were taken from the nearest site of upper air soundings Kolpashevo (WMO №29231). Gases apriory profiles (recommended by NDACC) were created using WACCM (Whole Atmosphere Community Climate Model). Information on spectroscopic line parameters was taken from the HITRAN 2004 database (http://www.hitran.com). Ground-based routine measurements of the water vapor total column and the aerosol optical thickness in the atmosphere are carried out at IAO SB RAS (Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Sciences) by automated sun photometers (SP series). Time required for single measurement is of one minute. Observations are performed under conditions when the Sun is not covered by clouds.

Water vapour is highly variable constituent of the atmosphere therefore adequate comparison of different observational systems requires simultaneous measurements. H_2O total columns measured by sun photometer at 8:48:21 (1.295 g/cm^2) and 8:49:21 (1.293 g/cm^2) were compared with FTIR observations at 08:48:35 (1.301 g/cm^2). Difference between these values is of 0.8%. Mean values of H_2O total column calculated for the both instruments over period of 08:48–08:59 (1.296 g/cm$_2$ and 1.301 g/cm^2 for sun photometer and FTIR respectively) agree within 0.4%. Comparison shows that FTIR observations could give reasonable agreements with sun photometer data within 1%. This value is less than combined error (1.2%) of both types of measurements.

FTIR and sun photometer data on H_2O total column were also compared with Infrared Atmospheric Sounding Interferometer (IASI) MetOP-A satellite measurements (for the period of 11–12 a.m.). Average values of total H_2O obtained for the three measurement systems were as follows: 1.50 g/cm^2 and 1.49 g/cm^2 for the Fourier spectrometer and sun photometer, respectively, and 1.84 g/cm^2 for IASI. This indicates that H_2O total columns from the European satellite IASI MetOP for the date of combined experiment (May, 22, 2012) are higher than ground-based data and require further comparisons and calibrations.

The work has been fulfilled under support by RFBR (№12-05-00596a, 11-02-93112-CNRS_a), the program RAS 3.9, State agreements of Ministry of Education and Science (11.519.11.5009) and grant of SPbU 11.37.28.2011.

Ground-based Spectroscopic Measurements of the Atmospheric $(O_2)_2$ Total Contents

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The authors present the results of the oxygen complexes $(O_2)_2$ total contents measurements by means of spectroscopic technique with using a high resolution Fourier transform spectrometer IFS-125 M and sun tracker [1]. The measurements have been performed within the complex experiment which was carried out on May 22, 2012 in Tomsk region. The atmospheric total contents of the $(O_2)_2$ absorber were derived from the fit to experimental data.

It was revealed there are several strong oxygen complexes absorption bands with center at λ = 1.06, 0.630, 0.577 and 0.477 µm well as O_3 absorption band centered at λ = 0.602 µm that is confirmed by the earlier experimental works [2]. The FTIR solar absorption spectra were recorded in the spectral range 0.477–1.06 µm with spectral resolutions 0.01 cm^{-1} for different solar zenith angles. Using the observed spectral data and analysis least-squares fitting software, we could derive the oxygen complexes and ozone total contents. The O_4 observed data were fitted to experimental data from work [3] and for ozone fitting the experimental data from [4] were used.

Obtained from the fit ozone total contents were compared to satellite data that served as additional criterion of correctness of $(O_2)_2$ total contents measurements. The obtained data can be used for problems of atmospheric spectroscopy and atmosphere chemistry.

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The Photometric Measurements of Aerosol Optical Depth and Total Water Vapor Content in the Volgograd Area

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Systematic measurements of aerosol optical depth and total water vapor content with use of mobile sun photometers SPM, developed at the Institute of Atmospheric Optics, have been started in Volgograd area. These photometers record solar radiation in a wide spectral range from the UV (340 nm) to mid-infrared (2014 nm). In the summer-autumn period of 2011 measurements were made with a photometer, developed in 2008, and since 2012 measurements have been made with photometer, developed in 2011. GPS navigator and digital weather sensors to measure the temperature and air pressure are integrated in the upgraded photometer (2011).

The first and the second moments of the distribution of the values of the aerosol optical depth for the period of observation will be presented in the report. Average daily and monthly aerosol optical characteristics will be evaluated. The Angstrom parameter that characterized the spectral behavior of AOD in the wavelength range 440–870 nm according to observation data was determined. The results of comparison of the AOD measured by sun photometer and by satellite radiometer MODIS will be presented. To match the results of measurements from different photometers intercalibration procedure with use of a sun photometer Cimel of AERONET was carried out in Yekaterinburg.

The results of simulation retrieval of total water vapor from the photometric data of the Sun for the regions of Western Siberia and the Lower Volga region will be presented. To realize this, two samples of meteorological profiles were taken in the climate conditions of Novosibirsk and

Volgograd regions. Then, on the basis of these meteorological data the line-by-line calculations to obtain regression dependence of transmittance from the total water vapor content were performed. The simulation results showed that:

1) The functional dependence of the transmittance from the total water vapor content for the conditions of Volgograd and Novosibirsk are similar. So, the photometer calibrated for Western Siberia, can be used for measurements in the Lower Volga region. This result was expected.

2) The errors of retrieval of total water vapor content, due to the temperature dependence of the molecular absorption coefficient reached 10%.

3) It is shown that the approximation formula used for retrieval of total water vapor content in AERONET, can lead to errors coming up to 30%. The use of a polynomial function depending of the total water content in the atmosphere from transmittance of atmospheric reduces the error to 10%.

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Пути повышения точности измерения горизонтальной дальности в открытой среде

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Поиск рациональных теоретически обоснованных и практически реализуемых решений измерения дальности в открытой атмосфере представляет несомненный интерес для решения ряда научных и отраслевых задач, актуален для создания высокоточных дальномерных систем метрологического обеспечения средств измерения длины в диапазоне от десятков и сотен метров до нескольких километров. Конкурентоспособные высокотехнологичные системы измерения длин наиболее полно отражены в открытой информации Международного бюро мер и весов (BIPM). Среди них стоит отметить интерференционные измерители длин NPL (Великобритания), METAS (Швейцария), PTB (Германия), NMIJ (Япония), CMS (Китай), NSK IM (Украина), эталон ГЭТ 2-2010 (ВНИИМ). Особое внимание заслуживают системы высокоточных измерений в открытой атмосфере. Развитие дальномерных высокоточных систем объединяет научно-исследовательский опыт в нескольких предметных областях: физическая прикладная оптика, оптические измерения, зондирование и прозрачность атмосферы, взаимодействие лазерного излучения с атмосферным аэрозолем, разработка оптико-электронных приборов научных исследований; лазерная техника и технологии; геодезия, геоморфология, метеорология.

Источники погрешностей измерений включают инструментальную погрешность лазерной оптико-электронной дальномерной системы и составляющие погрешности измерения расстояний. На этапе разработки очень важно понимание причинно-следственных связей источников погрешностей обеих групп, определение степени влияния источников погрешностей на конечный результат, нахождение доминирующих и поиск методов их минимизации. Следует правильно учитывать характер взаимодействия отдельных составляющих суммарной погрешности оптико-электронной системы и измерения. Точностной расчет макета дальномера целесообразно проводить в несколько этапов. Уменьшение инструментальной погрешности дальномера возможно за счет применения высокостабильных источников и приемников лазерного излучения, исключение влияния градиента температур на выходные параметры лазерного излучения – путем термостабилизации с обратной связью, на расфокусировку оптической системы – учетом условия нерасстраиваемости оптического прибора в расчете и выборе оптических компонентов.

Существенное влияние на результат измерения длины имеет значение показателя преломления воздуха. Учет влияния рефракции на кривизну луча требует индикации метеопараметров (температуры, влажности, давления) по всей длине трассы. В работах [1] с использованием уравнений Эдлена теоретически обоснована и экспериментально доказана перспективность метода двухволновой интерферометрии для дистанции 30 метров в стационарных условиях «сухого воздуха» при изменении влажности не более 5%. Показана необходимость учета в расчетах длины (траектории луча от источника до приемника) значения влажности воздуха и парциального давления водных паров.

Прозрачность приземного слоя атмосферы для видимого излучения определяется аэрозольным рассеянием, закономерности и количественные характеристики которого подробно рассмотрены в работах В.Е. Зуева. Фундаментальные исследования количественного определения прозрачности атмосферы в ИК-области (1.3–1.5 мкм) были проведены Фоулем для дстанции 85–170 м в 1908–1917 г. Позднее, в 1918–1951 г., Эльдер и Стронг [2] получили зависимость, описывающую прозрачность атмосферы в 8 «окнах»: 0.7; 0.92; 1.1; 1.4; 1.9; 2.7; 4.3; 5.9; 14.0 мкм, совпадающих с центрами колебательно-вращательных полос поглощения паров воды и CO_2. Интерес к исследованию динамики изменчивости прозрачности атмосферы выражен в экспериментах E. Hinklei по зондированию профиля влажности атмосферы методом дифференциального поглощения с использованием лазерного излучения.

Перспектива эффективности разработки высокоточной дальномерной системы для открытой атмосферы стимулирует развитие разработок в данном направлении. Однако, не стоит забывать о трудоемкости теоретического обоснования, математического моделирования, материализации инженерно-технических решений, значительной стоимости высокотехнологичного оборудования, ответственности и опасности малообоснованных и ошибочно принятых решений.

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Automated System for Monitoring of Atmospheric Path Optical Parameters

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An automated system for monitoring of atmospheric optical parameters is used for determination of optical characteristics of atmospheric paths when testing different optoelectronic systems in atmospheric conditions. The system enables to measure a set of meteorological parameters of the atmosphere at the initial point of the path and to calculate automatically the transmittance and radiance of the atmospheric self-radiation in different spectral intervals of the IR range for the atmospheric paths of interest.

The following characteristics of the atmosphere are measured at the bottom point: pressure, temperature, relative humidity, meteorological optical range. On keyboard inquiry or in automatic mode (access rate makes up 15 seconds) the measured values are transferred to the computing unit. Data about geometrical characteristics of the atmospheric path of interest (the path length and zenith angle) also come to this unit in a manual or automatic code. Then the average values of transmittance and radiance in different spectral intervals of the IR range for these paths are calculated by special software. At that the required characteristics of the upper atmosphere are defined using the relevant model atmosphere (seasonal, latitudinal, regional), and for the lower atmosphere (lower than 12 km) through interpolation of the measured values. A specially developed procedure is used for the aerosol component in the lower atmosphere [1].

In addition to the average values of transmittance and radiance the functions of spectral transmittance and spectral radiance (W/(cm^2·ster·μm)) are calculated for these intervals with the required spectral resolution. Boundaries of the operating spectral ranges correspond to the atmospheric transparence windows (1.8–2.7 μm, 3.2–4.2 μm, 4.5–5.3 μm, 8–12 μm) and can be varied on the customer's request. Estimations of a total absolute error in determination of average transmittance for a vertical path in the 8–12 μm range are presented.

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A Complex MR-32 for Atmospheric Gas and Aerosol Composition Monitoring. II. Monitoring of Atmospheric Aerosol

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Since spring of 2013, operational testing of a complex MR-12 designed for monitoring of atmospheric gas and aerosol composition has been started. The development efforts were made under the order of Roshydromet. They were carried out by specialists of FSBI "RPA "Typhoon" in cooperation with specialists of Kazan State Technical University named after A.N. Tupolev (KSTU) and of the company "Infraspek" from St. Petersburg. The complex MR-32 consists of three modules:

- complex for monitoring of atmospheric gas composition;
- complex for monitoring of atmospheric aerosol;
- complex for data accumulation, archiving and transfer.

The paper presents a complex for atmospheric aerosol composition monitoring. It measures the intensity of direct and scattered by the atmosphere solar radiation. The spectral aerosol optical depth, total column water vapor content in the atmosphere and the Angstrem parameter are determined from these measurements. In future, we are planning to determine the phase scattering function, single scattering albedo and aerosol particles size distribution function.

The complex comprises a solar photometer and an orientation and control system. The solar photometer basis is in two practically identical polychromators on concave holographic gratings with compensated astigmatism and a flat focal plane. The polychromators are located in one casing. A test specimen of such a coupled polychromator was developed and made by the specialists at the Optical and Electronic Department of the KSTU. The photoreceivers of the polychromators are the linear CCDs (TCD1304AP) with the total number of pixels 3648 nm and 340–1000 nm and 440–1000 nm for the blocks measuring the intensity of direct and scattered solar radiation, correspondingly. The spectral ranges are divided by glass absorbing light filters into three bands to avoid superposition of orders. The spectral half-width of the entrance slits is 8 nm. A 12-bit analog-to-code converter is used in the polychromator. The electronic circuit provides the automatic choice of accumulation interval from 10 microseconds to 100 ms. The temperature control inside the polychromator casing is ensured by two thermistors installed in the vicinity of the photoreceivers. At a decrease of temperature below 20^o C inside the casing, inner heaters are switched on automatically.

The stability of the spectral scale during operation is controlled according to the position of O_2 atmospheric absorption band (762 nm). Energy calibration is made with the spectral density standards of brightness and illuminance certified at the ROSSTANDART. The field of view is formed with the help of blinds. The blind of a block measuring the intensity of scattered radiation has a depolarizer, and for the alignment with the needed (1.2°) angle with the field of view of the polychromator – a single-lens objective.

The system of orientation and control consists of a controlling computer and the system of tracking and orientation. It ensures tracking the Sun with the help of four photodiodes at measurements of direct solar radiation intensity, the guidance of the sighting line to a preset point of the sky during the measurements of scattered solar radiation intensity and an automatic control of the operation of the whole complex monitoring aerosol composition of the atmosphere on the basis of a schedule prepared earlier. When the system tracking the Sun loses its sight, the orientation system continues the guidance according to the calculated coordinates of the solar disc. In this case, a corresponding flag appears in the output file. The solar photometer is located in the compartment, the flux of light is transferred with the help of a mirror-prismatic beam guide.

The measurements of direct solar radiation are made in cycles of ten measurements with an optimally chosen accumulation time (averaged later) and at five cycles with the intervals of about 30 s between them. Averaging in a cycle is made by the controlling computer, and output file, formatted in a proper way, is sent to the complex of data accumulation, archiving and transfer. The subsequent processing procedure comprises cloud screening, computations of aerosol optical thickness at several wavelengths (coinciding basically with those accepted by the AERONET system), of water vapor total content and the Angstrem parameter. Time synchronization of the controlling computer is provided by the GPS block in the auxilliary equipment of the data accumulation, archiving and transfer complex.

SESSION 7. "WAVE CHARACTERISTICS, MACROCIRCULATION AND DYNAMICS INTERACTIONS IN ATMOSPHERES OF THE EARTH AND OTHER PLANETS"

Chairman: Prof. **A.I. Pogoreltsev** (RSHU, SPb)
Co-chairmen: Prof. **N.M. Gavrilov** (SPbSU, SPb), Dr. **V.P. Yushkov** (MSU, Moscow), Prof. S.S**. Suvorov** (Mozhaisky MAA, СПб), Prof. **Ch. Jacobi** (University of Leipzig, Institute for Meteorology, Leipzig, Germany)

Splitting of the Stratospheric Polar Vortex in December 2009

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The 2009–2010 Arctic stratospheric winter in comparison to other recent winters is mainly characterized by a Major Sudden Stratospheric Warming (SSW) wavenumber 1 type in the late January. This event led to a large increase of the temperature of the polar stratosphere and to zonal wind reversal. Unlike other Major SSW events in recent winters the westerlies and polar vortex did not restore to pre-warming strength after this Major SSW until the final warming. As a result of it a destruction of the ozone layer inside the stratospheric polar vortex over the whole winter was one of the modest over the past 20 years.

The other distinguishing feature of this winter is the splitting of the stratospheric polar vortex into two lobes in December 2009. Observed 10–17 December splitting was accompanied by an increase of the temperature of the polar stratosphere, weakening of westerlies but without its reverse. The splitting occurred when, in addition to the high-pressure system over northeastern Eurasia - northern Pacific, the tropospheric anticyclone over the north-eastern Atlantic-Europe amplified. Analysis of wave activity in the extratropical troposphere revealed two Rossby wave trains propagating eastward to the northern Atlantic several days prior to the vortex splitting. The first wave train propagated from the subtropics – mid-latitudes of the eastern Pacific over Northern America and the second one propagated from the northern Pacific. These wave trains could contribute to amplification of the tropospheric anticyclone over the northeastern Atlantic–Europe and to the splitting of the stratospheric polar vortex.

A Three-Dimensional Thermosphere General Circulation Model

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This report presents a new global three-dimensional model of the Earth's thermosphere (for altitudes from 90 km to 500 km) with high spatial resolution. A new thermosphere circulation model is created on the basis of the previously developed atmosphere general circulation model (GCM) (including the troposphere, stratosphere, mesosphere, 0–90 km) of the Institute of Numerical Mathematics of the Russian Academy of Sciences (INM RAS). The physical processes description of the thermosphere circulation – the standard equations of geophysical fluid dynamics – are updated with the key physical processes specific to those heights. The system of hydrodynamical equations is numerically solved in the model (the equations of motion for the horizontal velocities, hydrostatic equation, the equation of heat transfer and the continuity equation that represents the conservation of mass law). In this version of the thermosphere model, the temperature and geopotential are calculated as deviations from some average thermospheric vertical profile. Dynamic block of the INM atmosphere circulation model was transformed (pressure is used as vertical coordinate instead of sigma-coordinate).

The key physical processes for the thermosphere are the molecular diffusion and thermal conductivity, the momentum exchange between neutral and charged particles in collisions (the so-called ion-neutral drag force) and pressure gradients generated by inhomogeneity of the molecular composition (formally described in first approximation as variability of average air molecular mass). The interaction of the thermosphere and ionosphere is described directly by the exchange of momentum and energy between the charged and neutral particles in the collisions. Given the strong vertical diffusion and hydrostatic approximation, the contribution of this force in the equations of motion is considered only for the horizontal components of the wind velocities. In thermodynamics, the radiation block is key component of the model, inclusion of which is a separate large problem. In the model a simplified description of the heat sources and sinks is used.

The report describes the computational algorithm and numerical methods used in the model. Numerical stability of the model dynamic (adiabatic) block and analogues of conservation laws are investigated. The emphasis in the analysis of modeling results is laid on the average large-scale thermosphere circulation reproduction and the computational dynamic core work. The numerical experiments describe the reproduction of the thermosphere general circulation for the equinox solar maximum conditions. A comparison with the results the NCAR TGCM model as well as empirical models is made. It is shown that the model reproduces the main features of the thermosphere general circulation with sufficient accuracy (for a given level of heat sources parameterization).

Further development of the model deals with issues of accurate reproduction of radiation balance, taking into account the gas composition variability, specification of the ionosphere parameters, (taking into account the auroral currents in the polar caps). Creation of the ionosphere model block, which takes into account the processes of ionization and recombination, calculates the charged particles motion and their contribution to the radiation sources, as well as the creation of a full-fledged radiation block is a separate large problem. At the same time the thermodynamics of this region is also determined by interaction with the lower layers of the atmosphere, which leads to the problem of constructing a coupled model of the thermosphere and lower atmosphere.

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Analysis of Planetary Wave Disturbances in the System Troposhere-Middle Atmosphere on the Basis of UK Met Office Analysis Data and Cosmic Experiment Radio Occultation Soundings

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Project includes the processing and approximation of radio occultation temperature data on a regular grid for the convenience of further work using the software package developed for the analysis of COSMIC temperature data and meteorological data, assimilated in the UK Met Office model. Planetary waves were subdivided into stationary and traveling ones and analyzed according to their amplitudes, periods and propagation direction. Planetary waves during the winter period of 2008–2011 were considered and characteristics of the waves were compared with data obtained from the UK Met Office analysis.

Analysis of the results suggests that the data on the temperature of the COSMIC experiment is applicable to detect planetary waves in the stratosphere, however, the amplitude of the oscillations in temperature fields characterize conditions of wave propagation mainly.

Influence of the QBO on the Nonlinear Saturation of Planetary Waves in the Stratosphere

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The analysis of the UK Met Office re-analysis shows a strong interannual variability of quasi-stationary planetary waves (SPW) during winter months in the stratosphere. Using a numerical model of the middle and upper atmosphere (MUAM), the stratospheric response to an increase of SPW amplitudes at the lower boundary under different quasi-biennial oscillation (QBO) phases is investigated. The results obtained show that nonlinear wave-mean flow interaction leads to the saturation of the stationary planetary wave with zonal wave number 1 (SPW1) in the stratosphere. The increase of the SPW1 amplitude at lower boundary caused substantial changes of the mean flow in the lower stratosphere at middle and higher-middle latitudes that leads to distortion of the vertical propagation of the wave into the stratosphere.

The results of numerical simulation with the MUAM show that the response of the stratosphere to an increase of SPW amplitudes at the lower boundary substantially depends on the SPW1 amplitude. In the case of larger amplitude at the lower boundary the stratospheric response is nonlinear due to the restriction of wave amplitude originates in the stratosphere that is called the nonlinear saturation. Numerical simulation shows that the nonlinear saturation appears earlier, i.e., under smaller SPW1 amplitude, during the easterly QBO conditions.

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Analyzing the Factors Affecting the Origin and Evolution of Sudden Stratospheric Warmings

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There is no doubt that sudden stratospheric warmings (SSWs) are caused by large-scale dynamic processes in the troposphere. The cause for the SSW evolution may be the orographic or thermal excitation, blockings, eigenoscillations in the lower atmosphere. Quasi-biennial oscillations, low-latitude wave disturbances, solar and geomagnetic activity also affect SSWs. Some researchers mention an inverse effect: the tropospheric circulation response to SSWs.

By using empirical data, we endeavor to reveal the role of different sources in generating SSWs. To estimate the intensity of orographic excitation, we propose an index determined by the heterogeneity underlying surface and the wind speed. It turned out that there is an increase in the index for the lower troposphere several days before SSWs. This feature can be used to predict the stratospheric warmings. We monitored the evolution of blocking situations through blocking index. The origin of blocking or their evolution in some sectors of the Northern Hemisphere contributes to the SSW evolution. The SSW dependence on the blocking and on the orographic excitation simultaneously may be explained by a blocking effect on the structure of jet streams near mountains. SSWs are sometimes followed by the torsional oscillations propagating from the low latitudes. To analyze the spatial structure of the wave and of the vortex energy transport, we used the wave activity three-dimensional fluxes. The wave activity transport typically occurs from the troposphere to the stratosphere before and during SSW. At the SSW final phase, the wave activity 3D flux mainly streams downward.

Numerical Modelling of Stationary Orographic Wave Influence on the Meridional Circulation and Planetary Waves in the Middle Atmosphere

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Generation of stationary orographic gravity waves (OGWs) by the Earth's surface topography and propagation of these waves into the middle and upper atmosphere may lead to the changes in the general circulation, as well as the amplitude and other parameters of planetary waves at high altitudes. The sensitivity of the general circulation of the atmosphere at altitudes from the troposphere to the thermosphere to the effects of the OGWs propagating from the troposphere, is studied. Parameterization of dynamical and thermal effects of stationary orographic gravity waves generated by the Earth's surface topography is incorporated into a numerical model of general circulation of the middle and upper atmosphere (MUAM).

The numerical simulation of the general circulation in the atmosphere and the influence on the meridional and vertical winds exerted by the stationary orographic waves are performed. Changes in atmospheric circulation and amplitudes of planetary waves due to variations of OGW generation and propagation are considered. It is shown that the main OGW dynamical and heat effects occur in the middle atmosphere, where changes in planetary wave amplitudes due to OGWs may reach up to 50%. It is also shown that taking into account the dynamical and thermal effects of OGWs in the numerical model results in the changes in the meridional circulation and related ozone flux of up to 20–30% at the maximum altitude of the ozone layer. To investigate the dependence of orographic wave propagation conditions on the phase of the quasi-biennial oscillation (QBO) of the zonal flow, the background fields and initial conditions typical to western and eastern QBO phases are used in the MUAM calculations. It is shown that changes in zonal flow over the equator significantly affect the conditions of propagation of orographic waves.

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A Study of Mesoscale Cyclonic Vortices Embedded in the South Atlantic Convergence Zone

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The objective of this work is to study the behavior of mesoscale cyclonic vortices (MCVs) over South America, principally those that form in association with the South Atlantic Convergence zone (SACZ), with a view toward identifying the basic characteristics of the formation of these MCVs. Such vortices, embedded in the SACZ cloud band are selected by means of an objective criterion based on the vorticity and circulation of the systems, and was applied from 2000 to 2009, during which period a total of 300 moist MCVs were detected in the lower troposphere and 277 in the upper troposphere. In the lower troposphere the majority of the MCVs are found more to the SW of the continental coastal zone (CCS) of the SACZ and are possibly related to topographic effects and local instability generated by transient systems that penetrate the SACZ region. Other striking features of the MCVs are that a small portion of the total rainfall associated with these systems is of convective origin with the most intense vortices (stronger cyclonic rotation) extending from above the planetary boundary layer (PBL) up to approximately 700 hPa. Also, it is verified that in this region vortices of maximum cyclonic vorticity correspond to extremes of precipitation. A thermodynamic analysis of two selected MCVs in the oceanic regions (OCS) of the SACZ and in the CCS, emphasizes that both systems are associated with an intense transport of moisture to the upper troposphere, from formation until dissipation, when the fluxes of sensible and latent heat are reduced. In this sense, it is believed that they may be more efficient than cyclonic vortices at upper levels in producing heavy rainfall by being close to the surface, where dissipation enhances the convergence. These MCVs extended to more than one level in the troposphere, quickly dissipated and caused precipitation of over 150 mm.

Analyzing Propagation of Low-Frequency Dissipative Oscillations in the Upper Atmosphere

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At a horizontally homogeneous isothermal atmosphere approximation, we have obtained a general ordinary six-order differential equation describing low-frequency linear disturbances in terms of heat conductivity and viscosity of medium. The wave problem may be solved analytically by representing the solution through generalized hypergeometric functions only at a nonviscous heat-conducting isothermal atmosphere approximation. The analytical solution may be used for qualitative and quantitative analysis of propagation of infrasound and internal gravity waves in the real atmosphere; i.e., for classification of waves of different frequencies and horizontal scales by a degree of damping and thus by their ability to appear in observations and in the general dynamics of the upper atmosphere; for investigation into variations of amplitude and phase characteristics during disturbance propagation in a height region with dominant dissipation; for analysis of applicability of the quasi-classical wave description in a medium with exponentially increasing dissipation.

We describe wave and quasi-classical methods for constructing waveguide solutions (non-dissipative ones fitting a range of internal gravity waves) with due regard to wave leakage into the upper atmosphere. We propose a qualitative scheme which formally connects the leakage wave solution to the wave solution in the upper dissipative atmosphere. Spatial and frequency characteristics of dissipative disturbances in the upper atmosphere generated by the waveguide leakage effect are demonstrated to agree well with observed characteristics of middle-scale traveling ionospheric disturbances.

Analysis of Gravity Wave Parameterizations for General Circulation Modeling of the Middle and Upper Atmosphere

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Investigation of coupling between atmospheric layers by waves with different spatial and temporal scales is an important problem of atmospheric dynamics. In this work, we study the influence of internal gravity waves (IGW) on the dynamics and thermal state of the upper atmosphere layers. We performed numerical simulations with the general circulation model of the Middle and Upper Atmosphere (MUAM) using different parameterization schemes for breaking and/or saturation. Results of simulations that employed the parameterization of Lindzen-Holton [1, 2] and spectral schemes of Yigit [3] and Medvedev [4] will be analyzed. We will discuss the advantages and shortcomings of both parameterizations in general circulation modeling of the middle and upper atmosphere.

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Spreading and Features of the Spectral Characteristics of Atmospheric Acoustic Waves in the Foothills and Mountainous Areas in Seismically Quiet Periods and at the Time of Kapchagai Earthquake 2011

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Acoustic waves with the periods about 600 seconds and more are registered in the surface layer of atmosphere and can be generated by gassing from lithosphere cracks at seismic activity increasing, and spread on a long distances [1]. In this regard monitoring of atmospheric waves with the period about 600 s can be used for identification of precursors of the preparation of large earthquakes. Relevance of research of ground atmospheric pressure micropulsations (MGAP) is connected with attempt of identification of the signals coming from the centers of earthquakes and their precursors.

Monitoring of MPAD is carried out continuously in Tien-Shan mountains in the range of frequencies (1/400–1/800 Hz) at the altitude of 3340 m (point 1 – Cosmostation, 43 ° 02' 33.9" N 76 ° 56 '38.1" E) and 2750 m above sea level (point 2 – Radiopoligon Orbita, 43 ° 03' 29.9" N 76 ° 58 '25.0" E), and also in the foothill at the altitude of 850 m (point 3 – Almaty, 43 ° 13' 01.8" N 76 ° 54 '22.1" E). Measurements of MPAD background fluctuations have showed that spectral characteristics of signals from a microbarograph depend on a condition of the surface layer of atmosphere which within a day has a various wave activity. The fluctuations of MPAD don't exceed 2–3 Pa in "quiet days". Sometimes (one-two time a year) train of oscillations and prolonged periodic fluctuations of MPAD of high amplitude to 50 Pa are observed within several hours. It was established that the average frequency of a spectral power of surface MPAD is equal 1/617 Hz at the altitude of 2750 m, – is displaced in area of higher frequencies and is equal to 1/452 Hz at the altitude of 850m. Simultaneous registration of train of oscillations of MPAD with the period of 400–800 s at altitude and foothill (26.01.2012) was executed. It was showed that the speed of spreading of the fluctuations, measured in the mountains between points 1 and 2, was in the range of 10–12 m/s, and the speed of spreading of the same fluctuations between points 2 and 3 equaled 85 m/s.

The analysis of data of MPAD before and during the Kapachagaysky earthquake (01.05.2011, mb=5.4) revealed that the spectral power of MPAD in the range of frequencies from 0.0040 Hz to 0.150 Hz (range of the periods 25–6.6 s) on Radiopoligon Orbita and its envelope significantly increased from the beginning of seismic activity. Pays attention that increasing of spectral power in this interval of frequencies started before 1 hour 18 minuts prior to the first main seismic push. Aftershocks earthquakes following the main push also gave the response in envelope of spectral power of MPAD. The detection features of spectral characteristics of MPAD can be identified, apparently, as a precursor of strong earthquakes – a precursor of the Kapchagaysky earthquake.

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Short-Period Free Oscillations of the Atmosphere

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Theory predicts short-period gravity free oscillations of the atmosphere (FOA) (the ~ 1–5 h period range). The classical theory for FOA yields an asymptotic formula in the limit of high frequencies. This formula predicts the frequency spacing of about 8 μHz between gravity FOAs which differ by one in the meridional index. By now there are only two studies for the period range under consideration, in which signs of this spacing have been revealed in frequency spectra derived from series of both seismometer and microbarometer measurements.

In present study the data on steady oscillations at the considered periods are collected. The data are derived in a variety of ways, namely, by seismic instruments (seismometers, gravimeters, strainmeters, and tiltmeters), microbarometers, and magnetometers. The processing of these data has revealed the frequency spacing of ~ 7–8μHz in spectra for all the seasons with exception of winter. This is evidence that the short-period gravity FOAs exist. The most strong FOAs are during autumn. The processing of the observational data is supplemented by computing the frequencies of gravity FOAs in the “shallow-water” approximation. The applicability of asymptotic formulae is validated as well.

Revealing of Short-Period Global Waves of the Atmosphere from Simultaneous Seismometer and Microbarometer Measurements

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Both the harmonics of thermal solar tide and free oscillations of the atmosphere are studied for the ~ 1–5 h period range. The study is based on continuous co-located seismometer and microbarometer measurements for the full year of 2002 at Collm, Germany (51.3° N, 13.0° E). The raw records have been filtered to eliminate successively oscillations with frequencies less than 40, 80, 120, 160, and 200 μHz . The frequency spectra have been obtained for 5-day segments from the one-year series. The segments are shifted along the series by 1 day. The results of series processing are given in two forms, namely, as frequency distributions for number of spectral peaks for confidence levels of 90 and 99%, and as spectra obtained by multiplying the initial spectra. The dependence of emergence of global waves on season was studied. The existence of gravity free oscillations of the atmosphere at frequencies from 50 to 250 μHz has been established with confidence.

An Observational Study of Temporal Structure in the Atmospheric Thermal Tide

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The thermal tide in the atmosphere presents itself as a collection of quasi-periodic perturbations of dynamical parameters. The natural periods for such perturbations are integer fractions of the solar day, and indeed, spectra of many atmospheric time series clearly show the corresponding peaks. Thus, it is both mathematically convenient and physically meaningful to model the tidal components as simple sinusoids with fixed frequencies. However, in order to reproduce the real-world data, one has to assume that the amplitudes and phases of the sinusoids vary with time. My goal has been to investigate the dynamics of such variations using archival barometric data from several sites.

To obtain the dynamics of amplitudes and phases of several tidal harmonics from a single-station record is a very overdetermined problem with infinitely many solutions. However, under some a priori conditions on the processes underlying the changes in the parameters of the tide it can be solved with the ensemble Kalman filtering. I have applied this technique to the barometric time series from Teddington, Kolm and Saint-Petersburg of more than four years combined duration. Nine highest tidal harmonics have been detected and studied. All showed a remarkably varied phase structure with multiple cross-correlations suggesting their second-order nonlinear interactions. Possible causes for this unsteadiness are discussed, although no conclusive theory has been as yet devised.

The purpose of this work is to draw attention to the study of the volatile non-averaged temporal structure of the solar tide, it being a possible indicator of the dynamical processes in the atmosphere that defy observation by other methods.

The Year-to-Year Variability of Spring and Autumn Transition Dates in Wind Regime of the Mid-Latitude Mesosphere/Lower Thermosphere

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We introduce a definition of the spring and autumn transition dates in wind of the mid-latitude mesosphere/lower thermosphere (MLT) region. The MLT wind data obtained at Obninsk and Collm with radars in 1979 through 20011 are analyzed. The time series of the transition dates do not demonstrate any significant long-term tendency. However the year-to-year date variability significantly correlates (in autumn) or anti-correlates (in spring) with the variability of the Northern Annular Mode index in the stratosphere and troposphere under a definite phase of the quasi-biennial oscillations. The variability of the MLT spring date also significantly anti-correlates with the polar vortex breakup date. Numerical simulations with the COMMA-LIM model confirm the influence of the lower stratosphere and troposphere variability on the variability of the transition dates.

Meteorological Effects in the Stratosphere, Mesosphere, and in Seismic Activity of the Baikal Rift Zone

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We study the troposphere dynamics, the temperature regime in the stratosphere and the mesosphere, the upper atmosphere emission, and seismic activity in the Baikal Rift Zone over 2012 November through 2013 March. Variations in the lithospheric, tropospheric, stratospheric and mesospheric characteristics occurred either simultaneously or with a time lag during this period. We found that the wind speed in the lower atmosphere within the mountain massif area reached a maximum several days before the seismic activity increase in the region. Then, it decreased to a minimum at the earthquake instant. The periods of this seismic activity growth coincided with episodes of stratospheric warmings and with an increase in the 557.7 nm atmospheric emission in the mesosphere and the low thermosphere (85–115 km). We discuss probable processes responsible for the synchronism of the considered parameters' variations.

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Wave Disturbances of Non-Equilibrium Medium: Atmospheric Gas-Solar Radiation

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The behavior of wave disturbances in non-equilibrium medium – the atmospheric gas-solar radiation – taking into account atmospheric structures and radiation flux interrelations was investigated in this work. The dispersion relation of acoustic-gravity waves was found from simplified system of dynamics in the frames of non-equilibrium thermodynamics. Calculations show that the taking into account of solar radiation leads to slowly decreasing of pressure with height than without taking it into account. The maximum deviation of pressure comes to heights of 10–15 km and amounts about 3%.

The dependence of AGW spectra deviation in the non-equilibrium atmosphere from the spectra in equilibrium atmosphere from the height was estimated. It has been found that in the frames of the non-equilibrium the spectra shifts into high-frequency region. Numerical calculations also shows that in the heights of ionosphere these effects shown up sharply at transitionally times at abrupt change of solar energy influx into atmosphere.

Analysis of pressure variations shows the experimental prove of existing of obvious trend of spectra shift into high-frequency region of daytime spectra relatively to nighttime spectra and the difference is 10% and proves the correctness of theoretical calculations.

Comparison of Torsional Vibrations in the Atmosphere, Obtained According to NCEP/NCAR Ranalysis I and ECWMF ERA-40 Data Archives

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In previous studies using NCEP/NCAR Ranalysis I data we found torsional oscillations – variations of the mean zonal flow with time scales ranging from weeks to months, extending along the meridian in the middle and low latitudes. In this paper, we compare torsional oscillations calculated with use two reanalysis archives: NCEP/NCAR Ranalysis I and ECWMF ERA-40. The calculations were based on the information about the zonal wind component on the levels 500, 150 and 10 hPa from 1958 to 2002. On the levels 500 and 150 hPa correlation coefficients have a value of about 0.6 before 1970. Since 1970, the correlation coefficients are increased gradually to 0.9. For the 10 hPa level before 1970 correlation coefficients are in the range 0.3–0.4. After 1970 correlation coefficients are increased to 0.7 by the end of the study period.

Long-term Variations in the Characteristics of the Northern Hemisphere Sudden Stratospheric Warmings in 1975–2013

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Studying the processes in the stratosphere and the stratosphere-troposphere couplings is important and topical when investigating the general circulation of the atmosphere. Sudden stratospheric warmings are the main feature of the winter stratosphere dynamics. They owe their existence to the interaction of tropospheric and stratospheric processes. We address and describe the Northern Hemisphere stratospheric warmings in 1975–2013. Also, we determine the main characteristics for each warming: maximal temperature and geopotential, duration, location (the hemisphere sector where the warming evolved).

SESSION 8. "STRUCTURE OF MIDDLE AND UPPER ATMOSPHERE OF THE EARTH AND OTHER PLANETS"

Chairman: Prof. **S.P. Smyshlyaev** (RSHU, SPb)
Co-chairmen: Prof. **A.I. Semenov** (IFA RAS, Moscow), Dr. **A.M. Zadorozhny** (NGU, Novosibirsk), Dr. **E. Rozanov** (World Radiation Center, Davos, Switzerland)

Mesosphere Temperature Profile Retrieval Based on the Wide-Angle Polarization Measurements of Scattering Radiation during the Twilight Period

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The work is devoted to the study of Earth's mesosphere optical properties based on the measurements of twilight sky intensity and polarization conducted at the latitude 55°N during the spring-summer period of 2011 and 2012 with wide-angle polarization camera (field of view is about 140°). The basic results are obtained in 2012.

The developed method of single scattering separation and calculation of its scattering function is based on observational data over the whole measured part of the sky. The exact polarization analysis of multiple scattering properties helps to subtract it from the total background. Linear relation of Stokes components of multiple scattering is established for the pairs of sky points, symmetrical relatively the plane perpendicular to the solar vertical. Single scattering field is retrieved at the altitude range from 70 to 85 km. Observational analysis had shown that the single scattering polarization in the mesosphere is usually close to Rayleigh value, revealing the domination of molecular scattering. For this case the altitude dependency of pressure and temperature can be obtained.

The temperature values based on the twilight measurements are compared with the satellite infrared emission data (experiment SABER onboard the TIMED satellite, experiment MLS onboard the EOS Aura satellite). The comparison shows that the twilight values are little bit less than SABER ones, but exceed the MLS temperatures (the difference between SABER and MLS data was found straight after the start of EOS Aura mission and reaches 5–10 K in the northern hemisphere during the summer).

The accuracy of temperature measurements and agreement with satellite data show the efficiency of twilight method for the mesosphere temperature control. The problem is actual due to the increase of mesosphere trace gases (first of all, CO_2) density and their influence to the temperature by the radiative cooling process.

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Temperature Variability in the Mesopause Region from Ground-Based Mid-Latitudinal Observations of the Hydroxyl Airglow

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Infra-red spectral observations of the hydroxyl airglow (80–100 km) at Zvenigorod (56º N, 37º E) from 2000 to 2012 and Tory (52º N, 103º E) from 2008 to 2012 have been analyzed to obtain the climatological longitidunal features of temperature variability in the mid-latitudinal mesopause region. The temperature was determined from the rotation-vibration OH(6-2) band. The analyzed parameters are the amplitudes and phases of seasonal harmonics, monthly and nightly variances, caused by the activity of waves of different time scile. The last two parameters are analyzed in relative units, i.e., they are taken as the ratios of variances to the square of temperature, averaged for the corresponding time interval. A comparison of these parameters of the temperature variability for the both observational sites is carried out. It is found that at these sites the mean annual temperatures (T = 191–193 K) and characteristics seasonal harmonics (apart from ter-annual harmonic), amplitudes of which are A1 = 23–24 K and A2 = 5–7 K, are close. Differences are noted in the variances, the values of which are higher at Tory. Especially it is seen in the monthly variances, which at Tory are larger by a factor of 1.9.

The year-to-year variations of the temperature variability parameters are investigated on the base of the data from Zvenigorod. The qusi-beannual and 5.5-year oscillations, dependence on solar activity and long-term trend are established.

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UV Emissions of the Extended Hot Atom Coronae of Terrestrial Planets

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Solar forcing on the upper atmospheres of the terrestrial planets via both UV absorption and atmospheric sputtering results in the formation of an extended neutral corona populated by the suprathermal (hot) H, C, and O atoms (see, e.g., [1]). The hot corona, in turn, is altered by an inflow of the solar wind/magnetospheric plasma and local pick-up ions onto the planetary exosphere. Such inflow results in the formation of the superthermal atoms (energetic neutral atoms – ENAs) due to the charge exchange with the high-energy precipitating ions and can affect the long-term evolution of the atmosphere due to the atmospheric escape.

The origin, kinetics and transport of the suprathermal H, C, and O atoms in the transition regions (from thermosphere to exosphere) of the terrestrial upper atmospheres are discussed. Reactions of dissociative recombination of the ionospheric ions CO_2+, CO+, and O_2+ with thermal electrons are the main photochemical sources of hot atoms. The dissociation of atmospheric molecules by the solar UV radiation and accompanying photoelectron fluxes and the induced exothermic photochemistry are also the important sources of the suprathermal atoms. Kinetic energy distribution functions of: (a) suprathermal atoms were calculated using the stochastic model of the hot planetary corona [2]; (b) superthermal (ENA) atoms were calculated using the Monte Carlo model [3] of the high-energy proton and hydrogen atom precipitation into the atmosphere. These functions allowed us to obtain and compare the space distribution of suprathermals in the transition regions of Venus, Earth and Mars and to calculate the UV emissions. Recent observations of the Ly-alpha H emission by the SPICAM instrument onboard Mars Express spacecraft showed the presence of hot and thermal fractions of atomic hydrogen in the extended corona at Mars. Collisional coupling between light hydrogen and hot heavy atoms is considered in calculations as an important additional source of the suprathermal hydrogen atoms in the corona. Results of calculations were also compared with the observations of the UV emissions by the UV spectrometer of SPICAM (SPICAV) instrument and ENA spectra measurements made by ASPERA-3 (ASPERA-4) instrument onboard of the ESA Mars Express (Venus Express) spacecraft.

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Some Aspects of Quasidecadal Oscillations of Total Ozone, Geopotential Height and Temperature During Solar Cycles 23–24

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Quasidecadal oscillations (QDO) in total ozone (TO) were analyzed early in many papers. Possible association of these oscillations with 11-year sun activity (SA) was marked in numerous statistical and modeling studies. Though solar irradiance varies slightly over the 11 year cycle, solar cycle length (if to exclude the abnormal periods such as Dalton or Maunder minima) vary from 10 to 12 years. Comparison of the phase between SA and TO QDO shows a number of interesting features [1]. Before 1960-s maxima of TO QDO lag behind corresponding maxima of SA and can be even close to an antiphase. During 1970-s years almost synchronous variations were observed. During subsequent solar cycles maxima of the total ozone QDO began to outstrip maxima of solar activity.

Variations of solar activity in the XXI century are unique and are similar to Dalton minimum in the beginning of XIX century. Cycle 23 of the solar activity had a maximum approximately in 2001 and lasted 3 years longer than cycle 22 up to the end of 2009. Cycle 24 maximum probably takes place in 2012. If solar activity depends on total ozone QDO then the next total ozone maximum also should come with a significant delay. But if total ozone QDO is caused by other mechanisms, for example by the own oscillation of the Earth climatic system, then tendency found in [1] should be kept, i.e. the next ozone maximum should significantly outstrip the cycle 24 maximum. It can be suggested that similar phase relations exist for other ozone correlated parameters of the upper troposphere-lower stratosphere.

To verify this hypothesis the phase relations between quasidecadal oscillations of solar activity, total ozone, temperature and geopotential height are analyzed by the composite method [1, 2]. The data set used in the present study are monthly mean values of the total ozone (Aroza, from 1932 to 2012), temperatures and a geopotential heights over Aroza (NCEP-NCAR, from 1949 to 2012) and international index of sunspot numbers (SIDS-team). Results obtained have shown that total ozone had a maximum in 2009 and at present time ozone QDO are in an antiphase to solar variations. The temperature and geopotential height quasidecadal oscillations at 50-100 mb lag behind total ozone with phase shift approximately for 1–2 years and during the last years they also vary approximately in antiphase with solar activity. The period through which sign of the correlation between total ozone and 11-year solar cycle inverted is about 38–40 years. At upper pressure levels these tendencies remain for geopotential height but for temperature they will more complicated.

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Моделирование влияния солнечной активности на межгодовую изменчивость содержания озона и температуру атмосферы

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Modeling of the Solar Activity Impact on the Atmospheric Ozone and Temperature Interannual Variability

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Одиннадцатилетний цикл солнечной активности приводит лишь к незначительным вариациям солнечной постоянной в пределах десятых процента, однако в ультрафиолетовой области спектра изменчивость потоков солнечной радиации может достигать процентов и даже их десятков. Такая изменчивость может оказать существенное воздействие на состав и структуру атмосферы. В настоящей работе химико-климатическая модель нижней и средней атмосферы используется для исследования физических и химических процессов, определяющих изменчивость температуры и состава атмосферы в зависимости от уровня солнечной активности. Приводятся результаты модельных численных экспериментов, в которых подключалось и отключалось влияние солнечной активности на нагрев и химию средней атмосферы. По результатам модельных экспериментов приводятся численные оценки чувствительности состава и температуры атмосферы к изменчивости солнечной активности.

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Модельное исследование глобальных эффектов вулканических выбросов в стратосферу

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A Model Study of the Global Effects of Volcanic Eruptions to the Stratosphere

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Вулканические выбросы оказывают существенное влияние на химический состав и радиационный режим атмосферы в районе выбросов и прилегающих регионах. При этом в большинстве случаев эти эффекты являются краткосрочными и перестают ощущаться уже через несколько месяцев после извержений вулканов. Однако в некоторых случаях вулканические выбросы достигают стратосферы, и тогда их воздействие на состав и структуру атмосферы может продолжаться в течение нескольких лет, причем может ощущаться глобально в результате переноса продуктов вулканических выбросов общей циркуляцией атмосферы. Основное влияние вулканических выбросов на атмосферу происходит в результате радиационных и химических эффектов формирующегося в результате извержений сульфатного аэрозоля, который поглощает и рассеивает солнечную радиацию и создает условия для гетерогенных химических реакций на его поверхности.

В настоящей работе физические и химические эффекты увеличения содержания стратосферного аэрозоля после крупных вулканических выбросов исследуются с помощью глобальной химико-климатической модели нижней и средней атмосферы. Межгодовая изменчивость содержания стратосферного аэрозоля задается по данным спутниковых измерений SAGE, а химико-климатическая модель, учитывающая влияние аэрозоля как на радиацию, так и на химию атмосферы, используется для расчетов изменчивости содержания озона и температуры тропосферы и стратосферы в период крупных вулканических выбросов конца XX века.

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Численное моделирование влияния арктических выбросов метана на изменение состава и структуры атмосферы

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Numerical Modeling of the Arctic Methane Emissions Impact on the Atmospheric Structure and Composition

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Выбросы метана из Арктических газовых гидратов в атмосферу, с одной стороны, могут повлиять на радиационный режим, а с другой стороны, оказать возмущение на химию атмосферы. В результате этого могут возникать положительные и отрицательные обратные связи между изменениями температуры и химического состава как Арктической атмосферы, так и в глобальном масштабе. Положительные обратные связи могут приводить к еще большему увеличению концентрации метана и температуры атмосферы. Отрицательные обратные связи могут смягчить эффекты влияния метана на климат и химический состав атмосферы. Помимо этого, в результате влияния метана на содержание гидроксильных радикалов в приземном слое атмосферы, для которых метан является одним из основных разрушителей, может ухудшиться способность нижней атмосферы к самоочищению. В результате этого может ухудшиться экологическая ситуация в регионе выбросов метана не только в результате увеличения его концентраций, но и за счет увеличения концентраций других компонентов, разрушение которых происходит в результате химических реакций с гидроксильными радикалами.

В настоящей работе выполнено модельное исследование влияния выбросов метана на химию и радиационный режим средней атмосферы.

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Влияние гетерогенных реакций на отклик атмосферы на аэрозольное воздействие в стратосфере

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Heterogeneous Reactions Impact on the Atmosphere Response to the Stratospheric Aerosol Forcing

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Совместная химико-климатическая модель атмосферы [1] используется для оценки роли гетерогенных реакций в формировании отклика атмосферы на температурный режим атмосферы и содержание озона. Показано, что в противовес к радиационному эффекту вводимого в стратосферу сернокислого аэрозоля, когда температура стратосферных слоев возрастает, гетерогенные реакции приводят к убыванию температуры этих же слоев. Однако если радиационное взаимодействие с ростом концентрации аэрозоля способствует непрерывному росту температуры, то гетерогенные эффекты убывания температуры с ростом концентрации аэрозоля быстро насыщаются, перестают меняться, достигнув некоторого порогового значения. В результате с ростом концентрации частиц аэрозоля все же начинают преобладать радиационные эффекты, и температура стратосферы в итоге возрастает. При этом на коротковолновый баланс радиации на верхней границе атмосферы гетерогенные реакции влияют слабо. То же можно сказать и об уходящей длинноволновой радиации с верхней границы атмосферы.

По данным наблюдений временной ход аномалий температуры нижней стратосферы четко показывает влияние вулканических выбросов Эль-Чичон (1981) и Пинатубо (1991) на изменение температуры аэрозольных слоев. Если в модели учитываются гетерогенные реакции, то эти выбросы сказываются на изменениях температуры слабо. Гетерогенные реакции сглаживают влияние вулканов. Если же в модели отключить гетерогенные реакции, оставив только радиационное взаимодействие, то влияние вулканов в поле температуры проявляется очень хорошо.

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Seasonal Variation of Aerosol Vertical Distribution in the Martian Atmosphere and Detection of the Bimodal Distribution from Solar Occultations on Mars-Express

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Dust cycle is one of the most important in the Martian climate system. Martian dust, consisting mainly of mineral particles, lifts from the surface by winds and dust devils. Being active radiation, dust with water clouds is involved in the heating and cooling of different atmospheric layers, absorbing, scattering and re-radiating solar radiation in the thermal infrared. Furthermore, the dust particles are condensation nuclei for the formation of water and CO_2 ice clouds.

We will present results of long-term observations of the Martian atmosphere by solar occultation technics in the near-IR range. SPICAM spectrometer on board the Mars Express spacecraft has been working on the orbit of Mars since January 2004. During the four Martian years 800 solar occultations have been performed. SPICAM spectral range allows simultaneous observations of 1.43 µm CO_2 band for the atmospheric density, the 1.38 µm absorption band of water vapor to get the H_2O density, and the distribution of aerosols with altitude measuring the opacity of the atmosphere in the spectral range from 1 to 1.7 µm. In the experiment, aerosol extinction profiles have been obtained at altitudes from 0 to 90 km with a vertical resolution of 2 to 10 km depending on distance to limb. We also consider their seasonal and latitudinal variations. Retrieved values of effective radius vary from 0.1 to 1.5 µm.

Special attention was paid to the summer in the northern hemisphere, where the water vapor supersaturation in the middle atmosphere has been recently discovered (up to the values of S = p/psat ~ 3–5) [1]. Simultaneous analysis of aerosol extinction in the UV and IR range at different altitudes during this period has enabled the first direct detection of a bimodal distribution of Martian dust particles with characteristic radius of 0.04–0.07 µm and 0.7–0.8 µm. The number density of small fraction varies from 103 cm^{-3} at 10 km to 10 cm^{-3} at 40 km. The concentrations and the effective radius of the particles correspond to the Aitken particles in the Earth's atmosphere. Unfortunately, the spectrometer cannot determine the nature of the particles, so dust and ice particles were considered. Such concentration of small particles in the presence of a large fraction should be unstable to coagulation process, The coagulation time for obtained bimodal di stribution varies from 1 to 50 days, which requires a source of particles. If it is not the condensation phase, the particles lift from the surface. The sedimentation time varies from 100 to 1000 days (for particles 0.1 microns and 0.01 microns, respectively) at 20 km and 10 to 100 days at 40 km, and these particles may be transported by Hadley cell from the northern to the southern hemisphere in the observed period of the summer solstice in the northern hemisphere.

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Peculiarities of Altitude Ozone Distribution over Moscow in 2011–2013 from Millimeter-Wave Observations

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New results of investigation of vertical ozone distribution (VOD) in the stratosphere over Moscow are presented for time of considerable depletion of the ozone layer in the Northern hemisphere in spring 2011 as well as for periods of strong disturbances in stratospheric circulation under sudden stratospheric warmings (SSW) in 2012 and 2013. Measurements of the VOD were done at millimeter waves by means of high-sensitive LPI radio spectrometer [1]. Maps of geopotential height, potential vorticity and temperature in the stratosphere [2] were used for analysis of the observational data.

Altitude-temporal distribution of ozone volume mixing ratio (VMR) C_{O3} over Moscow was drawn from results of the regular measurements. The most noticeable changes in ozone were observed in cold half-years. At the beginning of January 2012 polar vortex air was in the stratosphere over Moscow. Ozone VMR in the air was decreased. For example, it was about of 4.1 ppm at altitude of 35 km at January 4, 2012. Then C_{O3} began to grow and reached 7.6 ppm at January 20, 2012. The change in the ozone layer was connected with midwinter SSW, with increase in planetary wave harmonic $n = 1$. Ozone increase in January 2012 observed at millimeter waves resulted from the fact that air at altitude of 35 km occurred out of the vortex. The midwinter SSW happened in 2013 too. The stratospheric polar vortex divided into two parts. This corresponded to increase in planetary wave harmonic $n = 2$. The most noticeable change in the VOD profile over Moscow was observed at altitude of 30 km between January 6 (stratosphere over Moscow inside the vortex) and January 16, 2013 (out of the vortex). At January 6 ozone VMR was decreased to $C_{O3} = 4.3$ ppm, and at January 16 it grew up to 7.2 ppm.

The dominant feature of the stratospheric circulation in cold half-year 2010–2011 was long-life intensive polar vortex without midwinter SSW. Values of the ozone VMR C_{O3} in the vortex air at altitude of 30 km over Moscow in the cold season varied from 4.6 to 5.3 ppm. An important peculiarity of the 2010–2011 cold half-year was appearance the vortex air with decreased by 30-35% stratospheric ozone over Moscow at March 30 and April 7, 2011. An edge part of anomalously depleted ozone region appeared over Moscow in the days, while center of the depleted region was located at high latitudes [3]. Interannual differences of altitude-temporal ozone distributions in cold seasons 2010–2011, 2011–2012 and 2012–2013 were related with differences of dynamical processes and peculiarities of evolution of polar stratospheric vortexes in the seasons.

Radio physical methods of monitoring of the vertical ozone distribution provide unique data on processes in the ozone layer including events of severe ozone depletion inside the stratospheric polar vortex as well as strong disturbances resulted from stratospheric warmings.

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Water Vapour and Clouds in the Arctic Stratosphere: Unprecedented Observations of Water Vertical Redistribution in the Polar Vortex in January 2010

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We present high-resolution measurements of water vapor, aerosols and clouds in the Arctic stratosphere in January and February 2010 carried out by in situ instrumentation on balloon-sondes and high-altitude aircraft combined with satellite observations. The measurements provide unparalleled evidence of dehydration and rehydration due to gravitational settling of ice particles. An extreme cooling of the Arctic stratospheric vortex during the second half of January 2010 resulted in a rare synoptic-scale outbreak of ice PSCs (polar stratospheric clouds) detected remotely by the lidar aboard the CALIPSO satellite. The widespread occurrence of ice clouds was followed by sedimentation and consequent sublimation of ice particles, leading to vertical redistribution of water inside the vortex. A sequence of balloon and aircraft soundings with various types of hygrometers (including balloon- and aircraft-borne versions of Russian fluorescent hygrometer) and backscatter sondes conducted in January 2010 within the LAPBIAT and RECONCILE campaigns captured various phases of this phenomenon: ice formation, irreversible dehydration and rehydration. Consistent observations of water vapor by these independent measurement techniques show clear signatures of irreversible dehydration of the vortex air by up to 1.6 ppmv in the 20–24 km altitude range and rehydration by up to 0.9 ppmv in a 1 km-thick layer below. Comparison with space-borne Aura MLS water vapor observations allow to derive and upscale the spatiotemporal evolution of dehydrated air masses within the Arctic vortex.

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Trajectory Modeling of Atmospheric Tracer Vertical Profiles

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The method of trajectory reconstruction of water vapor profiles based on reanalysis ECMWF data was developed to compare these profiles with observations and to study their laminated vertical structure. 10-day backward trajectories were initiated at observational locations on different potential temperature levels. Then gridded ECMWF data of specific humidity were interpolated into the end points of trajectories and were advected in forward direction as tracers to the points of observations. In the lowermost stratosphere the water vapor is mainly controlled by advection.

The water vapor profiles obtained during LAUTLOS campaign by FLASH-B hygrometer on February of 2004 in Sodankyla (67.40º N, 26.60º E) have been used for validation of reconstruction method. ECMWF specific humidity and potential vorticity have been used as passive tracers. The results clearly demonstrate the advantages of using the trajectories instead of linear interpolation of gridded data to reproduce the laminated structure of vertical profiles. The observed water vapor laminae are primarily caused by differential advection. In the middle stratosphere such laminae are usually observed near the vortex-edge region where the air masses from the vortex interior and exterior exist at adjoined vertical levels. In the lowermost stratosphere near the tropopause the laminae are caused by the entrance of the humid tropospheric air into the stratosphere. Reverse domain filling (RDF) method was used to get the horizontal structure of the vortex filamentation. RDF method is similar to reconstruction method, but the backward trajectories were initiated in the nodes of the grid with high resolution at the fixed potential temperature level. This method visualizes the filaments responsible for existence of laminae.

To reconstruct the water vapor profile in tropical upper troposphere-lower stratosphere (UTLS) the trajectory model was coupled with cirrus parameterization scheme including the processes of homogeneous nucleation, growth/sublimation of ice particles and their sedimentation causing the dehydration of air masses. Model results are also compared to FLASH-B hygrometer data. Lagrangian trajectories with turbulence parameterization were applied to simulate the CO_2 and relative humidity vertical profiles over Fyodorovskoe (56º N;33º E) where aircraft observations of these parameters were conducted and CO_2 vertical profiles over Domodedovo airport (55.40º N; 37.90º E) to compare them to aircraft observations obtained in frame of CONTRAIL Project. We applied the modified trajectory model to calculate backward trajectories based on ERA-Interim winds and initialized using ERA-Interim specific humidity and CarbonTracker CO_2 concentrations.

All comparisons of modeled and observed profiles demonstrate the better agreement than in the case of bilinear interpolation of surrounding gridded values to observation point at the time of observations.

Long-Living Component of Microparticles Streams in the Near Space

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When microparticle moves along an equatorial orbits around the Earth a transformation of the orbit occurs due to the solar light pressure. Such particles drop into the atmosphere after several turns around the Earth [1]. The microparticles lifetime is proportional to particle's mass and depends on the orbit apogee. Other situation takes place in the case of inclined orbits. The microparticles lifetime can essentially grow. For orbits with a low perigee this time is determined by friction of particles in the atmosphere in a perigee section of trajectory [2].

Calculations of lifetime for microparticles in the orbits with a high perigee are fulfilled. The gravitational fields of the Earth, Moon and Sun; the electrical and magnetic fields of the magnetosphere, the microparticle's charging in a gas-plasma medium and under the influence of visible and ultraviolet light of the Sun; and the solar light pressure were taken into account. The trajectories of microparticles with sizes 0.1–100 µm in the near space were considered. The three-dimensional model of the magnetosphere and self-consistent model of microparticles charging for various configuration and particle's types (dielectric and electroconductive) is used.

Presence of long-living microparticles in inclined orbits with high perigee is confirmed. The magnification of microparticles lifetime occur due to solar pressure [2]. The microparticles lifetime is regulated by charging and plasma friction. Rate of falling off the inclined orbits with high perigee is of 2–5 orders below then for orbits with the low perigee. It means that time of their natural self-cleaning exceeds ten thousand years.

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Rotation-Vibration Linelist of $HD^{16}O$ For Investigation Of the Terrestrial Planets Atmospheres

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Infra-red spectroscopy represents one of the remote sensing methods for determining the $HD^{16}O$ contents in the atmospheres of planets, and the results obtained are interpreted using the HITRAN and GEISA databases (DB) adapted for studies in the Earth atmosphere. Unfortunately, these databases are incomplete: there are gaps in wavenumbers and intensities depending on the spectral region, while the line shape parameters represent averaged values or entirely missing. Unlike Earth, atmospheres of Mars and Venus consist, mainly, of the carbon dioxide, CO_2 (~ 96%), and have different range of the pressure and temperature variations, which complicates the use of available DB. Recently, a number of papers dealing with the line broadening of water vapor and its isotopologues in the CO_2 atmosphere have been published (see, for example, [1]). These studies, however, involved specific spectral regions and were not generalized on the total spectral range.

This paper is aimed at generation of the complete absorption linelist of $HD^{16}O$ isotopologue assigned for modeling its spectrum in the atmospheres of Earth, Mars, and Venus in the 0–26000 cm^{-1} spectral region. The linelist includes line shape parameters caused by self-, CO_2 -, and air-broadening, as well as the temperature dependence coefficients. This list is based on the $HD^{16}O$ variational linelist known as VTT [2]. Application of the VTT linelist made already it possible to refine the water vapor contents at Venus' surface by taking into account the previously unknown weak absorption bands of $HD^{16}O$ in the 1.05–1.2 μm region [3]. Self- and air-broadening parameters were taken from [4]. The rovibrational labeling established in [5], as well as that provided by the spectra.iao.ru database was used to label majority of VTT lines stronger than 10^{-25} cm/molecule. Reliable rotation-vibration labeling allowed to calculate the linewidths more accurately. VTT line positions were changed, where possible, on the differences between the experimental upper and lower energy levels using the energy levels set from [5]. Calculations of the $\gamma(HD^{16}O\text{-}CO_2)$ depending on the complete set of rotation-vibration quantum numbers have been performed using semi-empirical approach [6], which has been widely used earlier for calculations of the broadening coefficients for different kind of mixtures: H_2O -N_2 (O_2, H_2O), O_3-N_2(O_2), CO_2-N_2 (O_2, N_2O), see, for example, [7].

VTT linelist as well as estimates of the line shape parameters $\gamma(HD^{16}O\text{-}HD^{16}O)$ and $\gamma(HD^{16}O\text{–air})$ are published on the websites ftp://ftp.iao.ru/pub/VTT/ and http://www.exomol.com/molecules/H2O.html. Estimates of the isotope composition of water vapor for Earth, Venus, and Mars (normalized to unit) will also be presented in poster. Data on $\gamma(HD^{16}O\text{-}CO_2)$ as well as the temperature dependence coefficients in case of HDO-CO_2 broadening are available from the authors on request.

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Lidar and Satellite Temperature Measurements during the Sudden Stratospheric Warmings over Siberia and the Russian Far East in 2008-2013

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The report presents the comprehensive study of disturbances of temperature regime of the Earth’s stratosphere, which are related to sudden stratospheric warmings over Western and Eastern Siberia and the Russian Far East in winters 2008–2013. The study is based on data obtained using temperature remote sensing techniques (lidar and satellite ones). The analysis rests on data on vertical temperature distribution in the stratosphere, obtained from lidar measurements over regions of Tomsk (56° N, 85° E), Yakutsk (61° N, 130° E), and Paratunka, the Kamchatka territory (53° N, 158° E). For the complex analysis of the spatial-temporal temperature distribution in the middle atmosphere, the lidar measurement data are applied along with satellite data on temperature acquired by Microwave Limb Sounder (MLS) on the EOS Aura satellite. We consider the regional effects of sudden stratospheric warmings that were observed over the Asian region of Russia (~ 85–160º E) in winters 2008–2013.

There were stratospheric warmings over the Asian region of Russia each winter during the period under consideration, as deduced from lidar and satellite measurements of temperature. Lidar and satellite measurements of temperature have evidenced the previously known peculiarities of development of winter stratospheric warmings. On the whole, agreement between lidar and satellite measurements of height distribution of temperatures is satisfactory. Possible reasons of the divergences under consideration are discussed.

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Lidar Observations of Stratospheric Aerosol after the Chebarkul Meteorite Fall

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Passage of Chebarcul meteorite above Chelyabinsk city at 15 February 2013 had a wide public resonance and aroused interest of researches of different speciality. Meteorite mass was estimated by 10 000 tons. Meteorite explosion in stratosphere leaved aerosol trace which could be registered by lidar sounding method as described in [1].

In this thesis the results of lidar observations of high-altitude aerosol layers appeared in atmosphere in Moscow, Obninsk and Yakutsk after Chebarcul meteorite fall. Trajectory analysis of air mass transfer had shown that observed layers were carried from meteorite falling area. First aerosol traces of meteoric origin were registered by Obninsk lidar station at 18 February at altitude about 42 km. Then layers had been observed at 21–26 February at altitudes of 34–38 km. Analogous results were obtained in Moscow at a distance of 110 km from Obninsk. After the meteorite fall thin aerosol layer was registered above Yakutsk at 20 February, 14:00 UT at altitude 39.5 km. After the meteorite fall the lidar observations in Tomsk were carried out at 16, 20, and 21 February. No evident layers were registered in these observations.

To analyze the origin of registered stratospheric aerosol calculations of isentropic trajectories of air masses were carried out as described in [2]. The trajectories started from the coordinates of the meteor trail, estimated by Czech scientists by the videos of meteorite fall [3]. Air mass moving occurred in the east, in accordance with the rotation of the circumpolar vortex in the winter season. The highest velocity had the air masses at altitudes 42–44 km, they came to Obninsk and Moscow at 18–19 February at the altitudes of aerosol observations, going around the North Pole. It should be noted rather good agreement between altitudes of passing of calculated trajectories of air masses near Obninsk, and altitudes of aerosol observation.

The estimate of data errors influence on trajectory modeling results, carried out by the Monte-Carlo method, showed that at the altitudes of 30-40 km the random dispersion of trajectories in five days was about 300 km, and in ten days was 300–800 km. The nearest distances from the observation points to the trajectories had the same order, therefore they can be used as a criterion that trajectories reached an observation point. Thus, the analysis of the calculated air mass trajectories had shown that stratospheric aerosol observed from 18 February 2013 by the network of lidar stations at latitudes of 55-65N apparently had the meteoric origin.

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Classes of Particles Levitating in the Atmosphere under Gravito-Photophoretic Forces

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The explanation of the existence of aerosol layers at certain altitudes in the middle atmosphere involves photophoretic (gravito-photophoretic) forces [1–2]. Meanwhile, these forces are theoretically poorly understood. Earlier we have analyzed the motion equations for aerosol particles and clusters absorbing solar radiation [3]. Calculations were carried out on the basis of Monte Carlo algorithms [4] and free-molecular-mode approximation. It was shown that Rohatschek's particles used for explanation of gravito-photophoresis since 1955, can levitate if pressure is less than 500 Pa. It corresponds to the stratosphere. At low pressures due to weakness of viscous friction the loss of stability of particle's orientation takes place and an average projection of photophoretic force on the vertical axis (gravito-photophoretic force) become less than the force of gravity. It has been found that there is an asymmetric form of aerosol particles which can levitate at low pressures corresponding to the upper stratosphere or mesosphere. Levitation mechanism for such particles differs from that for Rohatschek's particles [3]. The particles preferential orientation in space arises in the rotational state, the average projection of photophoretic force on the vertical axis may be greater than the force of gravity.

In this report we present the results of finding the extended class of aerosol particles that can levitate at low pressures. Aerosol aggregates are representative of this class. The simulation showed that the clusters consisting of spherical particles can stably levitate in the atmosphere up to an altitude of 70 km. A photophoretic force acting on a cluster is body-fixed force. Levitation takes place due to arising of gravito-photophoretic force. Previously, we described this type of gravito-photophoresis as delta T-gravito-photophoresis [5]. Initially the temperature difference over the particles in the cluster arises due to difference of optical characteristics of the particulars materials. Now we consider a case when the particles temperatures differ due to the differences in their sizes. Thus, it was shown the fundamental possibility of stable levitation of aerosol aggregates in the middle atmosphere due to the gravito-photophoresis forces.

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SESSION 9. "PHOTOCHEMISTRY AND KINETICS OF EXCITED STATES OF ATOMS AND MOLECULES AND NON-LTE RADIATION IN THE ATMOSPHERE OF THE EARTH AND OTHER PLANETS"

Chairman: Prof. **N.N. Shefov** (IFA RAS, Moscow)
Co-chairman: Dr. **V.A. Yankovsky** (SPbSU, SPb)

Infrared Radiation in the Mesosphere and Lower Thermosphere: Energetic Effects and Remote Sensing

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The translational degrees of freedom of atmospheric molecular and atomic gaseous compounds represent the heat reservoir. This reservoir obtains or loses energy due to a number of sources and sinks, among them heating and cooling related to various types of mass motions, redistribution of energy released in the course of various photochemical reactions (the translational energy, the chemical energy and the nascent electronic, vibration and rotational energy of the reaction products), and absorption and emission of the infrared (IR) radiation. In the latter case, one deals with interaction between matter and the IR radiative field, which, for the case of the mesosphere/lower thermosphere (MLT), includes the atmospheric radiation formed in these layers, the upwelling radiation from the ground and lower atmosphere, and, during daytime, the IR solar radiation.

In this talk, we address the energetic effects of IR radiation in the MLT and its radiative coupling with lower atmosphere by analyzing the interaction between IR radiation and matter. In the MLT, this interaction is strongly affected by the situation when vibrational (and in its upper part also rotational) excitation of the molecules does not obey Boltzmann's law with the local kinetic temperature. As a result, the IR radiation emitted in these layers does not reflect the thermal state of the matter. This situation is referred to as the breakdown of local thermodynamic equilibrium (LTE) for the vibrational (or rotational–vibrational) degrees of freedom. Detailed treatment of non-LTE plays a crucial role for estimating thermal effects of the IR radiation as well as for the diagnostics of space-based IR observations.

We discuss the peculiarities of the non-LTE radiation formation in the IR bands of CO_2, O_3, and H_2O molecules, estimate radiative cooling/heating rates for typical atmospheric scenarios, and analyze the sensitivity of the MLT radiative energy balance to various mechanisms of populating/depopulating molecular vibrational levels. We also consider radiative pumping and small-scale gravity wave effects, which couple the MLT with the lower atmosphere.

Altitude-Latitude Distribution of Atmospheric Bands Emissions Intensities of Oxygen Molecules $O_2(b^1\Sigma^+{}_g$, v=0, 1, 2)

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Besides of well known methods of remote sensing of altitude distribution of ozone in the mesosphere and lower thermosphere (MLT) from measurements of oxygen atmospheric bands intensities of $O_2(b^1\Sigma^+{}_g$, v=0) and $O_2(a^1\Delta_g$, v=0) we worked out methods of remote sensing of altitude distribution of ozone from measurements of oxygen bands emissions intensities of

$O_2(b^1\Sigma^+_g$, v=0, 1) and of altitude distribution of atomic oxygen from bands emissions intensities of $O_2(b^1\Sigma^+_g$, v=0, 1, 2) [1].

The objective of this study is the creation of models of altitude-latitude distribution of atmospheric bands emissions intensities of oxygen molecules $O_2(b^1\Sigma^+_g$, v=0, 1, 2) for four seasons. In the calculations we used the atmospheric models from the series of events TIMED-SABER satellite experiment (version 1.07 and version 2.03). For detail analysis of altitude dependences of electronic-vibrational levels $O_2(b^1\Sigma^+_g$, $v\leq 2$) populations in the mesosphere and lower thermosphere the last version of the model of electronic-vibrationally excited products of photodissociation of ozone and molecular oxygen YM-2010 [1, 2] is used. We consider the system of kinetic equations for four levels: three electronic-vibrationally excited levels $O_2(b^1\Sigma^+_g$, $v\leq 2$) and the first vibrationally excited level of atomic oxygen $O(^1D)$. Besides of formation of excited states $O_2(b^1\Sigma^+_g$, $v\leq 2$) at O_3 photolysis in the Hartley band and O_2 photolysis in the Schumann-Runge continuum and Lyman-alpha line, the excitation of three vibrational levels of electronic state under consideration $O_2(b^1\Sigma^+_g$, v) by direct absorption of solar radiation in the bands 762, 689, 629 nm are also taken into account. All processes of quenching of excited states $O_2(b^1\Sigma^+_g$, $v\leq 2$) and $O(^1D)$ at collisions with molecules $O(^3P)$, O_2, N_2, O_3 and CO_2 are considered. As a whole 27 processes of $O_2(b^1\Sigma^+_g$, $v\leq 2$) and $O(^1D)$ excitation and deactivation are included in the model. We used spectra of solar radiation in the interval 120–310 nm from the base SOLAR2000 for the date and time corresponding with the data of measurements of TIMED-SABER experiment. The calculations are performed for transitions Atm (2-0) $O_2(b^1\Sigma^+_g$, v=2 $\rightarrow X^3\Sigma^-_g$, v=0) at 629 nm, Atm (1-0) $O_2(b^1\Sigma^+_g$, v=1 $\rightarrow X^3\Sigma^-_g$, v=0) at 689 nm and Atm (0-0) $O_2(b^1\Sigma^+_g$, v=0 $\rightarrow X^3\Sigma^-_g$, v=0) at 762 nm for altitude interval 60–120 km for four seasons (fall and vernal equinox, winter and summer solstice) and Solar zenith angles from 0 to 80°. The analysis of results of numerical statistical experiment shows that these emissions could be used for remote sensing of ozone altitude profiles in the range 60–95 km and atomic oxygen profiles in the range 82–120 km.

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Comparison of the Rotary Temperatures of the Hydroxyl OH(6,2) and OH(3,1) Measured with Two Spectrographs

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In the paper comparisons of rotary temperatures of the OH(6,2) band and OH(3,1) band at the altitude of 87 km measured with two spectrographs installed at the optical station of Maymaga (φ = 63º N, λ = 129.5º E) are presented. The first instrument represents the infrared digital spectrograph (IDS) consisting of the diffraction SP-50 spectrograph and digital CCD–camera. IDS registers a band of hydroxyl OH(6,2) being radiated in the close infrared area of spectrum ~ 840 nm. The CCD camera is cooled up to – 50°C. An angle of vision of spectrograph is equal to 9°. The opening of entrance crack is 0.6 mm that corresponds to the transfer function of 0.8 nm. The second optical instrument is the SR303i spectrograph of the ANDOR Technology production with the iDus InGaAs DU490A-1.7 light emitting diode (LED) line. The working area with a quantum efficiency of registering camera more than 85% is 1000–1600 nm. The SR303i spectrograph registers OH(3,1). The working cooling is – 60 C. The angle of vision is ~ 5º. The resolution of spectrograph at a width of entrance crack of 0.2 мм is equal to 1 nm. The instruments register a nightglow at the same zenith angle 47° and both are directed to the west. For both instruments the estimation method of rotary temperature of molecular emissions is based on adjustment of the model spectra. The transfer function of instrument was constructed taking into account the spectrum really measured using a standard least squares method.

For the analysis the data of observation for January, Februar March, 2013 have been used. Moonless clear nights have been chosen. It is shown that in February the rotary temperatures of the OH(6,2) band measured with IDS are systematically below, on the average, of 8 K (with a standard deviation of 3.7 K). In March the difference decreases and constitutes, on the average, 4K (with a standard deviation of 3.3 K). The comparisons of ground measurements of temperature with data of the SABER radiometer installed aboard the American TIMED satellite will be additionally presented.

The Ionization of the Substance of the Atmosphere by Cosmic Rays and the Release of Stored Energy

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It has been shown that cosmic rays (CRs) may affect the aggregate transitions of water in the free atmosphere through the ionization of air and, thereby, atmospheric parameters. The pressure variations derived from measurements of the water content across the atmosphere have been estimated. According to these estimates, the magnitude of possible pressure variations caused by CRs in the form of Forbush decreases of GCRs is ~ 4.8 mbar. Data on the near-Earth pressure at three considerably distant points (Moscow, Apatity, and Yakutsk) have been analyzed in order to prove this effect.

It follows from an analysis that the effect of GCRs on the atmosphere is simultaneously observed at least in polar and midlatitude regions of the Earth. In this case the magnitude of this effect over different regions may differ by a factor of 2–3 (~ 6 mbar in Moscow, ~ 1.5 mbar in Yakutsk, and ~ 3 mbar in Apatity). Despite such a large difference in the amplitude, the time variation differs insignificantly. At all three points the effect (the pressure increase) is maximal 13–14 days after of the main phase of the Forbush decrease. The average duration of the effect is approximately the same at all points (19–15days).

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Effective Potential Energy Surface of $HD^{16}O$ for an Accurate Prediction of Highly Excited States nv_3 and v_1+nv_3

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A new potential energy surface (PES) for $HD^{16}O$ is presented. This surface was constructed by adjusting the ab initio PES of Polyansky et al. [1] through fittings to the experimental nv_3 and v_1+nv_3 energies only. In the refinement the experimentally derived term values up to 25330 cm^{-1} with $J < 9$ were used, in total 740 energy levels were included. In particular, 424 nv_3 with n = 0–8 and 316 v_1+nv_3 with n = 0–7 energy levels were utilized covering the energy range up to 25200 cm^{-1}. The resulting refined PES, referred to as 00V3, reproduces the 740 experimental energy levels with a root-mean-square (rms) error of 0.003 cm^{-1}. To improve the extrapolation properties of the empirical PES, the restraint that the resulting PES remains close to the ab initio surface was imposed.

Detailed comparisons with the recently reported empirical PES of HDO VTT [2], [3] will be presented. All data are available on ftp://ftp.iao.ru/pub/VTT/HDO_v3/. We hope that our calculations will be helpful in studies of energy levels of HD16O characterized by very high excitations of the O-H stretch [4].

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Variations of Sulfur Oxides above Venus' Clouds

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Sulfur compounds are key components of Venus' atmosphere because the planet is totally covered by H_2SO_4 droplets clouds at altitudes 50–70 km. Any significant change in the SOx oxides above and within the clouds affects the photochemistry in the mesosphere (70–120 km). Very recent papers about sulfur dioxide (SO_2) on Venus provoked more questions than gave answers concerning SO_2 behavior above the clouds. Belyaev et al. [1] reported detection of two SO_2 abundance layers from Venus Express (VEX) solar occultations: 0.02–0.1 ppm at 65–80 km and 0.1–1 ppm at 90–100 km with negligible content at 80–90 km. This structure of vertical profile was confirmed by photochemical models, where existence of the upper layer is described as a result of possible sulfuric acid photolysis [2]. Nevertheless, study of H_2SO_4 content above the clouds disputed this version of SO_2 production [3, 4]. Another source – oxidation of Sx – is discussed to be less possible. Generally speaking, all measurements (ground based [5, 6]; VEX nadir [7]; our VEX occultations) show high variability of SO_2 mixing ratios, especially in the lower layer.

Goal of the present paper is an overview and discussion of several puzzles that arose as results of SO_2 exploration on Venus. Venus Express (VEX) is an ESA's orbiter that has been operating around Venus starting from 2006 up to now. For our science we are using data from a set of SPICAV / SOIR spectrometers; they are sensitive to detection of SO_2 absorption in the IR (4 µm) and UV (200–220 nm) above Venus' clouds either in nadir or in solar occultation mode. That facility provides us to study vertical and latitudinal variations of SO_2 content in period 2006–2012.

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The Field of Non-Equilibrium Radiation of the Upper Atmosphere under the Influence of Ionizing Pulse

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We study the amplitude and timing of the fluorescent light (FI) signals in the upper atmosphere under the influence of ionizing, including X-rays, photons. The point isotropic source (PS) of X-rays is much higher than the absorbing layers of the atmosphere and has a temporal flux function, which is close to the δ-pulse. Calculations are performed for a wavelength of 0.3914 μm, corresponding to the emission of negative ions of nitrogen N_2^+. The field characteristics are defined on a spherical model of the earth's surface in the range of distances from 0 to 1500 km to the epicenter of the PS.

It is shown that due to the small time steps PS and appearance optical photon the source of PS is in the form of receding rings with respect to the vertical to the surface of the earth, drawn from the epicenter of the PS. With cloudless atmosphere flow FI reaching the earth's surface directly from the luminous region is proportional to the solid angle subtended by this area, and the flux density has a maximum value at the epicenter of the PS. Therefore, for an observer located in the epicentral area, this phenomenon should be presented as a bright flash in the direction of the PS and grows into a moving across the sky and disappearing behind the horizon ring. Made for these conditions, calculations show that the amplitude of the signal FI coming into hemispherical receiver rise rapidly in the first time 1 μs, then held nearly on the peak level within a few tens of microseconds, followed by a slow recession of the signal.

In the presence of cloud cover major contribution to the flux density makes multiple scattered radiation. The calculations in this case are performed by the Monte Carlo method using the modified local estimates. It is shown that in the epicentral area the beginning of the incoming signal is shifted to a value of 4–5 μs, but the further formation of the peak region is almost the same as in the absence of clouds. However, the recession of the signal in this case is more pronounced. The main share of the incoming radiation is concentrated in the range of zenith angles $v \le 45°$, and on the near-skyline ($v \ge 70°$) account for less than 10%. The difference in the signal amplitudes at the epicenter of PS in absence and the presence of clouds with an optical thickness of substantially 20 units is not observed.

With increasing distance from the epicenter the picture of the signal FI varies considerably. Herewith the observer's position relative to run up the ring plays a significant role. At distances of several hundred kilometers in the clear atmosphere the signal has a bimodal shape. Herewith the signals maximum corresponds to a time of intense glow of the horizon area in the initial period of the FI formation and the time passage of the rings segment above the point of observation. The glow of the passing ring segment on the presence of clouds is observed. Removal from the epicenter in the 1000–1500 km in this case leads to the amplitude decrease of the signal up to a hundred times or more.

Intensities of Spectral Lines of Vibrational-Rotational Transitions in Atmospheric Gas Molecules

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The excitation of vibrational-rotational states of terrestrial atmosphere's molecules occurs in high-temperature gases mediums or by optical radiation with using of the remote sounding methods. In recent times the remote laser methods of investigations are mostly developed and used and they provide obtaining of information with high operational accuracy and in wide spatial scales. Methods of the laser sounding of atmosphere are based on spectroscopic effects, the resonance laser radiation absorption accompanying with vibrational-rotational excitation of molecules is one of them. Fundamentally new effects and peculiarities are observed during excitation of vibrational states of atmospheric molecules by laser radiation, and these effects appear in numerous resonances which bind the excited vibrational states with other closely situated vibrational levels. During this excitation the redistribution of vibrational energy and the increasing of a density of spectral energy levels occur as well as the frequency's displacement of spectral lines in long-wave region, the growth of width and the displacement of band's centre during the increasing of vibrational energy, these all facts at a great extent make difficulties for processing and identification of observed lines. The difficulties of experimental spectroscopic researches establish the necessity of a creation and a development analytical methods of the modeling excited vibrational states in polyatomic molecules.

In our work the theoretical investigations of the excited vibrational-rotational states of polyatomic molecules have made based on the proposed and developed analytical method of the discontinuous spectral analysis in the operational perturbation theory and of the construction of the transforming function for excited vibrational-rotational Hamiltonian. The determinative equations for the wave functions and energy values of ground and excited vibrational states have demonstrated in the work. The equations for matrix elements of excited vibrational-rotational transitions and absolute intensities of spectral lines for single-quantum transitions are derived not only for ground but also for excited vibrational states in fundamental lines of infrared (IR) absorption spectrums of polyatomic molecules. Also for the determinative equations the evident connection between spectral line's intensities of excited transitions and vibrational and rotational quantum numbers are derived as well as influence of temperature on the peculiarities of intensity's forming and modification.

The modeling algorithm has been created based on the derived equations, which is realized in the applied program which permitted to carry out numerical experiment for calculation of vibrational-rotational states energies, frequencies and intensities of spectral lines in fundamental bands in IR absorption spectrums of water molecules H_2O and carbonic gas molecules CO_2. In infrared region of spectrum the atmosphere absorption is observed first of all in the troposphere because the troposphere contains just the main part of these important, optically active and absorbent IR radiation gas components of atmosphere.

Water Vapor Spectra: Current Data Processing Techniques

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Water is a substance involved in different processes responsible for the life on the Earth. That is why investigations on the spectral properties of water found in the terrestrial and exoplanetary atmospheres will remain a topical problem of the atmospheric radiation for a long time to come. At present there is a wide variety of information sources relating to the spectral line parameters of the water molecule. It will suffice to mention traditional databanks [1], information systems [2] and results obtained from variational computations [3]. The diversity of inconsistent data raises a question as to what information trustworthy. Check of the spectral line parameters according to trust criteria [4] has revealed that about 7% of data $H_2{}^{18}O$, $H_2{}^{17}O$ isotopologues from [1] were not published or confirmed by variational computations. Most likely these are approximate calculations. In the majority of cases, the spectral line intensity is less than 10–24 cm/mol. Calculations of the integral characteristics of radiation fluxes in the atmosphere have shown that untrusted lines make a minor contribution. When used in remote sensing tasks, however, the untrusted lines are a critical factor.

The W@DIS (http://wadis.saga.iao.ru) built at the Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences (Tomsk) enables the user to determine the extent to which the data in the ranges of change of wavenumbers, line intensities, collisional line halfwidths, etc., under study are inconsistent. The system is based on data extracted from more than 1000 papers and makes use of information archives obtained in the framework of IUPAC project N 2004-035-1-100 "A database of water transitions from experiment and theory", URL: http://www.iupac.org/web/ins/2004-035-1-100). Aligning inconsistent data on vacuum wavenumbers for water isotopologues was performed in [5]. The results obtained were imported to W@DIS.

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Modelling of the Non-Equilibrium Emissions of the Martian Atmosphere in the Near-IR Bands of the CO_2 and CO Molecules Taking Account Aerosol Extinction

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Aerosols are permanently present within an extended layer of the Martian atmosphere and have a considerable optical thickness (especially during the periods of global dust storms) in the visible and near-infrared (NIR) spectral range. The reason of interest to the problem of aerosols on Mars consists that its aerosols define to a great extent both the illumination of the surface and the thermal balance on this planet and, thus, participate in establishing the climate of Mars. Therefore, a development of new independent approaches for retrieving the optical properties of the Martian aerosols is an actual and important problem.

It must be kept in mind that the Martian atmosphere consisting for 95% of the CO_2 molecules has a rather low density. Therefore, both a rarity of molecular collisions, on the one hand, and the high rate of excitation of the vibrational states of the CO_2 and CO molecules due to an absorption of the solar radiation in the NIR spectral range, on the other hand, result in breakdown of the Boltzmann distribution of the excited vibrational state populations of these molecules within wide altitude intervals of the Martian atmosphere, i.e. the vibrational non-local thermodynamic equilibrium (vibrational NLTE) takes place. The optical depth of the Martian atmosphere for various ro-vibrational radiative transitions which should be considered in NLTE models for calculating the intensity of radiation in the NIR CO_2 bands, varies in very wide range. For example, for the main isotopologue of the CO_2 molecule, the optical depth for the central frequency of the most intensive line belonging to the fundamental radiative transitions of the NIR bands near 4.3, 2.7, 2.0, 1.6, 1.4, 1.25, 1.2 and 1.05 μm equals to $2.3x10^8$, $2.5x10^6$, $4.4x10^4$, $4.9x10^2$, $1.5 x10^3$, 87.7, 34.5 and 1.75, respectively. As for both the minor CO_2 isotopologues and the hot ro-vibrational radiative transitions contributing into the bands mentioned above, the such optical depths can be less unit, i.e. to be comparable to the optical depth of aerosols.

In this work, the problem of radiative transfer in the ro-ibrational bands of the CO_2 molecules (near 4.3, 2.7, 2.0, 1.6, 1.4, 1.25, 1.2 and 1.05 μm) and of the CO molecules (near 4.7, 2.3, 1.6 and 1.2 μm) under conditions of the vibrational NLTE in the Martian atmosphere has been solved for the first time taking account for both scattering and absorption of radiation by the Martian aerosols. The 545 ro-vibrational bands rising between the 206 vibrational states of 7 isotopologues of the CO_2 molecules and the 10 ro-vibrational bands rising between the 8 vibrational states of 2 isotopologues of the CO molecules are included into the NLTE model. Using the accelerated lambda-iteration approach, an original method for solving the problem of radiative transfer in molecular bands under vibrational NLTE in a planetary atmosphere taking account for an accurate treating of the frequency overlapping of all the ro-vibrational lines within the 1.05-15 μm spectral range, which were included into the model, and a reflection of radiation by a planetary surface has been developed. Also this method allows to take into account the processes of scattering (with a phase function of general type) and absorption of radiation by aerosols at the frequencies belonging to the spectral ranges of the CO_2 and CO ro-vibrational bands.

For the daytime atmosphere of Mars and for realistic models of the mineral dust aerosols, calculations of the non-equilibrium populations of the CO_2 and CO vibrational states have been carried out for the first time. Also the spectra of the limb radiation outgoing from the Martian atmosphere in the NIR CO_2 and CO bands were calculated taking account for the aerosol extinction of this radiation. An analysis of the response in the values of the limb radiation intensity to variations of some optical parameters of the aerosol model adopted has been carried out.

The most variability in the values of the radiation intensity to changing the parameters of the aerosol model is found for rather optically thin ro-vibrational transitions which have the optical depth of the same order as the one of aerosols and which have no considerable overlapping in frequency with another ro-vibrational transitions. Therefore from the viewpoint of possible development of new approaches for retrieving the optical parameters of the Martian aerosols, for the short-wave NIR spectral range it is more preferable to consider a radiation in the fundamental transitions of the main CO_2 isotopologue. A radiation in the fundamental transitions of the minor CO_2 isotopologues is more preferable for consideration if it is concerned the spectral range from 2 to 5 μm.

Spectral Instruments for Re-Equipment of Roshydromet Ozone Network

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28 stations of the Roshydromet total ozone network, equipped with filter ozonometers M-124, are the only source of the regular information about the protective ozone layer above Russia territory. In the WMO judgment the ozonometer is one of the 3 world ozone network instruments, suitable for evaluation of changes in the ozone layer. However, after 25 years of continuous operation ozonometers are needed the replacement by the modern automated equipment. The new instruments should ensure the preservation and continuation of a multi-year observation rows.

Moreover in accordance with modern requirements the ozone network these instruments ought to measure the incoming to earth UV radiation

The task of the specialists of MGO and of optical organizations of St. Petersburg was to develop the automated spectral equipment that operated under all weather conditions on the Russia territory. Ultraviolet ozone spectrometer (UVOS) was created on the basis of the polychromator (diffraction grating + CCD line). Experimental samples were tested in practice at the 5 ozone stations.

The UVOS pre-production model was manufactured by the firm «Laser center ITMO». UVOS spectral range is 290–400 nm, spectral resolution – about 1 nm, the time of recording of the spectrum – from 2 ms up to 2 s. The instrument detects the spectra of UV radiation from the hemisphere and from the Zenith sky. Zenith radiation is used for measuring the total ozone up to 85° zenith angle, including measurements for fast-changing cloud condition. UVOS specifications satisfy the WMO requirements to total ozone measurements and UV spectral measurements.

Advantages of the UVOS are the performance, the composition and volume of the received information, the ability to perform measurements of total ozone under any cloud, simplicity of design with no moving parts, ease of operation. The instrument is capable to work in the Russia territory in any range of astronomical and weather conditions and in difficult operating conditions at Roshydromet stations.

Авторский указатель