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NATIONAL REPORT

for the
International Association of Meteorology
and Atmospheric Sciences
of the
International Union of Geodesy and Geophysics
2007–2010

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This report of the Meteorology and Atmospheric Sciences Section (MASS) of the National Geophysical Committee of Russia presents information on atmospheric research in 2007-2010 in Russia. It is based on reports of 10 National Commissions:

1. Atmospheric Chemistry (Chairman I.K. Larin);
2. Atmospheric Electricity (Chairman V.N. Stasenko, E.A. Mareev et al.);
3. Atmospheric Ozone (Chairman N.F. Elansky);
4. Climate (Chairman I.I. Mokhov);
5. Dynamic Meteorology (Chairman V.N.Lykossov and V.N. Krupchatnikov);
6. Meteorology of Middle Atmosphere (Chairman A.A. Krivolutsky and A. Repnev);
7. Physics of Clouds and Precipitation (Chairman N.A. Bezrukova);
8. Planetary Atmospheres (Chairman O.I. Korablev et al.);
9. Polar Meteorology (Chairman A.I. Danilov and V.E. Lagun);
10. Radiation (Chairman Yu.M. Timofeyev and E.M.Shulgina).

Contents

Atmospheric Chemistry

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A brief review of Russian scientific works of 2007-2010 in the field of atmospheric chemistry, including chemistry of the troposphere, ozone layer and the effect of chemical processes on climate change is presented. The review is prepared in the Russian State Geophysical Committee by the Commission on Atmospheric Chemistry and Global Pollution.

The studies in the field of atmospheric chemistry, carried out in Russia in 2007-2010, were conducted on a number of the traditional fields, including laboratory study of atmospheric chemical and photochemical processes, theoretical analysis of atmospheric mechanisms, natural monitoring and mathematical modeling of atmospheric processes [1]. In course of this work a number of the new important result, allowing deeper understand of the role of atmospheric chemical and photochemical processes in change of the physical characteristics of atmosphere, occurring under influence of natural and antropogenic factors has been received. Revealing a relative role of these factors in some cases was the main "applied" purpose of these studies, particularly when it is a question of change of ozone layer and climate.

Chemical and photochemical processes in the atmosphere proceed not separately, but in close and various interaction with other atmospheric processes that complicates the determination of the formal field, which refers to as chemist of the atmosphere. For this reason we, possible, shall break these borders, to give the more broad belief about the subject.

Materials of the report are a little bit conditionally distributed on sections "Chemistry of the troposphere", "Ozone layer and reasons of its change", "Chemistry of climate and its change".

1. Chemistry of the troposphere.

At the last years the most important achievements in the field of tropospheric chemistry are connected with study of heterogeneous processes, proceeding with participation of aerosol particles and playing a key role in formation of acid rains, as well as in depletion of the ozone layer and climate change.

In connection with the last direction in the Institute of energy problems of chemical physics, Russian Academy of Sciences for the first time a possibility of the influence on the ozone layer of heterogeneous chemical reactions with participation of hydrogen peroxide (H_2O_2) [2] has been studied. Dissolution of H_2O_2 in particles of sulfate aerosol (in Junge layer) brings about formation of the strong oxidizers $H_3O_{(aq)}{}^+$ and $HSO_{5(aq)}{}^-$ (Caro acid) on reactions:

$$H_2O_{2(aq)} + H_3O_{(aq)}{}^+ \leftrightarrow H_3O_{2(aq)}{}^+ + H_2O_{(aq)},\ K_1(298) = 8\times10^{-4} \quad (1)$$

$$H_2O_{2(aq)} + HSO_{4(aq)}{}^- \leftrightarrow HSO_{5(aq)}{}^- + H_2O_{(aq)},\ K_2(298) = 1.2\times10^{-2} \quad (2)$$

These reactionary-capable and well dissolved chemicals enter in quick liquid-phase reactions with being present in sulfate aerosol the chloride and bromide anions. Being formed haloid components destroy ozone that enlarges a scale of so called haloid activation of the lower stratosphere particularly at spring period in Antarktida and also in the middle latitudes in condition of active volcanism.

Studies of physico-chemical characteristics and chemical processes, proceeding in dripping moisture of tropospheric clouds were continued. So, in [3] new data of natural and laboratory studies of cloud drop characteristics and liquid particles of sulfate aerosol are reported, mechanisms of the chemical conversion of sulphur dioxide and products of transformation of anthropogenic freons in atmospheric dripping moisture are considered, as well as kinematic and thermodynamic features corresponding to reaction, monitoring data of atmosphere and results of mathematical modeling of the influence upon gas composition of liquid-phase chemical reaction. It's clear that gas composition itself also influences on chemical composition of aerosol particles. So, in [4] it was shown that in conditions of high moisture and in presence of gaseous NH_3 and H_2SO_4 liquid faction of aerosol particles $H_2O/H_2SO_4/(NH_4)_2SO_4$ of the different composition is formed. In [5] a complex mathematical model, taking into account mutual influence of the aerosols and gas components to each other has been described. The model includes blocks of the carrying the gas component and aerosols in atmosphere with taking into account of homogeneous binary nucleation, kinetic processes of condensations/evaporations and coagulation, as well as chemical processes, proceeding in gas and liquid phase, with account of the processes of mass exchange at interaction gas-drop. Data of numerical experiments are compared with data of natural studies of concentration of gas components and aerosols, as well as with a change of ion composition of aerosol particles in Baykal region under influence of emissions from powerful industrial sources. The results of modeling the processes of the formation of aerosol particles in troposphere and, in particular, formation of the particles in cloudy systems are considered in work [6-8]. A quasi-static model of nucleation and its application for description of the process of ice formation in the troposphere has been presented in [9, 10].

In connection with an observed anomaly of the ozone concentration in the coast sea zone in the N.N.Semenov Institute of chemical physics of the Russian Academy of Sciences and in the Institute of the energy problems of chemical physics, Russian Academy of Sciences, with use of the mass-spectrometer technic a complex of investigations of the mechanism of capture of NO_3, $ClNO_3$, H_2O and atom of chlorine on covering, imitating sea aerosols have been continued. Within the framework of offered models of the process the data on dependencies of probability of the capture of gas-reagents from external conditions: concentrations of the gas-reagent, relative moisture, the temperature and composition of the saline covering have been managed to describe. It should be noted that for the first time phenomenon of practically full depletion of ozone in Arctic troposphere at spring time has been observed as far back as in 1986 and hereinafter repeatedly has been occurred in other sea regions. Simultaneously in these cases high concentrations of chlorine and bromine have been existed due to reactions, leading to direct nonphotolitic formation of ozone depleting halogen in the gas phase:

$$NO_{3(g)} + NaCl_{(s)} = Cl_{(g)} + NaNO_{3(s)},\ \Delta H^0\,(298) = -6.8 \text{ kilojoule /mole} \qquad (3)$$

$$NO_{3(g)} + NaBr_{(s)} = Br_{(g)} + NaNO_{3(s)},\ \Delta H^0\,(298) = -68.7 \text{ kilojoule /mole} \qquad (4)$$

Results of the investigations of this sort are presented in [11-19].

Significant attention in these years was paid to field observations of aerosol particles in the troposphere. So, in [20] radioactive contamination of Middle Russian eminences and its vicinities 21 year later of Chernobyl event has been analysed. In [21] data about acidity and chemical composition of the snow samples in Moscow and its suburbs during winter seasons 1999/2000-2006/2007 have been reported. Average acidity of the samples for Moscow was 6,09 pH, but for the suburbs - 5,63 pH. When removing from the city a value of pH was decreasing i.e. acidity of the samples was increasing. Average values of mineralization of snow samples in Moscow and in suburbs have made up 15,9 mg/l and 9,4 mg/l accordingly. Increasing snow pollution has been observed in Moscow and nearest suburbs (about 15 km) at the last years.

A lot of various data on aerosols in Northern Eurasia has been received in course of expeditions of the mobile laboratory TROICA (Research Manager of the TROICA Experiments Prof. N.F.Elansky, A.M.Obukhov Institute of atmospheric physics RAS) and presented in brochure of The International Science and Technology Center [22].

Other "aerosol" questions (spreading, modeling, radiation characteristics, ion composition, influence upon ecology) are discussed in [23-33]. In [34-36] questions of the artificial influence on cloudy systems are discussed and in [37], in particular, modern concept of the meteoprotection of megalopolises by methods of active actions is considered.

Regular observation for atmospheric conditions, air quality, aerosol particles and gas components, polluting atmosphere, is of great importance for protection of the environment and health of the population [38, 39]. When arising extreme meteorological situation (like conditions of summer 2010 in Central region) the real threat to nature and population appears. Thence it is clear an importance of the problem of the study of such sort situations for the reason their possible forecasting, as well as softening their consequence. These questions are discussed in [40-42], in which conditions of the origin of convective clouds at blast and fire are analysed as well as formation of aerosols and carbon monoxide at fire. In this connection it is necessary specifically to note all-russian conference taken place in Moscow (November 25, 2010) "A state of the Moscow air area in extreme weather conditions of summer 2010" [43]. On the conference there were presented such works, as "Blocking: conditions of summer 2010 in context of the modern state of the knowledge." (N.P.Shakina, A.R. Ivanova, B.A. Birman, E.N. Skriptunova); "Meteorological, aerosol and radiation features of the atmosphere during the fires in summer 2010 by the data of Meteorological observatory of the Moscow State University" (N.E. Chubarova, E.V. Gorbarenko, P.I. Konstantinov, M.A. Lokoschenko, E.I. Nezval', O.A.Shilovceva); "Gas composition of the atmosphere in Moscow in extreme conditions of summer 2010 by the data of the station of the A.M.Obukhov Institute of atmospheric physics RAS " (N.F. Elansky, I.I. Mokhov, I.B. Belikov, E.V. Berezina, A.S. Elohov, V.A. Ivanov, N.V. Pankratova, O.V. Postylyakov, A.N. Safronov, R.A. Shumsky V.S. Rakitin, E.V. Fokeeva); "Influence of smokescreen from wildfires on concentration приземного ozone in atmosphere of the background region by summer 2010." (S.N. Kotelinikov, V.A. Milyaev); "Hot summer 2010 and death-rate of the population of the European part of Russia" (B. A. Revich) and some others.

In part, concerning gasphase tropospheric chemistry, it is necessary to note achievements in the field of monitoring the composition of the surface air ща urban and background regions. So, in mentionned above work [22] an monitoring data of many years observations on extensive continental territory, executed by means of unique mobile laboratory TROICA (Transcontinental Observations into the Chemistry of the Atmosphere), which have not a world analogue in this field are presented. They includes data about gas admixtures and aerosols (ozone, nitrogen oxides, greenhouse gases, volatile organic substances), about contamination of atmosphere in megalopolises and in conditions of extreme situations, data about contribution of local antropogenic sources in contamination of atmosphere and much other important information, important for analysis chemical and physical processes running in the lower troposphere. Among the works let's mark out the observations for the antropogenic ozone depleting chemicals (CFCs 11, 12, 113, halon 1211, CCl_4, CH_3CCl_3), which attract much attention in connection with execution Monreal protocol and forecasting time of the ozone layer recovery. Let's point out also that in [22] a question about toxicology in the arid regions and, in particular, formation of trichloroacetic acid (the dangerous pesticide) from methylchloroform (CH_3CCl_3) has been considered. [22] includes also the data about volatile organic substances, which are not monitored in Russia, in spite of their great role in chemistry of the troposphere. Apart, in [44], a question about surface concentration of ^{222}Rn is considered. The interest hereto element is connected with that it is one of the sources to ionize surface atmosphere, which brings about formation of additional amount of ozone, as well as hydroxyl radical OH. Aside from this, radon possible to consider as "deterministic" indicator of natural and technogenic hydrodynamic processes [45]. Let's add that in [46] the particularities of emanation of ^{222}Rn with depth are considered.

Some works of this period were dedicated to contamination of the city air by transport and objects of energetics [47-53]. In this row we mark out the work [54], where an experimental and model study of NO_2 concentrations at the various high-altitude levels and in column of the atmosphere in winter and summer in Moscow and sensitivity of NO_2 to action of different factors, including solar radiation, the temperature of air, turbulent diffusion, as well as organic substances are presented. In [55-62] the monitoring and modeling data of the contents of small atmospheric components in different regions of the Russia and Europe are given.

The interesting information about influence of the storm activity on gas composition of atmosphere are presented in [63], where, in particular, it is shown that as a result of variability to storm production of nitrogen oxides their concentration in upper troposphere and lower stratosphere can be changed in two-three times that, taking into account an influence of the nitrogen oxides on ozone and other gas components, creates the potential for essential indignation of the gas composition and heat mode of the atmosphere.

Bearing in mind importance of solar radiation for tropospheric processes, let's specify an analytical review [64], in which basic results of investigations in the field were summarized and submitted for International Symposium of the countries C.I.S. "Atmospheric radiation and dynamics" (ISARD-2009), took place in Saint-Petersburg, June 22-26, 2009.

In conclusion this part let's point out the work [65], in which, probably for the first time, tropospheric homogeneous and heterogeneous processes were considered with standpoint of their importance for planning and decisions of the monitoring problems.

2. Ozone layer and reasons of its change.

The studies of chemical reactions of haloid cycles of the stratospheric ozone depletion were continued. Much attention was paid to the least studied iodine cycle. By means of the flow kinetic installation the rate constant of the chemical reactions were measured with use of the method of the resonance fluorescence including reactions of ozone with iodine atom, radical IO, HI and nitrogen oxides [66], the rate constants of the reactions of iodinemethane and perftoriodinepropane with chlorine atom [67], the rate constants of the reactions of oxygen atom oxygen with chlorine and iodinemethane [68], as well as formation of the iodine atoms in heterogeneous reaction of chlorine with iodinemethane [69]. Besides that it was received a number of important for stratospheric chemistry results: study of the reaction of chlorineethylene with chlorine atoms [70]; a general description of the mechanism of the radical reactions with ozone [71]; using a quantum-mechanical methods to study mechanism of reactions of ozone with acetylene [72], reaction of ozone with hexafluoride propylene [73], ethylene [74] and tetrafluoride ethylene [75].

There were continued observations for ozone in high latitudes, where, as it is well known, at spring months its destruction occurs as a result of heterogeneous processes with participation of aerosol particles of the polar stratospheric clouds (PSC). So, in [76] the results of the observations for ozone layer in north-west sector of Russian Arktik in winter-springtime 2003-2004 are communicated, which have fixed the reduction of ozone at heights 25-40 km in April 2004. In [77] it is reported on a record chemical destruction of ozone in the Arctic during winter 2004-2005, which was caused by the intense formation of the polar clouds (PSC) due to extremely low temperatures during this period, that reduced the total ozone to 25 March 2005 at 116 Dobson units, which was comparable with the results, characteristic for the Antarctic ozone hole. The interest result of PSC study was presented in [78] which provided a new test to detect PSC. As before it is actual the multi-year data of ozone observation to determine its trend. Such data are given in [79], where the interannual variations and trends of middle-latitude series of total ozone from 1979-2005 are presented. Stratospheric ozone, and its column content, influenced by the various geo- and helio-physical factors such as solar activity cycles, quasibiennial cycles, Arctic and Southern Oscillations and others that lead to periodic variation of ozone that must be taken into account when considering ozone trends and patterns in mean atmosphere. The data of this sort is presented in [80, 81]. Another "periodic" factor of middle atmosphere is the galactic cosmic rays (GCR), intensity of which changes in phase with solar activity. GCR action leads to the formation of radicals OH and nitrogen oxides, which destroy ozone in the stratosphere in the known catalytic cycles. In [82] data on the effects of GCR on minor atmospheric components, including OH, HO_2, O_3, $O(^1D)$, $O\ (^3P)$, NO, NO_2, NO_3, N_2O_5, HNO_2, HNO_3, $ClONO_2$, HNO_4, ClO, HCl, HOCl, Br, BrO, HOBr are given. It is shown that the relative change of individual components at altitudes of 15-20 km in the middle latitudes under action of GCR can reach 20% or more, making the necessary an account of this factor in models of middle atmosphere. It has been also shown that the reduction of total ozone at mid-latitudes under influence of GCR may reach one third of the reduction of total atmospheric ozone in the late of 20^{th} century, caused by anthropogenic emissions of CFCs. In addition to GCR the middle atmosphere is influenced by solar cosmic rays and other manifestations of solar activity. Comprehensive information on the impact of cosmic factors on ozonosphere of the Earth are contained in the monograph [83].

It must be said that if the ozone layer at the end of the last century was destructed mainly by heterogeneous reactions in the lower stratosphere, now it is adopted that the recovery of the ozone layer in the northern hemisphere should further accelerate due to homogeneous processes in the upper stratosphere, and will determine the time of recovery of the ozone layer. It will occur because global warming will cause a lowering of temperature in the stratosphere, which will lead to slower of reactions of ozone depletion in known catalytic cycles, including halogen cycle. In this connection let's mark out the work [84], which dealt with the future impact of greenhouse gases on stratospheric temperature and ozone layer of the Earth.

In literature discussions on the reasons of ozone depletion in the late of 20th century have been continued. So, [85] global monthly mean sets of the total ozone in 1964-2006 have been constructed by the data of the terrestrial world ozone network and it has been revealed a strong relationship of total ozone with solar activity that, according to the authors, means that a strong reduction of total ozone in the 1970's and the 1990's should not be explained only by antropogenic factor. In other work on this topic [86] by linear multiple regression a summary contribution of seasonal, quasibiennial, solar cycles, and Arctic and Southern Oscillations in trend of the total ozone of global and zonal scale in 1979-1990 has been estimated. It has been shown that in zone 65 S - 65 N a contribution of natural factors in trend during this period does not exceed 16%, that means a dominate action of human factors.

From the "application" works in the field of protection of the ozone layer from the influence of anthropogenic factors let's point out works [87, 88], which identified Ozone Depletion Potentials and Global Warming Potentials of some substances that can be used as fire extinguishing agents.

In conclusion of this part, let's mark out the work [89], which has been demonstrated a rigid link between UV absorption of ozone molecules and molecules of DNA. It has been shown that if the curve of cross-section of ozone would be shifted toward shorter wavelengths just one nm, ozone would not be able to provide biological protection from the solar UV radiation (due to life 400 million years ago appeared on the land) and life could develop only in the ocean.

3. Climate chemistry and its change.

Role of chemistry in climate is determined by the fact that atmospheric greenhouse gases (such as CH_4, O3, chlorofluorocarbons and their substitutes), as well as the aerosols particles are largely controlled by atmospheric chemical and photochemical processes. Particular attention in this series focuses on methane, which is one of the most powerful greenhouse gases and has a short atmospheric lifetime, which is important when developing a strategy to combat global warming. That explains the inclusion of a special methane box in modern climate models [90.91]. Another reason to focus on methane are vast stocks of this gas in so-called gas methane klatrats in permafrost and on the ocean floor, which can be released under action of global warming. This makes it necessary to monitor the content of the gas in the atmosphere. Results of observations of methane and other greenhouse gases are in the works [92-98].

You know that the rate of warming in Siberia considerably exceed those for globe [99]. Bearing in mind the existence there of permafrost and methane in klatrats, you must carefully monitor the impact of warming on soil conditions in the area. This is discussed in [100]. [101] discusses the current state of the underwater permafrost on the East Siberian shelf. Interesting supposition on the rapid methane warming 55 million years ago is discussed in [102]. [103] addresses the general framework for monitoring emissions and anthropogenic greenhouse gases. [104] shows the influence of volcanic activity on climate change over the last few centuries, [105] examines the current state of climate change and its prediction.

Considerable attention in recent years has been paid to possibility to slow global warming by different means. These approaches are discussed, inter alia, [106]. The paper deals with two main approaches to the challenge: forced change of radiation balance of the Earth and removing from the atmosphere of excess carbon dioxide. The first classified techniques such as introduction to the stratosphere sulphate and other reflective aerosols, orbital reflectors or reflectors in Lagrangian point, increasing cloudiness over oceans and land surface albedo change itself. The second approach addresses the increased uptake of carbon dioxide in forests, oceans and artificial sinks. The comparison showed that the most effective would be to use the stratospheric sulphate aerosols. [107] states that while the establishment and subsequent maintenance of artificial aerosol layer in the stratosphere in principle would eliminate or delay the warming of the climate, but accompanied by decline in global precipitation, particularly in the tropics. Moreover, a screen of stratospheric aerosol does not solve the problem of increasing CO_2 in the atmosphere, which in turn leads to further oxidation of the oceans and thereby adversely affect the marine part of the biosphere. [107] also discusses political and ethical issues related to the deliberate human intervention in a global environment. [108] estimates of aerosol optical thickness and mass of sulphate aerosols, needed to offset the average annual temperature of ground-level air caused by rising greenhouse gas emissions by measurements and by scenario A2 IPCC report for the period 1970-2050. It is marked absence of countervailing effects when placing screens in polar regions (out of 70 - 50 latitude in both hemispheres), as well as the impossibility of fully compensating the greenhouse global warming screen located in only one hemisphere. [109] shows that taking into account both greenhouse and sulfate impact overall warming of the climate in the model by the end of the XXI century relative to the end of the 20th century was 1.5-2.8 K, depending on the scenario and relative to the pre-industrial - 2.1-3.4 K and sulphate aerosol slowing global warming at different time periods to 0.1-0.4 K, depending on the scenario. Maximum deceleration warming (> 1.5 K) is in mid- and high latitudes of the northern hemisphere in the middle of the 21st century by scenario A2. Response of the climate model used is non additive towards the greenhouse and aerosol forcings. [110] describes the results of full-scale experiment to study transmission of solar radiation in the visible wavelength range in case model-generated aerosol environments in the lower troposphere using generators installed on the helicopter. Generated aerosol particles have refractive index and average size close to tipucal natural stratospheric aerosol. It is given the set of equipment used in experiments to control optical and microphysical properties of aerosol. Measurement results are satisfactory with the results of theoretical and experimental research in simulation chambers. In [111] it is reported that emission of sulphate aerosols, needed to prevent global warming, at the end of the XXI century ranges from 2 to 12 Mt S/year depending on the scenario of human influence and aerosol parameters. In the event of termination of such compensating emissions of sulphate aerosols rate of increasing global temperatures may reach 3 K per decade that is several times more than values, taking into account only the greenhouse effect.

To this we add that use of sulphate aerosols to stabilize climate should lead to significant damage to the ozone layer, as can be seen in the reduction of the ozone layer at the end of the last century due to not only significant levels of man-made chlorofluorocarbons, but mainly to sulphate aerosols in Junge layer and ozone loss following the eruption of Mount Pinatubo, significantly increased sulphate aerosols in the same region [112].

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Atmospheric Electricity

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Atmospheric electricity has become increasingly important and challenging since the late 1900s both from fundamental and more practical points of view. This field unifies classical topics such as fair weather electricity, air ions, thunderstorm structure, lightning observation and morphology, with rather novel areas – high-altitude discharges, weather and climate, high-energy processes correlated with electrical activity, global electric circuit modeling. International conferences on atmospheric electricity have consistently been the quadrennial scientific events devoted to the exchange of knowledge and information in this inter-disciplinary field since 1954. The 13th ICAE was held in Beijing (China) in August 13-17, 2007 (see Proceedings of this conference [1] and a special issue of Atmospheric Research journal [2]), and forthcoming 14th ICAE is going to be held in Rio de Janeiro (Brazil) in August 8-12, 2011. Correspondingly Russian conferences on atmospheric electricity are considered as major scientific events in Russia in the field, and their conduction has become recently more or less connected in time to ICAE conferences. In a reviewed period the 6th all-Russian conference on atmospheric electricity has been held during October 1-7 in Nizhny Novogorod at the Institute of Applied Physics, Russian Academy of Science. 57 oral and 87 poster papers have been presented at the conference. The Proceedings of 6th All-Russian conference on Atmospheric Electricity (Nizhny Novgorod, October 2007) [3] include 128 papers following to respective reports, presented at the conference, and contain an extensive information on recent research and development. In what follows a brief review of recent efforts in Russia devoted to atmospheric electricity studies is presented.

1. Ions and aerosols in the atmosphere. Fair weather electricity.

Studies of ions and charged aerosols in the atmosphere represent a classical part of atmospheric electricity. During 2007-2010, complex experiments devoted to the study of fair weather/disturbed fair weather electricity, its relations to geophysical and meteorological conditions, and its role in the global electric circuit, have been performed.

The influence of the characteristics of the atmospheric ionization and physical-chemical state of condensation nuclei on the electric state of convective cells has been studied [4]. Based on the results of experiments in an adiabatic chamber with a volume of 3200 m^3 , it was found that, with increase in relative air humidity H from 40 to 95% with an equivalent ascent rate of 100–400 cm/s, excessive charges in amounts of about 103 or more elementary charges per cm3 may be accumulated on the nuclei. The sign of the charge depends on the chemical composition of the hygroscopic nuclei. For instance, media with insoluble nuclei (porous silica, etc.) typically have prevailing negative charges; those with soluble nuclei (sodium chloride, etc.) are dominated by positive charges. At H = 60–90%, the electrization of soluble nuclei can be interpreted in the diffusion-kinetic models of the ion charging of aerosols. Considerable negative volume charges, which appear on insoluble hygroscopic nuclei during a rise in humidity from 40 to 70%, are explained by the structuring of surface water films, which exhibit a resemblance to negative lightweight ions. At high values (H > 90%), it is necessary to take into account the resemblance of the wetted surfaces to positive lightweight ions. It was shown for the first time that, at ion formation rates of 3 and 10^{10} ion pairs/(cm^3·s), the differences in the volume charge and wetting rate of condensation nuclei are insignificant. It is concluded that, in many meteorological situations, the first stage of electrization of the convection-derived cloud media is the ion charging of the condensation nuclei.

A charging conducting sphere moving in a weakly ionized gas was investigated [5]. An external uniform electric field is applied with arbitrary orientation relative to the gas flow. The ion current is obtained analytically and investigated numerically in ballistic assumption. It is shown that charging regimes depend not only on the net charge of the sphere but also on the gas flow type, and the parameter $\xi\pm$ – the ratio of ion drift velocity far from the sphere to the gas velocity. The cases $|\xi\pm|<1$ and $|\xi\pm|>1$ yield two different charging regimes for Stokes and potential flows. For the potential flow, the ion current has been found analytically in continuous $\xi\pm$-parameter space. The stationary charge of an isolated sphere is also calculated numerically as a function of α. It achieves maximum magnitudes in direct ($\alpha=0$) and back ($\alpha=\pi$) flows respectively.

Possible mechanisms of modification of effective relaxation time of space charge density in the atmosphere and formations of aeroelectric structures have been investigated [6]. The analysis of formation of spectra of pulsations of electric field and space charge density taking into account neutral gas turbulence and presence of aeroelectric structures is given. The fundamental role of non-local connection between electric field intensity and space charge density is specified for the conditions of spatially heterogeneous turbulence. Solutions of modeling problems on a spectrum of turbulent aeroelectric field pulsations in the presence of fluctuations of space charge density, considered as a passive admixture, are resulted. Results of measurements of a spectrum of short-period ($f=10^{-3}$-1 Hz) aeroelectric field pulsations for fair-weather conditions and for a fog are presented. It is shown, that aeroelectric field pulsations have power spectra in a frequencies band (10^{-2} -10^{-1}) Hz with the spectral index varying in the range -1.23 to -3.36 while the most probable values of the index are in the range from -2.25 to -3.0. The model of the system consisting of light aeroions and aerosol particles, taking into account dependence of interaction of these particles on external electric field intensity, is considered. It is shown for some interval of parameters, that growth of average electric field intensity leads to increase of a relaxation time of space charge disturbance. This effect amplifies with increase in concentration of aerosols. It is demonstrated that in the stationary case the concentration of aeroions decreases when concentration of aerosols increases, that results in reduction of atmosphere conductivity and growth of a relaxation time of a space charge.

The correlation of mechanical transfer current from the atmosphere to the ground with the process of space charge formation as a result of conductivity current divergence near ground has been considered [7]. Experimental data of conductivity current and mechanical transfer current acquired at three observation points for different meteorological conditions are analyzed. In particular, the peculiarities of mechanical charge transfer to ground under different stratifications of the surface layer are discussed.

The results of the development and generalization of earlier research in the field of the electric structure of the electrode layer of the atmosphere were presented [8]. The vast data store has been used gathered over a decade of atmospheric-electrical, meteorological and radiological complex measurements during expeditions in the Rostov region, in the south of the European part of Russia, steppe zone. Study of time–spatial variations of atmosphere electrical characteristics in the surface layer displays their significant dependence on meteorological processes near the ground. Years of experience brought us to the realization of the need for separate descriptions of the electrode layer structure for different stabilities of the surface layer, especially if the soil at the point of measurement emanates significantly. Considerable radon exhalation and its storage in the near-ground layer under stable atmospheric stratification noticeably influence the vertical distribution of conductivity in the electrode layer, increasing the ionization in the surface layer. This, in turn, influences the processes of space charge formation and thus the electric field and the charge exchange between ground and atmosphere. This work presents also experimental profiles of radon-222 concentrations and the lower 3-meter layer polar conductivity of the atmosphere, averaged separately for stable and unstable stratification of the atmosphere.

Dynamics of an electric field of the lower atmosphere was investigated [9]. It is displayed, that a series of monthly average values of an atmospheric electric field are stationary relative to average value for a time interval of 1998-2007. It is shown, that the annual trend of intensity of an aeroelectric field has a maximum in February-April and a minimum in October-November. It is revealed, that most authentically the daily curve of an aeroelectric field repeats a unitary variation in winter months of every year. It is noticed, that the spectrum of aeroelectric field variations contains quasi-harmonics with the periods of 12 months, 24 h, 11-14 h, 1 h, 25-40 min. It is confirmed, that the short-period pulsations of an aeroelectric field have self-similar power spectrum for frequency band $\Delta f = 10^{-2}$ -1 Hz.

The fundamental problem on reconstruction of the altitude profiles of the surface layer electrical parameters according to near ground measurements was formulated [10]. The model of turbulent electrode effect, including meteorological characteristics of the atmospheric surface layer as its parameters, is presented. Characteristic scales of the model, its simplification and algorithms to numerical calculations are analyzed. The approbation of the model with usage of the near ground meteorological and air electric measurements on the Borok Geophysical Observatory is resulted. Daily variations of electrode effect parameters are revealed. Daily trends of the electric field in the surface layer are estimated. The application of the offered model to the monitoring of the atmospheric surface layer electricity in a near real time mode is discussed

According to results of surface observations, carried out in Borok Geophysical Observatory [58° 04′ N and 38° 14′ E], transfer speed of electric field inhomogeneities is determined [11]. This speed is different from horizontal speed of wind in the surface layer and related to the height profiles of space charge and of wind speed components. It is assumed that the horizontal transfer of aeroelectric field inhomogeneities in the surface layer is determined by presence and dynamics of electrical active regions of atmospheric exchange layer.

A model of non-stationary horizontally similar surface layer with single-charged aerosol influence is developed [12]. The distributions of electrical characteristics in the atmosphere surface layer in dependence of turbulence mixing and aerosol particles concentration are received.

The results of synchronous measurements of rapid fluctuations in air temperature, wind velocity components, and the intensity of the electric field in the surface air layer (at a record frequency of 16 Hz) were analyzed [13]. A strong correlation is revealed between variations in air temperature and the electric-field intensity, as well as between variations in the electric-field intensity and the wind-velocity components. In order to explain this correlation, it is assumed that an electric charge is emitted from the land surface, the stratification of charge density (which is similar to that of air temperature) is formed as a consequence, and a turbulent flux of electric charge occurs. This assumption is based on data on the correlations between air temperature and the concentrations of additives emitted from or precipitated onto the land surface (H2O, CO2, and O3). Our analysis is based on a description of correlations within the bounds of the scheme of the linear statistical prediction and on experimental data on the coherent structures of the temperature field.

The influence of a solar eclipse on solar-radiation fluxes, meteorological parameters, turbulence characteristics, and vertical temperature profiles in the atmospheric boundary layer was analyzed [14]. Air-temperature variations caused by an eclipse and time delays of these variations with respect to the onset of the total-eclipse phase in the atmospheric surface and boundary layers are determined. The influence of a solar eclipse on the turbulent kinetic energy, turbulent heat flux, and variance and spectral density of the power of air-temperature pulsations are estimated. Variations in aerosol parameters and concentrations of light ions during a total solar eclipse are discussed.

An experience of holding expedition researches of atmospheric electrical characteristics was reflected in [15]. The measuring complex has been created, which allows one to receive the experimental data necessary for studying atmospheric electrical processes in the surface layer. Measuring sites, devices used instruments and observation methods of atmospheric electrical and meteorological characteristics in the surface layer are described.

The review of experimental research of vertical atmosphere electric currents near the ground surface and from atmosphere to the Earth in the Rostov-on-Don region is presented in [16]. It is found out that the vertical change of the conductivity current density leads to the space charge formation near the earth surface; transit and distribution of this charge are due to mechanical transfer current whose density is appreciably determined by meteorological conditions in the point of observations.

The investigation of the interconnection of the electrical field of the atmosphere boundary layer with geophysical processes with the help of radio-technical and radio-physical methods and facilities was undertaken in [17]. The general task statement of the spectral process estimation, analyzed in this work and which consists of noise background and partially determined harmonic signal (moon and solar tide effects) is formulated in the following way: it is necessary to get the true estimation of the amplitude of the spectral components at the known frequences of the moon and solar tides according to the given discrete measurements of the vertical component of the boundary layer electric intensity at the final time interval. Perspectivity of using radiotechnical method of the correlative quadrature receiver for solving the problem of the estimation of the electrical field amplitude at the frequences of moon and solar tides has been proved.

A modern state-of the art of information technologies applied in geophysical observations has been analyzed [18]. A measuring complex of the "Borok" Geophysical Observatory is briefly described. The main features of separate stages for geophysical data informatization is discussed including information storage, processing, access organization etc. The principles of architecture for digital data networks and software for their using are considered.

2. Global electric circuit

A complex of research on the global electric circuit has been carried out. Physical mechanisms of formation of the global electric circuit (GEC) are considered and energy estimates are obtained for aeroelectric processes [19]. Global thunderstorm activity, the electrodynamics of mesoscale convective systems, the electric fields of the magnetospheric dynamo and ionospheric dynamo region, and the electrostatic field of the global unipolar generator form a quasi-stationary aeroelectric state and maintain the balance of currents of the GEC atmospheric interval. In essence, the GEC is an open dissipative system including microphysical and electrohydrodynamic processes of generation and dissipation of the aeroelectric energy. The atmospheric electric field in the range of short-period aeroelectric pulsations has power-law spectra and contains coherent aeroelectric structures. The main GEC characteristics can serve as an indicator of a stationary state and spatiotemporal dynamics of atmospheric processes.

Several new results have recently been obtained, which have led to a deeper understanding of the physical processes in the global electric circuit. A brief review of recent work in this field is presented in [20]. The main attention is paid to the following aspects: 1. A new description of the global atmospheric electric circuit has been proposed and substantiated. This description relies on the findings of an analysis of the energy characteristics of the quas-istationary field of thunderstorm and fair-weather regions. The resultant estimates characterize the global circuit as the most agile system among the existing geophysical systems with a rather high energy level. The further development of research into the energy characteristics of the global circuit should involve a more comprehensive study and simulations of sources, an elaboration of gas-dynamic lightning models, and a monitoring of thunderstorm and lightning activities.

2. The transient currents that flow after lightning flashes and the contribution of these currents to the global electric circuit have been investigated.

3. Several (primarily numerical) new models have been developed, which permit describing nonstationary and electromagnetic processes in the global electric circuit in planar and spherical geometries. Models of stationary global current systems have also been developed. It is hoped that in the near future, the nonstationary models of the global circuit will be brought to a level enabling the description of large-scale geophysical perturbations and the long-term evolution of the system, gaining a deeper insight into the properties of atmospheric electricity for other planets of the Solar System. Of special interest are the studies of thunderstorm and lightning climatology and simulations of the global atmospheric electric circuit in different scenarios of climate development.

The lifetime of electric energy in the atmosphere is introduced and investigated as is the total electric energy of the atmosphere related to the total mean rate of electric energy dissipation [21]. This lifetime, as determined from general estimations and convenient analytical expressions, turns out to be very small – from about 10 to about 100 s, depending on the assumptions on the control parameters of principal sources in the global electric circuit. In particular the energy lifetime is less than the relaxation time of the "global condenser" and field relaxation time near the ground surface. It is explained by the high dissipative rate of the electric energy in the atmosphere, taking into account that the regions mainly contributing to the total energy and its dissipative rate are connected to the altitudes of active parts of electrified (thunderstorm) clouds in the atmosphere with exponentially increasing conductivity.

The paper [22] focuses on the physical phenomena, leading to large-scale space-charge and electric field generation (electric dynamo) in the planetary atmospheres, and ways of their theoretical description. The main attention is paid to charge-layer formation in atmospheres. Under terrestrial conditions, a problem of charge-layer formation in the atmosphere is important from the viewpoint of both thunderstorm and fair weather electricity. It is important also for the problems of intense layer generation under perturbed ionization conditions, charge layer formation over deserts, high field generation in the mesosphere etc. On the other hand, charge-layer treatment allows verifying electrification theories being applied to more or less simple 1D conditions such as the electrode effect, cloud screening layers, long-term charge layers in mesoscale convective systems. The paper reviews the results of recent research in this field. General conditions of the electro-hydro-dynamic description and their applications to the planetary atmospheres are discussed in terms of the Debye length, mean free path length of charged particles, Langmuir frequency and electrical conductivity. In terms of electrostatic interaction energy, it is found that three phases for charge carriers co-exist in strongly electrified clouds in the Earth’s atmosphere. Crucial role of turbulent motion of conducting media for electric dynamo realization is revealed. The results of recent research in the modeling of the electrode effect, fog electrodynamics, screening layers in clouds and aerosol/dust structures, long-term charge layers in mesoscale convective systems are presented. Nonlinear solutions, demonstrating the formation of charge layers in planetary atmospheres, are examined.

The study [23] examines the way in which different types of lightning, both cloud-to-ground (CG) and intracloud (IC) flashes, drive current in the global circuit. A numerical model of the transient electric field due to CG and IC flashes and their Maxwell relaxation (slow transients) is developed. The electric field (E) and current distributions, the decay time of E, and the total charge transferred to the ionosphere and the ground are calculated. Because of the slow transients, only a portion of the charge neutralized by a flash contributes to the global circuit, with the efficiency depending on the altitudes of the lightning charges. Typical CG flashes have efficiencies of 55–75%, and typical IC flashes have 5–15%. An example from balloon E data has been used to verify the theory. Total current estimations of the combined CG and IC slow transient processes in the global electric circuit range from 50–400 A.

A brief review of recent modeling of the global atmospheric electric circuit is presented in [24]. The main attention is paid to the principal sources of atmospheric electricity forming current systems of different scales.

The distribution of the electric potential, generated by the magnetospheric field-aligned currents flowing along the auroral oval and in the dayside cusp region at the upper atmospheric boundary in the polar ionosphere, is calculated [25]. The obtained electric potential distributions are used to calculate the electric field strength near the Earth's surface. The results of the model calculations are in good agreement with the electric field measurements at Vostok Antarctic station. It has been indicated that large-scale magnetospheric fieldaligned currents, related to IMF variations, can affect variations in the electric field strength in the polar regions via changes in the electric potential in the polar ionosphere, associated with these currents.

A problem of electric current and field dissipation was considered for a conducting atmosphere in absence of electric generators. An establishment of the stationary electric field in the atmosphere for temporal changes of the ionospheric potential determined by thunderstorm generators was analyzed [26]. Analytical solutions of these problems have been found in 1D approach for exponential conductivity profile. Experimental data on the simultaneous measurements of the total Maxwell current density in the USA and Estonia were discussed.

The results of investigations of modeling global circuit and electrification of thunderclouds are considered [27]. The influences of cloud discharges, cloud-to-ground discharges and generators of electrical field, acting in the upper layers of atmosphere on global circuit (global atmospheric potential and the strength of the electrical field near the Earth) are investigated. The theoretical estimates show that the contribution of cloud-to-ground discharges in electric field of atmosphere is less then 10%. Contribution of the generator of electrical field, acting in the polar region can reach a few ten of percents.

The results of modeling of electrification of convective cloud by collision mechanism are considered in ID и 2D cases. The important role of electrification by collisions between ice particles is proved. The 3D equations of electrification of convective clouds are formulated.

A mathematical model is considered to describe atmospheric electric fields in the framework of the quasi-stationary electric approximation [28]. The closed statement of the problem is given in terms of a scalar electric potential. Some correctness issues and some numerical solution algorithms are discussed.

The seasonal effect of the daily variations in the cosmic ray intensity on the conductivity of the Earth-high-conductivity layer column has been analyzed based on the observations of the cosmic ray intensity, atmospheric current, and electric field vertical component, performed from summer 2006 to spring 2007 at Apatity station. The method for correcting the measurements of the atmospheric current and electric field vertical component under complex tropospheric conditions by numerically simulating the spatial structure of the current and field lines in the observation region has been proposed. It has been indicated that cosmic rays are the main source of ions in the winter polar lower atmosphere and are responsible for the type of daily variations in the conductivity, whereas the daily variations in the atmospheric current more depends on the conductivity rather than on the vertical electric field [29].

On the basis of variations of the atmospheric noise electromagnetic field at the frequency of the first Schumann resonance (SR-1), as measured during 2007 in the central part of the Kola Peninsula, it is shown that the changes in SR-1 power reflect the main known space-time features of the global lightning activity. During 2007, the energetic relationships changed significantly between the power maxima of SR-1, caused by the effects of the African, Asian, and American thunderstorm centers. In February, practically full absence is observed of the African power maximum of SR-1. A clearly pronounced maximum of the SR-1 power is revealed near 6:00 UTC, whose the most probable source can be thunderstorm zone in the central Pacific with a maximum of activity within the range of 21:00–22:00 local time; the power of this zone being several times lower than that of three main world thunderstorm centers [30].

On the basis of the two-component measurements of the atmospheric noise electromagnetic field on the Kola Peninsula, a change in the first Schumann resonance (SR-1) as an indicator of global lightning formation is studied depending on the level of galactic cosmic rays (GCRs). It is found that the effect of GCRs is most evident during five months: in January and from September to December; in this case the SR-1 intensity in 2001 was higher than the level of 2007 by a factor of 1.5 and more. This effect almost disappears when the regime of the Northern Hemisphere changes into the summer regime. It is assumed that an increase in the GCR intensity results in an increase in the lightning occurrence frequency; however, the probability that the power of each lightning stroke decreases owing to an early disruption of the charge separation and accumulation processes in a thundercloud increases; on the contrary, a decrease in the GCR intensity decreases lightning stroke occurrence frequency and simultaneously increases the probability of accumulating a higher energy by a thundercloud and increasing the lightning power to the maximum possible values [31].

The observation results of Q-type bursts in the measurements of the horizontal component of the noise magnetic field in the range of the first Schumann resonance in polar regions (Lovozero high-latitude observatory) are presented. Automatic selection of Q-type bursts from the experimental data series is implemented on the basis of a waveform recognition algorithm. The resonant nature of Q-bursts is shown. The possibility of selecting such events in magnetic excitation conditions is highlighted. The global resonator quality upon decreasing the selected waveform amplitudes is estimated. The data obtained by this method are compared with estimates on the basis of Fourier analysis and values known from the world literature. The possible reasons for disagreements of the estimates are analyzed, including the problem of selecting the function approximating the spectrum, the problem of accounting for the background, and the possible irregularity of the spectrum. It is shown that Q-type bursts, besides the quality, allow estimating the resonant frequency of the first oscillation mode; however, the accuracy of such estimation is lower as compared to the results of Fourier analysis methods [32].

3. Thunderstorm electricity and lightning

Thunderstorm electricity is one of the fundamental problems of atmospheric physics attracting attention for many years. In spite of a great volume of performed studies, concerning numerous aspects of thunderstorm physics, there is still no complete understanding of the thundercloud structure formation, discharge initiation, global circuit operation [1-3, 33-37]. During last four years a number of experimental and theoretical investigations of thunderstorm electricity have been performed. A special attention was paid to the study of mesoscale convective systems due to their very high level of lightning activity.

The role of the M component mode of charge transfer to ground in lightning discharges in initiating sprites and sprite halos is examined. M components (surges superimposed on lightning continuing currents) serve to enhance the electric field at high altitudes and, as a result, may increase the probability of sprite (halo) initiation [33]. It appears that occurrence of an M component shifts electric field maximum from the axis of the vertical lightning channel and therefore increases the likelihood of initiation of sprites displaced from the channel axis. Since M components follow return strokes after a time interval of a few milliseconds or more, they may be primary producers of so-called delayed sprites.

A quantitative one-dimensional model treating the formation of charge layers near the 0 °C isotherm in stratiform regions of mesoscale convective systems has been suggested [34,35]. A number of factors principal for the field generation have been taken into account: both non-inductive and inductive melting charging, light ions, a complicated profile of the vertical air velocity near the 0 °C isotherm, the boundary conditions proper for the horizontally extended systems in the global electric circuit. It was found that both non-inductive and inductive melting mechanisms can contribute; the inductive melting charging of ice aggregates was found more preferable, while the contribution of non-inductive mechanisms might be significant depending on particular conditions [34]. The role of light ions in the formation of the positive charge layer near the 0 °C isotherm may be important. If the advection from the convective region ensures charge inflow to the upper charged layers, the melting charging mechanisms are able to explain an observable electric field structure in the whole stratiform region. It is important that the mutual position of the zero point on the vertical air velocity profile and the point of maximum melting-charge-transfer determines the fine structure of the electric field in the vicinity of the 0 °C isotherm.

A study of the conditions of initiation of two types of high-altitude discharges: sprites and halos was performed [36]. A quasi-electrostatic model of generation of the electric field in the middle atmosphere is developed; it takes into account the specific features of charge distribution and charge dynamics in the thundercloud, as well as real profile of the atmospheric conductivity. We take into consideration the nonlinear effects associated with the heating of electrons in the electric field. It is shown that the region where the electric field of the lightning flash exceeds the breakdown field is concentrated around an altitude of about 75 km, which is in agreement with the sprite observations. It is found that the dynamics of the current and discharge of the lightning flash plays a significant role in the initiation of high-altitude discharges in the atmosphere.

The study of regional features of lightning climatology is of great interest for different purposes. Such still widely used characteristics of regional thunderstorm and lightning activity as thunderstorm days and thunderstorm hours seem sophisticated for a modern meteo service. The lightning flash density is a very useful parameter, but it needs rather long-term and well-instrumented observations. We suggest a method of measuring a number of thunderstorm hours during a day as a quantitative, automatically measured index of regional-scale lightning climatology. Under the framework of this study, a multi-functional complex for the registration and analysis of electromagnetic fields has been arranged at the Upper Volga Hydro-meteorological observatory near Gorodets about 60 km North-West from Nizhny Novgorod, and field studies have been performed during the convective seasons of 2007-2010. Radio-emissions from near and far-away thunderstorms in the Upper Volga region were registered. A portable three component (two components of horizontal H-field and vertical E-field) ELF receiver has been used. The sampling frequency was 20 Hz under fair weather conditions and 20 kHz during one hour after the triggering signal when a thunderstorm is detected. The value of the triggered signal corresponded to the mean-level intensity of sferics generated about 100 km away from the observation point. So, we determined a number of thunderstorm hours during a day as a number of fast-rate records. The correlation between a suggested index and the atmospheric temperature has been studied under different meteorological conditions [37].

On the basis of the unique database of electrical and meteorological observations of 2005 and 2006 the statistics of thunderstorm activity events as compared to the fair-weather and disturbed fair-weather conditions over the Upper Volga region is presented. It is important for the estimation of global-scale, regional (synoptic) -scale and local-scale electrical currents supporting the global atmospheric electric circuit [37].

It is well known that there are two basic parts of electromagnetic emissions from a thunderstorm cloud. The 1st one is due to a return stroke and the second is generated by microdischarges on the lightning preliminary stage and between successive return strokes. The purpose of the paper [38] is to consider the second part of electromagnetic emissions from thunderstorm clouds in a frequency range from one to hundreds of MHz. A new approach is developed, which is based on a three-dimensional computer simulation of microdischarge activity in thunderstorm clouds. We suggest that microdischarges on the lightning preliminary stage are connected with the growth of internal electric cell structures in a thunderstorm cloud. The characteristic scale of cells ranges from ten to hundred meters. The source of these cells can be a beam-plasma-like instability in the thunderstorm cloud medium where microdischarges appear as a saturation mechanism for this instability. Interaction of neighboring cells leads to the formation of dynamic chains of microdischarges. Following step-by-step computer simulations, we calculate radio emissions from every microdischarge and sum up the wave amplitudes from all intracloud volume at the reception point. The standard model for a separate microdischarge current is adopted, and the electromagnetic radiation is estimated in the far zone. We obtain the wave forms of electromagnetic field, the temporal development of radiation and the number of electromagnetic pulses. We have found that signal statistics and calculated frequency spectra exhibit a universal power-law (fractal) behavior. The results of simulations are found to be in satisfactory agreement with the experimental data, because the model waveforms demonstrate a close similarity to the observed ones. Also the temporal development with the duration of pulse trains from ten to hundreds of microseconds and the microdischarge number rate up to hundreds of thousands per second are in agreement with the corresponding experimental data [38].

The fractal simulation code is developed [39] to take into account in more detail the temporal dynamics of the cloud discharge, and the fine structure of the electric field and charge in a cloud, to compare the results with the observations and to address some actual problems of lightning initiation physics. It allowed one in particular to understand better the role of the large-scale and fine structure electric field and charge distribution in a thunderstorm cloud, and to recognize some universal features of the breakdown process.

A simple model of a glow corona occurring near the tip of a grounded electrode in a thundercloud electric field that can be enhanced by an approaching downward leader has been studied analytically and numerically with regard to the effect of wind [40]. We obtained an approximate expression for corona current taking into account the (i) removal of space charge from the coronating point due to ion drift and wind and (ii) image of the charge in the ground. As the wind velocity decreases to zero, the expression tends to that obtained previously in the absence of wind. It was shown analytically and numerically that, in a thundercloud electric field, even moderate wind velocities lead to hundreds of percent increase in the corona current. This current decreases with time only slightly in a steady thundercloud electric field, as opposed to the current behavior in the absence of wind. However, even strong wind is not sufficient to affect the properties of a corona intensified in the electric field of an approaching downward leader. The occurrence of wind does not affect the conditions for initiation of an upward connecting leader from grounded objects and consequently the efficiency of lightning rods of ordinary height.

A positive leader in air has been investigated at an open experimental set-up in gaps up to 8 m length [41]. A 6 MV pulse-voltage generator or an artificially generated charged aerosol cloud served as which a voltage source. A dependence of a leader speed on the current changing between 0.2 and 8 A was measured due to synchronous registration of optical image of a discharge and its electrical parameters. A special attention has been paid to a main stage of the leader process when the streamer zone of the leader crosses the gap completely. It was shown that the dependence of a leader speed on the current does not change at this stage which allows one to use this stage on the studies requiring the current control under sufficiently wide interval.

The results of recent studies on lightning protection have been summarized in the monograph [42].

4. High-energy processes and thunderstorms

One of important aspects of atmospheric electrodynamics is nowadays the studies of runaway electron mechanism in the lightning initiation, generation of energetic particles, X-ray and gamma-ray emissions connected to the discharge processes in the atmosphere [43-53].

The observational evidence of RB-EAS discharge in a thunderstorm atmosphere has been obtained [43]. After RB-EAS discharge a discharge of a special type was named developing due to the runaway breakdown (RB) mechanism while an extensive atmosphere shower (EAS) passes through a thundercloud electric field. The observations were fulfilled at the Tien-Shan Mountain Cosmic Ray Station. The widely spread system of oscillation detectors, the special EAS trigger array and the HF radio interferometer were used for measurements. The results of the experiments registering different types of radiation of thunderstorm clouds at Tian Shan High-Altitude Scientific Station of the Physical Institute of the Academy of Sciences is discussed [44]. A series of events was discovered, in which spatial correlation of short gamma-quantum bursts (10–250 keV) and radio-frequency emission (0.1–30 MHz) with the passage of thunderstorm clouds over the facility is observed, as well as temporal correlation of the bursts of this radiation with lightning discharges and the passage of wide air showers. One can assume that the observed bursts of gamma radiation are an experimental proof of realization of the effect of the runaway-electron breakdown.

Variations in the neutron monitor counting rate at the at the mountain level (3340 m above sea level) during the passage of electrically charged clouds above the installation have been investigated [45]. It is established that the decrease in the counting rate with respect to fair-weather level is due to positive values of the atmospheric electric field

(40–50 kV m−1). This effect is observed in the low-energy part of the neutron component intensity and is absent in the high-energy part (neutron emission multiplicity exceeds 6).

The new model of lightning step leader is proposed in [46]. It includes three main processes developing simultaneously in a strong electric field: conventional breakdown, effect of runaway electrons and runaway breakdown (RB). The theory of RB in strong electric field is developed. Comparison with the existing observational data shows that the model can serve as a background for the explanation of gamma bursts in step leader and TGF.

The results of gamma emission observations obtained during thunderstorms at Tien-Shan Mountain Cosmic Ray Station are presented [47]. The energy spectrum radiation of the stepped leader gamma radiation is measured. The total energy of stepped leader emitted in gamma rays is estimated as 10−3–10−2 J. The experimental results are in an agreement with the runaway breakdown mechanism.

The results of the experiments registering different types of radiation of thunderstorm clouds at Tian Shan High-Altitude Scientific Station of the Physical Institute of the Academy of Sciences is discussed [48]. A series of events was found, in which spatial correlation of short gamma-quantum bursts (10–250 keV) and radio-frequency emission (0.1–30 MHz) with the passage of thunderstorm clouds over the facility is observed, as well as temporal correlation of the bursts of this radiation with lightning discharges and the passage of extensive atmospheric showers. One can assume that the observed bursts of gamma radiation are experimental proof of the realization of the runaway-electron breakdown effect.

Experimental data about a strong decrease of the intensity of cosmic ray muons are presented. The event occurred during a thunderstorm on September 24, 2007 in Baksan Valley (North Caucasus). The threshold energy of muons is 100 MeV. In comparison with other events of this type detected previously, this event is remarkable by a longer duration (more than an hour and a half) and by the fact that well-pronounced correlations with lightning strokes are observed for the first time [49].

Energy spectra (estimated experimentally and derived by numerical modeling) are analyzed for the most significant events of anomalous increases of the soft component of secondary cosmic rays detected during thunderstorms in Baksan Valley (North Caucasus) in the period 2003–2007 [50]. The estimates of experimental energy spectra are made using the counting rates in two neighboring ranges of energy release in scintillation detectors, 10–17 MeV and 17–30 MeV.

A new experiment on the detection of thunderstorm neutrons at orbital altitudes is presented. The aims of the experiment called “Scafandr” are to establish the nature of the neutrons and to explore their properties. Also, the dosimetric measurement program is included in the experiment mission. For the neutron program, measurement of the thermal neutron fluxes from an altitude of 350 km down to 200 km is planned. We plan to obtain substantial statistics and resolution of neutron bursts. This will allow for mapping of the neutrons' distribution on the considered altitudes for their comparison with the thunderstorm activity maps and for comparison with the results of neutron burst numerical modeling. Previous experiments carried out are discussed, and their comparative analysis with the presented one is given [51].

A theoretical analysis of the direct passage of neutrons in the atmosphere from an altitude of about 5 km up to several hundred kilometers is performed [52]. These neutrons are considered to be generated during thunderstorms in what favor there is some experimental evidence. Two main mechanisms of the neutrons generation in thunderstorms appeared in the literature: the nuclear synthesis directly in the lightning channel and the photonuclear synthesis owing to production of gamma-rays by the runaway electrons. Both of them are discussed in the present work. For the qualitative analysis we considered the process of neutrons propagation in the atmosphere as consisting of three stages: initial neutron deceleration to thermal energies, then diffusion, and further free propagation. Absorption of neutrons was neglected. Also, in modeling the atmospheric matter only nitrogen and oxygen were considered as the main atmospheric components. With these conditions and taking into account the predicted parameters of the neutron generation source, it is shown that the estimated flux well corresponds to the known experimental results. On this basis the preferred mechanism of the neutron generation is indicated. For a more rigorous picture of the neutrons propagation, capable for description of the slowing down, thermalization, and diffusion processes, one has to perform a numerical calculation and for this we propose a computer simulation scheme based on the cellular automation method. The corresponding plain analysis of the neutrons passage confirms the estimation mentioned above. The proposed scheme can be used for modeling the real neutron source. On the basis of our results we discuss some characteristic features of the observed neutron fluxes. The obtained results are to be tested by the “Radioskaf” experiment based on the scientific device called “RAZREZ.” One of the experiment objectives is detection of neutrons with different energies at altitudes of 200–400 km aiming to reveal the nature and characteristics of the neutron radiation source.

Experimental data related to electric discharges in the upper atmosphere are considered [53]. These discharges occupy enormous volumes of the atmosphere (up to 1000 km3) and are accompanied by optical radiation (in the UV, optical, and IR ranges), and also by gamma-ray radiation. Possible physical processes responsible for the evolution of such discharges are also considered.

5. Lightning and chemistry. Atmospheric electricity, weather and climate

A special attention has been paid recently to the study of atmospheric electricity as inherent part of the Earth climate system. In particular, the global circuit evolution under the climate change was investigated [20].

One of the most interesting problem in this field is chemical effects of lightning. A chemistry-climate model of the lower and middle atmosphere has been used to estimate the sensitivity of the atmospheric gas composition to the rate of thunderstorm production of nitrogen oxides at upper tropospheric and lower stratospheric altitudes [54]. The impact that nitrogen oxides produced by lightning have on the atmospheric gas composition is treated as a subgrid-scale process and included in the model parametrically. The natural uncertainty in the global production rate of nitrogen oxides in lightning flashes was specified within limits from 2 to 20 Tg N/year. Results of the model experiments have shown that, due to the variability of thunderstorm-produced nitrogen oxides, their concentration in the upper troposphere and lower stratosphere can vary by a factor of 2 or 3, which, given the influence of nitrogen oxides on ozone and other gases, creates the potential for a strong perturbation of the atmospheric gas composition and thermal regime. Model calculations have shown the strong sensitivity of ozone and the OH hydroxyl to the amount of lightning nitrogen oxides at different atmospheric altitudes. These calculations demonstrate the importance of nitrogen oxides of thunderstorm origin for the balance of atmospheric odd ozone and gases linked to it, such as ozone and hydroxyl radicals. Our results demonstrate that one important task is to raise the accuracy of estimates of the rate of nitrogen oxide production by lightning discharges and to use physical parametrizations that take into account the local lightning effects and feedbacks arising in this case rather than climatological data in models of the gas composition and general circulation of the atmosphere.

Recently the influence of transient luminous effects on the middle atmosphere has acquire a big attention [55].

Altitude–temporal cross_sections q(z, t) of atmospheric ionization rates by solar protons above the polar regions were calculated using the GOES_10 satellite data on solar proton fluxes for the period of solar proton flare (SPF) on July 14, 2000 [56]. The values of q(z, t) were used further in calculations of variations of the atmospheric chemical composition during the flare in the northern and southern polar regions (70°N and 70°S) by two different 1D photochemical models of the atmosphere (neutral and charged components). The calculation results have shown considerable variation of the ozone content after SPF: a decrease of [O3] was about 80% at altitudes of 65–75 km above northern and 25% in the layer of 55–65 km above the southern polar region. Such decrease of the ozone content is a result of reactions with [NO] and [OH] whose concentrations have grown substantially during SPF. According to calculations, the increase of electron concentration during SPF has reached 3–4 orders of magnitude at altitudes of 50–80 km. A comparison of the calculation results with the observational data on [NO], [NO2], and [O3] from the UARS and HALOE satellites for 70°N have shown a good qualitative correspondence, however, for variations.

From space the fluxes of cosmic rays and cosmic dust (particles with sizes from 0.001 to tens-hundreds microns) come permanently to the Earths atmosphere. In the paper it is shown that cosmic rays define the main characteristics of the atmospheric electricity and cosmic dust defines global cloudiness, albedo, and climate of the Earth. PACS: 96.50.Dj, 96.50.Sf [57].

The focus in the present paper on the nonlinear electro-dynamical systems in the atmosphere that exhibit peculiar scaling features in the spatial and temporal dynamics; we analyze them mostly in terms of their implications into the Earth's climate system[58].

6. Methods of thundercloud investigation for hydro-meteorological service

Atmospheric electricity problem in the field of operative practice has been transformed during last 15 years to practical aspects of thunderstorm electricity including forecast of weather hazards, connected with intensive convective clouds (thunderstorms, tornadoes, hails, squalls, intensive rains), prevention of airplane lightning damage and forest fires, powerful electric line service, definition of precipitation value when using satellite measurement methods, prognosis of tropical cyclone evolution etc. It was caused significantly by the wide using of instrumental methods of thunderstorm observation: ALDF, LDAR, SAFIR, OLS, LIS systems etc. As a result, experimental data on the peculiarities of electric activity of intensive convective clouds have been stored [59].

Reviews of the investigations on the modification of the cloud electric state are considered. Results of the experiments of the initiation of lighting «cloud to ground» are discussed [60].

The results of experimental investigations and some theoretical calculations ratio of variations of ratio amplitudes of the electric and magnetic components of radiation of the lightning discharges in frequency range from 0.3 up to 60 kHz are presented. [61]

Types of complexed passive and active radar weather information obtained for the benefit of different consumers at present are presented. The development of meteorological network based on domestic polarized selection Doppler weather radar is reviewed. The results and prospects of passive radar use in complex with weather radar for estimation of aircraft ice covering, cloud lightning risk, cloud active coercion control are presented. The prospect of common use of weather radars and lightning detectors for cloud lightning activity efficiency increase are presented based on experimental results. The use of radar profilers for wind detection on rocket and spacecraft launch heights provision is examined. A tendency for development of compact domestic weather radar is noted. For use in nowcasting a complexing of both radar and satellite data and terran weather network data is used [62].

The paper presents results of data processing of simultaneous lightning registration with the help of weather radars and lightning detection networks. Analysis shows that application of a one-station direction range finder increases efficiency of lightning detection with weather radars by 10%-15%. Simultaneous operation of a lightning detection network and weather radars allows us to achieve 1 km accuracy of radar thunderstorm detection, excludes instances of false alarms and increases thunderstorm detection efficiency with weather radars by 25-30 % [63].

Review of investigations made by department of atmospheric electricity of the Voeikov Main Geophysical Observatory during last ten years and their future development are considered in [64].

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Atmospheric Ozone

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1. Tropospheric ozone.

1.1. Observations.

Great interest to the problem of the climate change has favored the development of monitoring of the atmospheric composition and, particularly, of ozone and ozone-active compounds. The Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences (IAO SB RAS) set up three new observation sites. They were arranged in the background, urbanized, and sub-urbanized areas in the region of the city of Tomsk [*Arshinov et al., 2007*]. The Prokhorov Institute of General Physics of the RAS (IGR RAS) organized the network of three observation stations for measurements of the surface ozone concentration (SOC). These stations are located in the Karadag conservation area in the Crimea (the background station), in the town of Vyatskie Polyany in the Kirovsk region, and in St. Petersburg [*Zvyagintsev et al., 2010*]. The Obukhov Institute of Atmospheric Physics of the RAS (IAP RAS) equipped a new background station (Zotovo) in the Krasnoyarsk krai. Regular measurements of the O_3, NO, and NO_2 concentrations at the lower level (4 m) of the 300-m tower were started in 2007 in the framework of the ZOTTO international project [*Vivchar et al., 2009; Vivchar et al., 2010*]. The SOC observations were also performed at the 300-m tower in the town of Obninsk in the Kaluga region (the Taifun scientific production association). In April 2010, a Russian ozonometer 3.02P1 (OPTEC) was replaced by the network gas-analyzer 49i (Thermo Scientific). The obtained results showed that the Obninsk station has clearly defined features of a background station [*Tereb et al., 2010*].

In 2007-2010, monitoring was continued at all SOC-monitoring stations mentioned in the previous review of 2003-2006 [*Elansky, 2009a*], namely, at the background stations, such as the Kislovodsk High-Mountain Station (KHMS) and the Lovozero, Mondy, Danki, and Shepelevo stations; the urban stations, such as the Moscow, Dolgoprudnyi, and Tomsk stations; the Moscow ecomonitoring network (26 stations); and several other observation sites, which monitor on irregular basis in cases of emergency. All the background stations are equipped with the same sets of network instrumentation calibrated regularly against the ENV 03-41M № 1298 mobile standard and the Japan national standard (Mondy station).

The top-quality system of urban-air monitoring was organized in the Moscow megapolis. The only disadvantage of this system consists in its belonging to different departments, namely, to the Russian Academy of Sciences, the Roshydromet, and the Moscow Government, and, thus, in insufficient coordination of the observation regimes and of procedures of data-quality control. However, close collaboration between responsible experts and regular calibration of the instruments against either the mobile standard or the standard of the Russian laboratory of ecological monitoring allowed for obtaining the reliable information on the spatial distribution and temporal variability of ozone over the megapolis. This was demonstrated by an analysis of the SOC observations under extreme conditions of the summer 2010.

To study the peculiar features of the SOC distribution in the atmospheric surface layer over the territory of Russia, the TROICA (TRanscontinental Observations Into the Chemistry of the Atmosphere) field experiments were performed on the basis of the TROICA mobile railroad laboratory of the IAP RAS [*Elansky, 2007; Elansky et al., 2009b*]. In the period 2007-2010, five experiments were realized. In the course of these experiments, the atmospheric contents of ozone and other key minor species were measured along the Moscow-Vladivostok railroad section (2007, 2008, and 2009) and, in European Russia, along the Moscow-Michurinets (2008), Murmansk-Sochi (June 2010), and Nizhnii Novgorog- Moscow -St. Petersburg (December 2010) railroad sections. The

Russian-French large-scale flight experiments were performed aboard the AN-30 aircraft-laboratory of the IAO SB RAS [*Paris et al., 2010a; Paris et al., 2010b*]. To study the daily variations of the vertical ozone distribution in the atmospheric boundary layer, regular measurements aboard the AN-2 aircraft of the IAO SB RAS were started in 2010. In the period from 2007 to 2010, some institutions carried out field expeditions to study the local regional peculiarities in the ozone behavior under the effect of different meteorological and anthropogenic conditions.

In the last years, collaboration between the states of the Former Soviet Union began to re-establish. The joint SOC observations were performed at the Issyk-Kul' (Kyrgyzstan), Terskol (Russia), and Kiev (Ukraine).

The automation of measurements and the data-quality control were developed. Creation of the ozone primary standard intended for calibration of the secondary standards and gas-analyzers in the Mendeleev Institute of Standardization and Metrology was of great importance. A number of the stations (IAP RAS, IAO SB RAS, IGR RAS) were automated. In June 2010, Yu.P. Trutnev, the Minister of the Ministry of Nature, took part in observations performed along the Sochi-Adler railroad section (TROICA-14). He inspected the instrumentation installed aboard the TROICA laboratory and recommended to take this laboratory as a basis for the air-quality monitoring in Olympic Sochi.

The semiconductor-ozonometer elaboration by the members of the Karpov Institute of Physical Chemistry (IPC) has been continued successfully. Working instruments designed on the basis of semiconductor sensors of resistance type were manufactured. A comparison of these instruments with the DASIBI-1008RS network gas analyzers and ENV 03-41M standard was successful [*Obvintseva et al., 2007; Belikov et al., 2009*]. Numerous laboratory experiments on ozone interaction with hydrogen chloride, polymer materials of different chemical compositions, soil samples, and substances entering into the composition of atmospheric aerosols gave a number of practical results and led, in particular, to production of effective ozone-destroying filters, which are of commercial value.

1.2. Distribution and variability

The most long series (since 1989) of observational data on the SOC was obtained at the KHMS, (Fig. 1). The yearly mean SOC values decreased abruptly over the period from 1989 to 1996; then, up to 2006, the decreasing decelerated; in the last years, the SOC practically did not change [*Elansky, 2009a;Elansky et al, 2010*]. The linear SOC trend is equal to –1.53±0.14 ppb/year for 1989-1996 and to –0.44±0.06 ppb/year for the entire observation period 1989-2010. At the Alpine high-mountain stations, no significant trend was observed for the last decade. Thus, opposite SOC trends, i.e., a SOC decrease at the KHMS and a SOC increase at the Alpine stations, were observed only in the period up to 1999, when industrial production and industrial and transport emissions of ozone precursors in the Former Soviet Union decreased abruptly.

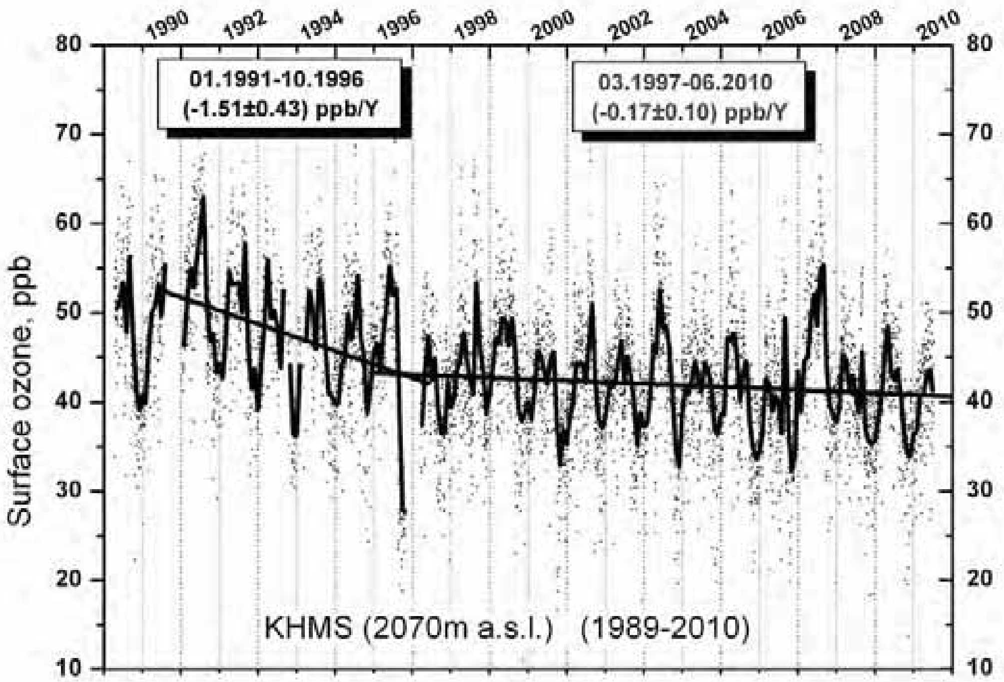

Fig.1. Daily and monthly mean surface ozone concentrations at High Mountain Kislovodsk Station for 1989-2010.

The SOC series sufficiently long-term (from late 1996 to 2010) for estimating the trend was obtained at the Mondy station [*Timofeeva et al., 2008*]. As compared to the KHMS, this station is located at the same altitude and at a close latitude. For these stations, the SOC values averaged over the period 1996-2010 are almost equal, 44.0 ppb (Mondy) and 42.0 ppb (KHMS). No significant trend was observed at these stations over this period; the amplitudes of the seasonal and daily variations were almost the same. The differences between the data obtained at these two stations consisted in the occurrence and in the absence of the August secondary seasonal maximum at the KHMSS and at the Mondy station, respectively, and in the different time of the SOC daily minimum, which was observed at 12:00-13:00 and at 10:00-11:00 local time at the KHMS and at the Mondy station, respectively. These differences represent the manifestations of the specificities in the uphill-downhill, regional, and large-scale atmospheric circulations and, to a small extent, of the anthropogenic effect [*Elansky et al., 2010*]. It seems to be of interest to perform a joint analysis of the long-term observations performed at high-mountain stations located in Alps, Caucasus, Siberia, and Japan and to specify the variations in the effect of the atmospheric circulation on the ozone content for the last two decades.

The ozone concentration measured under background conditions over the Siberian plain differs significantly from that measured at the high-mountain stations (Fig. 2). The yearly mean SOC observed at the Zotino station is 26.2 ppb, while the yearly mean SOC level measured in the TROICA experiments under background conditions (within the latitudinal belt 48^{o}N-58^{o}N between Moscow and Vladivostok) is about 27 ppb [*Pankratova et al., 2011*]. The daily-variation amplitudes and seasonal variations obtained at the plain stations are much greater than those obtained at the high-mountain stations. The main causes of the SOC formation in Siberia are intensive dry ozone deposition on the surface covered with vegetation under conditions of highly-stable nighttime atmospheric boundary layer and mild daytime vertical air mixing over the zone of boreal forests. In Siberia, such conditions are characterized by high seasonal repeatability. Therefore, the mean SOC level observable over these regions is lower in comparison with not only that obtained at high-mountain stations, but also that obtained at background island and coastal stations (e.g., Mace Head, see Fig. 2) where inversions are rather rare.

In [*Engvall stjernberg*], the contributions of the processes of ozone transport and of ozone sink on the ground to the ozone variability in Siberia were estimated. For this aim, the observational data obtained at the Zotino [*Skorokhod et al., 2007; Skorokhod, Verkhovets, 2006*] station and in the TROICA railroad and YAK-AEROSIB flight experiments (2006-2008) [*Belan et al., 2010*] were used. To specify the advective flows of minor atmospheric components, the potential emission sensitivity was calculated by using the FLEXPART Lagrangian dispersion model. It is shown that the Siberian region is characterized by unusually high vertical ozone gradient, namely, the summer ozone concentrations measured aboard the aircraft at altitudes over and below 3 km are 67 and 32 ppb, respectively, while the SOC is 18-27 ppb. Contacting of air with forest-covered surfaces under conditions of slight air mixing leads to ozone depletion. The ozone sink in Siberia is influenced not only by the dry ozone deposition but also by the volatile organic compounds (VOCs). In whole, in Siberia, the ozone sinks prevail over its sources connected with the advective transport of ozone and ozone precursors from southern and western regions (China, Europe, etc.). Thus, Siberia, due to its large-scale area, is capable of contributing significantly to the ozone global balance [*Elansky et al., 2009b;Pankratova et al., 2011; Engvall stjernberg*].

The results of an analysis of observational data obtained in the TROICA experiments are published in [*Elansky et al., 2009b;Pankratova et al., 2011; Engvall stjernberg*; *Elansky et al., 2010; Turnbull et al., 2009; Tarasova et al., 2007; Timkovsky et al., 2010; Vartiainen et al., 2007*]. The detailed structure of the spatial distribution of about 20 VOCs playing the most important role in the surface-ozone chemistry over continental Russia was first obtained by using a proton mass-spectrometer. In particular, high concentrations of terpenes and isoprene were recorded in the zones of boreal forests (the Siberian taiga) and of broad-leaved forests in the Primorskiy krai (between Khabarovsk and Vladivostok), respectively [*Timkovsky et al., 2010*]. A high level of biogenic VOCs was observed in the region of the Caucasian Black Sea coast (between Tuapse and Sochi). Enhanced concentrations of VOCs and salt aerosols, intense solar radiation, and high air humidity favor intensification of photochemical and heterogeneous processes over this region. In combination with breeze and uphill-downhill circulations, these processes represent the transport-chemical system that is complicated for numerical simulation. Apparently, the system of air-quality monitoring and weather forecasting that is under creation in the Olympic Sochi region should consider all the above-mentioned factors and trends.

The peculiar features in distribution of minor atmospheric species over Northern Eurasia are revealed. Along the latitudinal belt 48 ^{o}N -58^{o}N, SOC increases eastward in all seasons but winter [*Elansky et al., 2009b; Pankratova et al., 2011*]. The mean gradient is 0.47±0.02 ppb per 10^{o} of longitude. The SOC daily-behavior amplitude also increases eastward. These data are influenced by the eastward decrease in NO_x emissions, long-term intensive near-surface temperature inversions in the mountain areas of eastern Siberia, frequent forest fires, transport of pollutants from the north-eastern region of China, high isoprene concentrations in the Primoskiy krai, and the occurrence of the intensive subtropical high frontal zone with characteristic stratospheric-air intrusions over the eastern regions of the continent. In Siberia, moderate concentrations of ozone precursors, NO_x, CO, and VOCs of biogenic and anthropogenic origins as well as a rather low level of UV radiation do not favor active chemical formation and destruction of ozone. The seasonal and daily SOC variations depend largely on the vertical air mixing and ozone sink on the ground. Their character and amplitudes obtained for Siberian background areas (along the Moscow-Vladivostok route, background conditions covered from 35 to 52% of the total observation time) differ from those obtained at the Mace-Head station (see Fig. 2) just because of high stability of the atmospheric boundary layer over the central area of the continent.

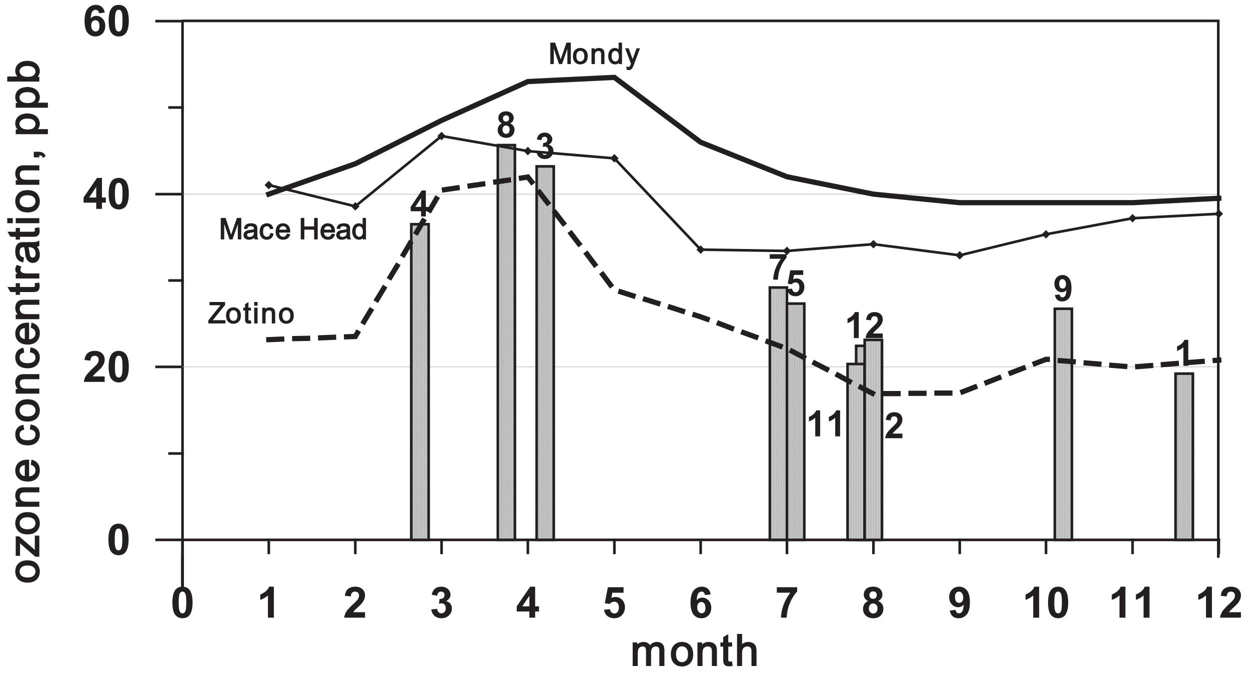

Fig. 2. Averaged O_3 concentrations over Moscow-Vladivostok corridor for TROICA experiments (1-12 – number of experiment) compared with monthly mean O_3 concentration values at Mondy, Zotino, Mace Head (Ireland).

The SOC distribution over the Northern Eurasia may be somewhat influenced by the significant methane emissions from the industrial and natural sources. A comparison of the observational data on the methane isotopic composition ($\delta^{13}C$) with the results of numerical simulation applying the values of emissions of different isotopic compositions showed that CH_4 sources located in the Western Siberia are underestimated [*Tarasova et al., 2009*]. The inventory of the CH_4 sources over the Russian area should be revised toward an increase in the emissions from the "light' sources (swamps, cud-chewing animals, rubbish recycling, etc.) and toward a decrease in the emissions from the "heavy" sources (extraction and processing of oil, gas, and coal, biomass burning, etc.).

The generalization of the 12-year data series of ozone observations aboard the AN-30 aircraft-laboratory over the Western Siberia revealed no noticeable trend in the ozone concentration within the atmospheric layer from 0 to 7-km height [*Antokhin et al., 2010a*]. The ozone concentration is significantly affected by the eastward transport of ozone precursors from Europe, which is well-marked in the free troposphere (above 2 km). In the atmospheric boundary layer, the zonal atmospheric transport is affected by Urals. Air trajectories round the mountains at the south or at the north [*Antokhin et al., 2010b*]. The statistical treatment of a great volume of observational data allowed for obtaining the reliable estimates for the ozone sink on cloud aerosols. The mean extension of clouds was about 1.5 km, and the decrease in the ozone concentration within the cloud was 11-15 ppb. According to the cloud type, this decrease varied by a factor of two [*Arshinov et al., 2010*]. These estimates are confirmed by laboratory experiments on ozone decomposition within the chamber with water aerosol [Kotel'nikov et al., 2011].

An analysis of the SOC values obtained at the world network of ozonometric stations gave a number of unexpected results. By the methods of cluster analysis, 114 stations were classified into six main groups differing by the seasonal and daily SOC variations characteristic for them: background stations (remote, unpolluted), plain stations slightly polluted, plain stations polluted, slightly elevated stations polluted, mountain stations, and polar (coastal) stations [*Tarasova et al., 2007; Zvyagintsev et al., 2008a*]. For the European region, characteristics of the periodic SOC variations were determined from the data of 98 stations that are included into the EMEP program. The maps of the "normal" distribution and standard deviations for the SOC fields were drawn for each calendar day and each hour of the year [*Zvyagintsev et al., 2008b*]. The effect of the direction of air-mass transport on the seasonal variations of the surface concentrations of O_3, CO, and NO_2 is estimated. Practically, for the territory of Europe, the summer maximum is highly pronounced when the air-mass transport is southern and eastern and is slightly pronounced when the air-mass transport is northern or western. From 10% (the Moscow region) to 30-40% (north-west of continental Europe) of the variations in the surface concentrations of these gases can be explained by the variations in the transport direction [*Zvyagintsev et al., 2010a*].

Ozone in cities

The extreme situation of the summer 2010 demonstrated the possibility of abrupt deterioration of urban air quality in accordance with the weather and climatic variations. This circumstance promotes attraction of attention to the development of the system for monitoring of ozone and its precursors in cities and industrial centers. Several workshops that dealt with the 2010 situation allowed integration of the disembodied observational data and their complex analysis; the obtained results are now presented at scientific conferences and prepared for publication.

The variations in the atmospheric composition over Moscow are described in [*Elansky et al., 2011*]. In the period from June 18 to August 18, 2010, the Moscow megapolis was within a blocking-anticyclone zone. The July-mean air temperature in Moscow was 26.0°C and exceeded the temperature averaged over the entire 120-year observation period by 7.8°C. On July 29, 2010, a record high temperature of 38.3°C was fixed. Such weather caused numerous forest and peat-bog fires; the smoke from these fires began to be perceptible in Moscow in the third decade of July. From August 6 to August10, visibility range decreased to100-200 m due to the dense aerosol fog. In the period of blocking action, the concentrations of O_3, NO_x, CO, VOCs, SO_2, CO_2, CH_4, NH_3, and aerosols increased. In June-July, in the absence of smoke, the SOC increment was 0.6 ppb/day. The maximum values of the concentrations of ozone and other pollutants were observed under the August 6-9 smog situation, when the plumes of the nearest peat-bog fires were summed with the plumes of remote forest fires. On August 7, hourly-mean concentrations of pollutants at the Moscow observation station reached the values that are maximum for the entire 2002-2010 observation period: O_3 - 134.2 ppb, NO – 175.9 ppb, NO_2 - 214.7 ppb, CO -15.8 ppm, CO_2 – 548.4 ppm, CH_4 – 3.9 ppm, and SO_2 -15.2 ppb. Accumulation of the pollutants in the surface air was promoted by the boundary-layer stability strengthened by the dense aerosol fog.

At the Dolgoprudnyi station and at the network of the Mosecomonitoring stations, close values for the concentrations of each of three gases, O_3, NO_x, and CO, were obtained [*Ivanov et al., 2010*]. At the Zvenigorod station (40 km to the southwest of Moscow) and at the Obninsk station (80 km to the south-southwest of Moscow), the concentrations of ozone and its precursors also reached the record high values on August 7-8, 2010, i.e., on the days of the highest smoke content. At the Obninsk station, the O_3, CO, CH_4, and CO_2 concentrations were equal to 125 ppb, 15 ppm, 3.1 ppm, and 450 ppm, respectively [*Ivanov et al., 2010*].

The long-term surface-ozone measurements were carried out not only over the Moscow region, but also in Kiev, the Ukraine capital. In [*Zvyagintsev et al., 2010b*], the SOC variations observed in these two megapolises are compared. It was found that the SOC seasonal and daily variations observed in these megapolises are close. In summer, in July-August especially, the episodes, when the ozone concentrations exceeded the Russian standard of the maximum permissible concentration (80 ppb), were often revealed in Moscow and in Kiev. Therewith, such episodes occurred more frequently in Kiev than in Moscow. To predict such extreme situations, a statistical model, in which the ozone concentration is presented as a regression function of the temperature and humidity, was developed [*Zvyagintsev et al.,2010b*]. More complete quantitative expression for the ozone concentration as a function of the temperature, humidity, wind speed and direction, other meteorological parameters, concentrations of ozone precursors, NO_x, and CO, and ozone concentrations in previous periods was established [*Zvyagintsev, 2008c; Zvyagintsev et al., 2008c*]. On the basis of this expression, a synoptic-statistical method of prediction of the daily-maximum SOC values for different cities and different ozone-observation sites was proposed.

Repeated crossing of cities by the mobile railroad laboratory in the course of the TROICA transcontinental expeditions allowed for revealing the peculiar features in the spatial distributions of ozone and other minor atmospheric components over [*Elansky et al., 2009b*]. For the Russian cities over the period from 1995 to 2009, a positive trend in the ozone concentration revealed itself as the general tendency. This trend was accompanied by an almost twofold increase in the NO_x concentrations. Their increase was also observed in the rural areas, although to a lesser extent. The evident cause of these trends consisted in intensification of NO_x emissions due to the revival of industrial enterprises and to the abrupt increase in the number of vehicles in Russia from 18 millions in 1995 to 36 millions in 2008. Other possible causes consisted in the wide use of new substances and compositions as fuel, building materials, household articles, and other subjects of human activity. This progressing tendency led to an increase in emissions of reactive VOCs to the atmosphere and to heightening in the oxidative ability of urban air. A decrease in the difference between the low ozone contents in cities and high ozone contents in rural areas is one of the consequences of these changes. Moreover, by the 2005-2009 period, the warm-season ozone concentration observed over small towns (with population less than 50000) began to exceed that observed over rural areas [*Elansky et al., 2009b*].

In [*Elansky et al., 2010*], the results of the unique experiment on observations of the atmospheric composition over Moscow from the mobile railroad laboratory moving across the megapolis and around it (the TROICA-6 experiment) are presented. In this work, the sources of pollutants and the character and degree of the megapolis effect on the regional atmosphere are revealed. An important advantage of observations from the mobile laboratory that moves along electrified railroads is the possibility of estimating the flows of pollutants from different sources, including the trans-boundary flows, i.e. the flows entering and leaving megapolises. In particular, it was found that the flow of aromatic hydrocarbons entering the Moscow megapolis area constitutes a quarter of the flow of these substances leaving this megapolis [*Elansky et al., 2010*].

2. Ozone in the stratosphere and mesosphere.

2.1. The total content.

The total ozone content (TOC) has been monitored at the Rosgidromet ozonometric network composed of 28 stations. The M-124 model of the ozonometers that have operated at the network for more than 25 years was recently modernized in the Boeikov Main Geophysical Observatory (MGO). This modernization provided maintaining of the high-quality measurements. The procedure of the TOC calculations from the data of zenith observations of clear and cloudy sky was also refreshed; this refreshment allowed for heightening the accuracy of the TOC values obtainable from the zenith-sky measurements up to that obtainable from the measurements of the direct sunlight. The volume of information incoming from the stations was increased significantly through new possibilities allowing measurements at any cloudiness (except rainy and snowy days) and at the solar heights from 5° to 70° and, thus, the possibilities of high-latitude stations were extended significantly. In 2008-2010, the experimental models of the ultraviolet ozone spectrometer (UVOS) intended for reequipment of the Rosgidromet ozonometric network were tested at four stations. These instruments allow the TOC, total UV radiation, and zenith-sky radiation measurements with no more than 2-s exposition over the spectral range 290-400 nm with a resolution of less than 1 nm. Reequipment of the stations with the new spectral instruments is expected by 2015. In 2010, the first-rank working standard for the spectral density of irradiance in the range 250-800 nm was put into operation in the MGO; this standard was attested by the Gosstandard [*Solovatnikova, 2009*].

The TOC measurements with the Brewer spectrophotometers were continued at the KHMS and at the Obninsk and Tomsk stations. In 2008, a regular calibration of the spectrophotometers against the mobile standard (the Brewer-17 spectrophotometer) was performed at the Obninsk station. In the high latitudes, the TOC was measured with the SAOZ spectrometers at the Central Aerological Observatory (CAO) at the Salekhard (66.5^{o}N, 66.7^{o}E) and Zhigansk (66.4^{o}N, 123.2^{o}E) stations [*Hendrick et al., 2010*]. The total NO_2 content measurements with the UV/Vis spectrophotometers were continued at the KHMSS and the Zvenigorod, Tomsk, Salekhard, Zhigansk, and Issyk-Kul' stations [*Gruzdev, 2007; Gruzdev, Elokhov, 2009a; Gruzdev, 2009b; Gruzdev and Elokhov, 2010a*]. Occasional measurements of the total O_3 and NO_2 contents were performed on the basis of the mobile laboratory (the TROICA experiments).

An activity aimed at creation of a system for monitoring of the contents of O_3, NO_2, and other minor atmospheric gases by using spacecrafts was started. Two different versions of the instrumentation intended for installation at different satellites are under design. A more complicated system under design will measure the TOC within the satellite-covered band of 800-km width with a spatial resolution of 10 km. The installation of this system at the Zond spacecraft that will move in a circular solar-synchronous orbit at heights from 600 to 650 km is planned. The launching of the spacecraft is planned for 2015. The launching of the simplified version of this system is planned for 2014 at the Ionosphere spacecraft.

In the framework of collaboration with the states of the Former Soviet Union, the O_3 and NO_2 contents and fluxes of UV solar radiation were measured in Belorussia (Minsk, the Molodezhnaya Antarctic station, field experiments), Moldova (Kishinev), and Kyrgyzstan (the Issyk-Kul’ station). A definite progress is also reached in the cooperative development of the methods of remote sounding and of consideration of observational data [*Krasovski et al., 2010a; Bolotsko et al., 2010; Krasovski and Liudchik, 2010b; Aculinin and Smicov, 2010a; Aculinin and Smicov, 2010b*].

An analysis of the observational data obtained over Russia on the basis of ozonometric stations and satellites for the period 1973-2009 showed that, the TOC decreased by 5-8% in 1973-1996 and later increased by 2-4% [*Zvyagintsev and Ananiev, 2010c*]. The long-term variations in the TOC are largely connected with the variations in the solar activity and index of the North-Atlantic oscillations. A comprehensive analysis of the observational data obtained at the Russian and world ozonometric networks and aimed at the formulation of statistical relations with such forms of circulation of the global stratosphere as the zonal-wind quasi-biannual oscillations (QBO) within the equatorial stratosphere, North-Atlantic oscillation, and El-Ninio is given in [*Titova et al., 2009*]. This analysis is extended over the results of satellite ozone measurements performed over the Northern Hemisphere. In particular, it was noted that, in the polar and middle latitudes of the Northern Hemisphere, the space region characterized by a high ozone content extended in January-February 2008-2009 and 2009-2010 over an unusually large region and the reconstruction of the winter stratospheric circulation to the summer regime occurred anomalously early, namely, in late January instead of the usual March-April period.

The results of a statistic NCEP/DOE reanalysis of the mid-zonal TOMS data for 1979-2005 and of the zonal-wind speeds and temperatures at the atmospheric heights of 20-100 mbar showed that the decrease in the TOC and in the lower-stratosphere temperature in the last decades was accompanied by a decrease in the rates of the western winds; this is most pronounced at the atmospheric heights around 50 mbar [*Visheratin, 2007*]. The TOC trends are significant at a level of 0.99 mbar out of tropical latitudes, the temperature trends are significant everywhere but a narrow equatorial zone and the latitudes less than 50^{o}S, and the wind trends are significant only at a height level around 50 mb and over the latitudinal belt 30^{o}-50^{o} in both Hemispheres. For most of the latitudinal zones, the temperature, wind, and TOC series show rather clearly the triplet in the QBO and in the oscillations characterized by periodicities of 4-6 and 9-13 years.

The connection between the TOC and the 11-year solar-activity cycles was studied [*Visheratin et al., 2008; Visheratin, 2011*] on the basis of satellite measurements. The phase of the maximum of the quasi-decade TOC oscillations starts in northern middle and high latitudes and coincides with the termination of the activity-increase phase in the 11-year solar-activity cycle. Over the tropical zone, the maximum oscillation phase is 0.5-1 year behind. The maximum delay for this phase is about two years over the latitudinal belt 40^{o}S -50^{o}S.

In [*Gruzdev and Bezverkhnii, 2010b*], indirect evidences of possible effect of ozone on the quasi-biannual cyclicity. The cross-spectral analysis of the temporal series for equatorial-stratospheric zonal wind-speed and for the solar UV-radiation flow revealed a high coherence between the variations of these parameters on a quasi-biannual scale (24-30 months) for the atmospheric layer 500-1 hPa (~6-48.5 km). The wind speed QBO delay relative to the solar-radiation flow QBO has a maximum value of about 24 months at a height level of about 100 hPa (16.5 km) and decreases with the height, and the wind-speed variations in the stratopause vicinities (~1 hPa) are in almost the same phase with the solar-radiation flow variations. This means that the QBO in the short-wavelength solar radiation can influence the quasi-biannual zonal-wind cyclicity in the vicinities of the equatorial stratopause, where the ozone temperature is maximum. The variations in the meridian gradient and in the degree of curvature of the meridian profile of the ozone content within this layer can synchronize the wind-speed QBO with the solar-radiation variations. To synchronize the oscillations characterized by close frequencies, a weak interaction is sufficient; under the conditions of QBO, the weak interactions in the vicinities of the stratopause can be caused by absorption of the UV solar radiation by ozone.

The effect of tropical cyclones on the TOC field was studied in [*Teteb and Nerushev, 2007; Nerushev, 2008*] for all steps of the cyclone development from the depression to the storm. It was shown that the effective size of a negative anomaly within an ozone layer and the depth of this anomaly depend on the sizes of the zones of storm and vortex winds and on the tropical cyclone intensity. Therewith, the correlation between the ozone-anomaly and tropical cyclone sizes is higher than the correlation between the ozone-anomaly depth and the cyclone intensity. In the ground of the interpretation of the results obtained in this work, The well-known conceptual model of the effect of tropical-cyclones on the ozone layer (see [*Elansky, 2009a*] underlies the interpretation of the results of the work.

The variations and trends in the total NO_2 content are analyzed on the basis of ground-based spectrometric measurements performed at the NDACC world network stations [*Gruzdev, 2007;Gruzdev, 2009b*]. A multiple linear regression model was applied. It considers the linear trend and the yearly behavior of NO_2, the effects of solar and geomagnetic activity, quasi-biannual cyclicity, El-Ninio (the Southern oscillation), and El-Chichon and Pinatubo eruptions on the NO_2 content. The estimations showed that the NO_2 yearly linear trends are, as a rule, positive over the middle and low latitudes of the Southern Hemisphere and negative over the middle and low latitudes of the Northern Hemisphere. The maximum estimated values of the positive and negative trends are about 10% per 10 years. The estimated yearly trends for the high and polar latitudes of both hemispheres are statistically insignificant. In the periods of maximum and minimum solar activity, the NO_2 contents differ significantly; in the middle latitudes of both hemispheres, the NO_2 content in the periods of minimum solar activity is higher than that in the periods of maximum solar activity, the difference reaching up to by 10%. A significant negative effect of the solar activity on the NO_2 content is forecasted for those stations where the solar-activity effect on the TOC is positive. In whole, the results of the model calculations of the linear trends and the solar-activity effect on the NO_2 content differ significantly from the estimates calculated on the basis of real measurements [*Gruzdev, 2007;Gruzdev, 2009b*].

The stratospheric ozone sensitivity to the NO_2 and HCl contents was studied in [*Gruzdev, 2009c*]. It was shown that the long-term conditions of lowered NO_2 contents in the stratosphere (that occurs over the middle latitudes of the Northern Hemisphere) promote ozone formation and, thus, somewhat mask its destruction by chlorine-containing minor gases. This means that the stratospheric ozone-destruction process caused by the emissions of Cl-F-hydrocarbons to the atmosphere is underestimated. Over the middle latitudes of the Southern Hemisphere, on the contrary, the positive trend of the NO_2 content promotes an increase in the ozone content and leads to overestimation of the contribution of Cl-F-hydrocarbons to ozone destruction if the NO_2 trend is ignored.

The results of ground-based measurements of the total NO_2 content at the Zvenigirod station of the IAP RAS are used for validation of the satellite data of NO_2 measurements with the OMI instrument [*Gruzdev and Elokhov, 2010a*]. The data comparison is performed for unpolluted conditions when the total NO_2 content is presented largely by its stratospheric portion. A rather good agreement of the NO_2 content values obtained from ground-based and satellite measurements; this agreement becomes better as the procedure of satellite data processing is being improved. A comparison of the values of the NO_2 content in the troposphere gives a bad agreement, which is, evidently, caused by strong spatial irregularity and temporal variability of the NO_2 field during episodes of pollution, what leads to different estimates of the NO_2 content in the troposphere due to different spatial resolution inherent in ground-based and satellite measurements.

Several papers [*Popovicheva and Starik, 2007; Shonija et al., 2007; Starik et al., 2010*] are dedicated to the study of the effect of aircraft flights on the gas and aerosol composition of the atmosphere. The processes of water-vapor absorption by soot particles, coagulation with sulfate aerosols, and an increase in the aerosol H_2SO_4 content are analyzed in detail. The consequence of these processes is an increase in the concentration of cloud condensation nuclei in the aircraft plume. In [*Popovicheva and StarikC, 2007*], the modern level of experimental studies of hygroscopicity of soot particles and their efficiency as crystallization centers is presented and estimated the ability of soot particles for formation of condensation nuclei in the aircraft plume and of nucleation nuclei in the upper troposphere. The consequences of emissions of aviation soot aerosols to the atmosphere, including their effect on the ozone content, are estimated.

2.2. Vertical distribution.

The long-term monitoring of the vertical ozone distribution (VOD) in the atmosphere over Moscow was continued in the Physical Institute of RAS (PI RAS) with the modernized spectroradiometer operating at the 142.2 GHz with the spectral resolution from 0.1 MHz (at the line center) to 20 MHz (at the line wings) [*Solomonov et al.,2009; Solomonov et al., 2010*]. The spectroradiometer allows for recording the ozone spectral line practically without shape defect, what is important for highly-accurate retrieval of the VOD in the stratosphere and mesosphere. In the PI RAS, the effective system for monitoring the upper-atmosphere composition is under creation. It is based on the instruments and methods of microwave sounding. New VOD and chlorine-oxide retrieval algorithms based on Tikhonov's regularization method and statistical regularization method are developed [*Solomonov et al., 2007*]. Numerical experiments performed by the closed algorithm allowed reveal the optimum combination of these two methods for VOD retrieval at the heights of stratosphere and mesosphere with minimum errors. The algorithm that uses the method of statistical regularization has significant advantages in the calculating speed for inverse problem solution and in the accuracy of retrieval at the heights of the lower

(12 - 20 m) in comparison with Tikhonov's algorithm. Meanwhile, Tikhonov's algorithm gives better results for retrieval of complex (deformed) profiles.

The peculiar features of the height-time ozone distribution are specified from the data of microwave sounding; these feature reflect the evolution of the ozonosphere over middle latitudes in 2007-2010 [*Solomonov et al., 2010*; *Kropotkina et al., 2007*]. The variations in the VOD characterizing response of the ozonosphere to strong stratospheric warming in January 2009 are studied. The ozone contents at different height levels of the stratosphere were correlated with the potential vorticity (*PV)*, temperature, location and intensity of the polar stratospheric vortex, and other atmospheric characteristics.

The simultaneous microwave observations of the VOD were continued over Moscow (PI RAS) and in high latitudes over the Apatites (Institute of Applied Physics RAS (IApP RAS) [*Kropotkina et al., 2007*]. In contrast to previous stages of the simultaneous observations in the winter of 2002/03 and in the period 2003-20006, observations of the ozonosphere in the cold season of 2009/10 was performed by the above-mentioned method with a modernized instrumentation of the PI RAS at a frequency of 142.2 GHz over Moscow and a new ozonometer of IApP RAS at a frequency of 110.8 GHz over the Apatites. The results thus obtained give a quantitative estimate for a significant influence of the atmospheric dynamics on the ozone spatial distribution in the stratosphere. For example, at a height level of 10 mbar (about 30 km), the coefficient of correlation between the ozone concentration and the potential vorticity (*PV*) was equal to −0,86±0,03.

The balloon sounding of the VOD was performed by the CAO in the winter-spring period at the Salerkhard station in the framework of the MATCH international program. In the winter 2008, the balloon sounding of the VOD was performed in polar latitudes at the Severnyi Polyus-35 floating station [*Jonson et al., 2010; Jonson et al., 2009*].

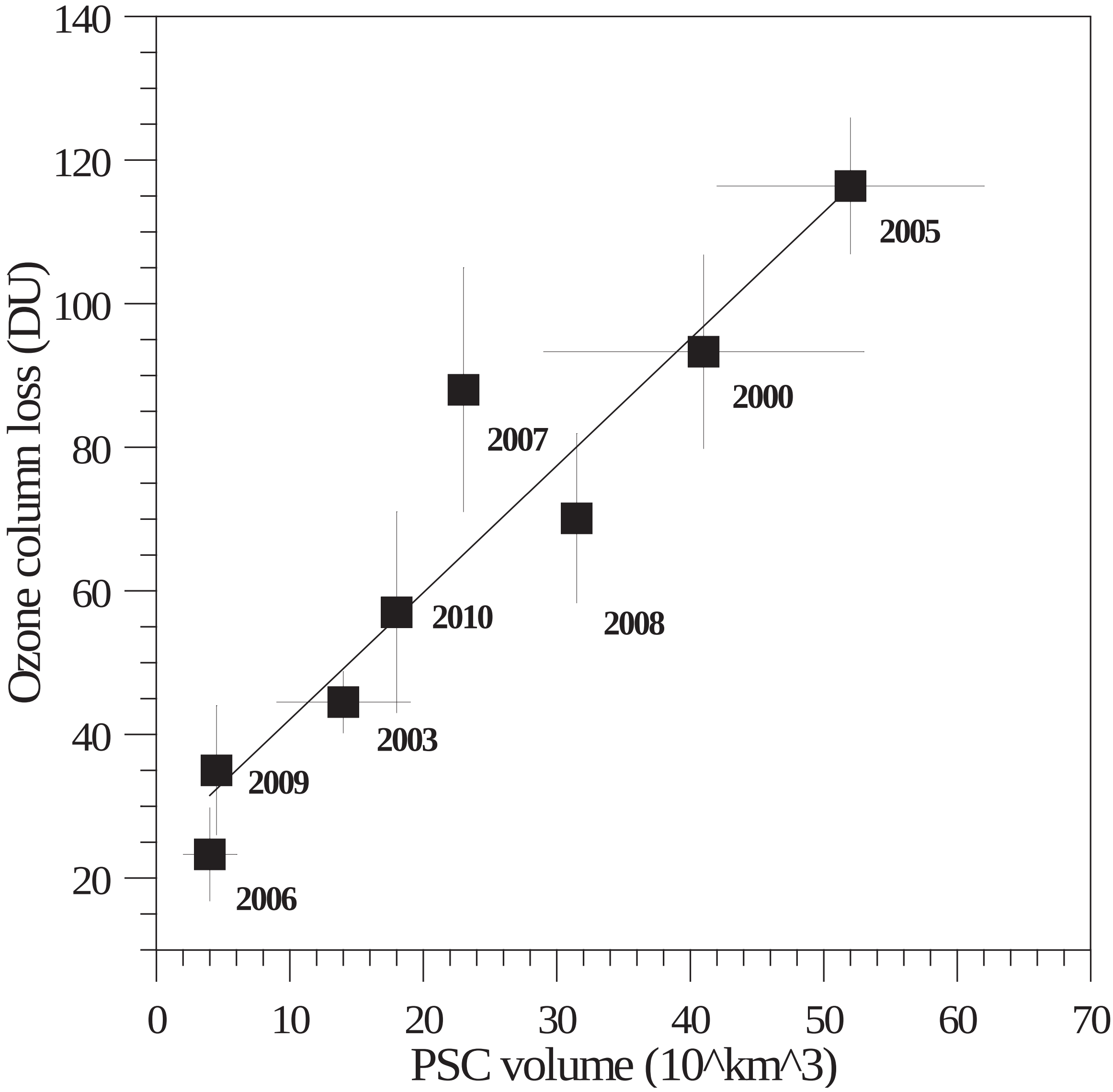

Fig. 3. Relation between ozone loss and polar stratospheric clouds (PSC) volume during winter-spring period. Chemical losses of ozone in partial column between 375-625 K isentropic levels derived from Salekhard ozonesonde data (2000, 2003, 2007 winters), NP35 ozonesonde data (2008), SAGE-III data (2005) and MLS-AURA data (2006, 2009, 2010 winters).

In spite of some decrease in the content of ozone-destroying substances in the stratosphere after 2000, the Arctic thermal regime still leads to significant ozone chemical losses of ozone (OCL) at polar stratospheric clouds. According to the data of the Alfred Vegener Institute (Germany), for the last 40 years, the volume of stratospheric clouds (as was found, the winter volume air mass is favorable for formation of such clouds) increased with a simultaneous increase in the amplitude of inter-annual variations. In [*Tsvetkova et al., 2007*], the values of TOC chemical losses for the last years in the Arctic winter cyclone were calculated on the basis of the data of ozone sounding at the Salekhard station and satellite measurements (SAGE III and MLS-AURA). In 2008, these losses reached 70±12 DU, which is only somewhat less than116±10 DU, the value observed in the winter 2004/05, the coldest winter of the last decade. Fig. 3 demonstrates a close relation between the ozone chemical losses and the volume of polar stratospheric clouds. The formation of clouds is directly connected with the thermodynamic regime of the Arctic stratosphere; therefore, the processes of ozone chemical destruction can be subject to meteorological control to a considerable degree.

In [*Kulikov et al., 2009a*] a method for retrieving the mesospheric concentrations of a number of key minor gases that cannot be measured directly is proposed. This method is based on the use of the specially-simplified models of atmospheric photochemical systems. The estimation of the accuracy of retrieval from noisy temporal series of observational data is described in [*Kulikov et al., 2009b*]. By this method applied to the results of simultaneous satellite measurements of the ozone and hydroxyl concentrations (CRISTA – MAHRSI), the vertical distribution of water-vapor concentrations in the mesosphere was retrieved [*Kulikov et al., 2009a*1].

For retrieving the VOD above 65 km from the measured intensities of emissions of the Atm and IR Atm oxygen bands, a new model of the electron-oscillation kinetics for the ozone-photodissociation products and molecular oxygen in the middle atmosphere was developed [*Yankovsky et al., 2007*].The sensitivity of the new model to the variations in the O_2, N_2, $O(^3P)$, O_3, and CO_2 concentrations, gas temperature, reaction-rate constants, and quantum yields of reaction products was analyzed. The group of reactions affecting maximally the errors of ozone retrieval from the measurements of the intensities of molecular-oxygen atmospheric emissions was revealed.

3. Numerical modeling.

The CHIMERE three-dimensional chemical-transport model was adapted for modeling the air pollution in the Central-European region [*Konovalov et al., 2009a; Kuznetsova et al., 2010*]. In particular, a “nested” model domain with a high resolution (about 13 km) was designed. This domain allows for describing the composition of the lower atmosphere over Moscow suburbs and neighboring regions in concord with the continent-scale processes. The model was validated through comparing the results of modeling with the data of SOC monitoring and with the satellite data on the NO_2 tropospheric content measured by the OMI instrument. The results showed that, in spite of the lack of reliable data on emissions of polluting substances, the designed version of the model describes rather adequately the atmospheric pollution over the region under consideration and the accuracy of the results is close to the calculation accuracy of demonstrated by the best models of Western Europe.

On the basis of application of the inverse-modeling original methods and data of satellite measurements, the decadal variations in the NOx emissions in Europe and countries of the Middle East were studied [*Konovalov, 2007; Konovalov et al., 2008a; Konovalov et al., 2009b*]. A strong decrease in the NOx emissions for the last decade in West Europe was confirmed, but, at the same time, significantly different patterns were revealed in East Europe. In particular, it was found that, in European Russia, the decadal trend in the NOx emissions was negative while EMEP recent data show a significant positive trend. Thus, it was first demonstrated that the use of the available satellite measurements can favor an improvement in the quality of model calculations of air pollution in the atmospheric surface layer.

The trends in the NOx emissions within 12 large-scale urban agglomerations of Europe and Middle East, including the Moscow and St. Petersburg regions, were estimated from the satellite data for the period 1996-2008 [*Konovalov, 2010*]. It was shown that, in six megapolises (Bagdad, Barcelona, Madrid, Moscow, and Paris), the trends in the NOx emissions were linear. The estimated trends in the NOx emissions for Madrid, Milan, London, and Paris are in good agreement with the data of independent ground-based measurements. A comparison with the EMEP data revealed significant inaccuracies in these data for some megapolises.

Natural fires in Siberia are powerful sources of the ozone precursors, NO_x and CO. In [*Vivchar et al., 2010*], the influence of anthropogenic pollutants and fires on the CO background concentrations in Central Siberia was estimated. The observational data obtained at the Zotino station, MODIS satellite data, and statistical analysis were used. In April-May 2008, large-scale fires in North Eurasia (especially, in the West Siberia) caused the increase in the surface CO concentrations at the Zotino station by about 60 ppb (daily mean concentrations) in comparison with the 2007 data. The estimates of the relative increment in the 12-hour mean CO concentrations in fire plumes at an advection time up to two days was about 10–15 ppb in the springs of 2007 and 2008 and about 60 ppb in the summer 2008, the maximum value being 250 ppb (April 2008). Thus, it is shown that natural fires in forests of the boreal zone in Western and Central Siberia, along with anthropogenic sources located in Southern Siberia, are the main factors defining the short-term (synoptic) variability of the surface CO concentrations in the region in the warm period of a year.

The fire areas and attendant CO emissions for the period 2000-2008 were estimated for the entire territory of Russia on the basis of the newest MODIS MCD45 satellite data and the Seiler-Crutzen emission model [Vivchar *et al., 2009*; *Vivchar et al., 2010; Vivchar,2011*]. For Russia in whole, these areas varied from 5.4 Mha (2000) to 33.0 Mha (2008) and the CO emissions varied from 7 to 41 Mt per year [*Vivchar,2011]*. Of the entire area that has been covered by fires in Russia in this period, 90% has fallen on southern regions of East Siberia and Far East and 50% has fallen on 2003 and 2008 characterized by extreme fire situation. It is revealed that the areas of forest fires are localized mainly within the latitudinal belt 50°N –55°N, i.e., approximately, along the southern boundary of boreal forests, where, according to climatic forecast, an increase in the fire-hazard index is expected. According to fire activity, the atmospheric CO emissions caused by natural fires can range from 25 to 200% of total anthropogenic emissions in Russia (from the data of the EDGAR-2000 model). Therewith, the predominant contribution is made by fires in the boreal forests, which accounts for 20-60% of total emissions from natural fires.

Diagnostics of long-term variations in the NOx emissions in megapolises is performed by algorithm of nonlinear approximation for the data of short noisy measurement series [*Konovalov et al., 2009a*]. For this aim, the artificial neural nets and the Bayesian probabilistic approach for choosing the optimum values for the neural-net parameters are used. The procedure of estimation of the "usefulness" of an arbitrary network of station for air-quality monitoring is given in [*Konovalov and Beekmann, 2008b*]. General guidelines on optimization of the system of O_3 и NO_2 monitoring are elaborated in view of their possible use for the above-mentioned aim.

In [*Elansky et al., 2009b; Safronov and Elansky, 2008*], it is shown that the measurements of the atmospheric stratification and distribution of pollutants in the atmosphere and in plumes of different natural and anthropogenic sources on the basis of the mobile railroad laboratory (TROICA) can effectively serve for validation of the results of numerical simulation. In particular, the RAMS 6.), MM5.v3, WRF 3.1, HYPACT 1.5, HYSPLIT 4.9. models were tested by the distributions of some pollutants in plumes of cities. All these models gave different approaches to the observational in accordance with the situation.

The 2-D numerical interactive dynamic-transport-photochemical model including an aerosol block was used for estimation of the variations in the stratospheric temperature and in the ozone-layer state under the action of anthropogenic emissions of gases CO_2, CH_4 и N_2O [*Dyominov and Zadorozhny, 2007; Dyominov and Zadorozhny,2008; Dalin et al., 2008*]. The results of calculations for the period 1975-2050 showed that the ozone content is influenced by stratospheric cooling caused by these gases. Therewith, a noticeable modification of stratospheric aerosol, which influences the distribution of ozone-active gases via heterogeneous reactions at the surface of particles, is revealed. This process makes the major contribution to formation of the ozone "hole" over Antarctica.

The effect of the chemical composition and middle-atmosphere temperature on the 27-day cycle of short-wavelength solar radiation was studied by using the results of calculations based on the HAMMONIA three-dimensional chemical-climatic model [*Gruzdev et al., 2009c*]. The latitude- and season-dependent estimates of the amplitudes and phases of the temperature response and response of the concentrations of minor gases, including O, O_3, H_2O, OH, and H_2SO_4, are obtained. The amplitude and phase delay of the ozone response in the tropical stratosphere and lower mesosphere are in satisfactory agreement with available observational data. The 27-day variations in the temperature and content of minor atmospheric components are very pronounced and time-constant in the upper atmosphere; however, they are highly time-variable in the stratosphere and mesosphere. The model calculations revealed a significant nonlinearity in the response of the temperature and content of minor gases to the 27-day solar forcing; this nonlinearity consists in decreasing of the response sensitivity with increasing of the forcing amplitude. In extratropical latitudes, the response is usually season-dependent and is stronger in winter than in summer.

The interactive three-dimensional chemical-climatic model combining the models of the gas composition and general circulation in the lower and middle atmosphere was used for studying the influence of the solar activity, polar stratospheric clouds, and thunderstorm activity on the content of ozone and other atmospheric gases.[*Smyshlyaev et al., 2010a; Smyshlyaev et al., 2010b; Smyshlyaev et al., 2010c*]. Variations in the solar activity vary radiative heating of the atmosphere and, accordingly, vary the rate of chemical reactions; what is considered as the first-type indirect influence of the solar activity on the atmospheric gas composition. Due to heating, the atmospheric circulation varies, influencing the transport of atmospheric minor components, what is considered as the second-type indirect influence of the solar activity on the atmospheric gas composition. The results of calculations showed that both types of indirect influence of the solar activity on the atmospheric gas composition are in order-of-magnitude agreement with the direct effect of the influence of the solar activity on the atmospheric gas composition [*Smyshlyaev et al., 2010c*]. The influence of the NO_x production by lightning on the atmospheric contents of gases was parametrically considered in the model. The NO_x production was specified within the limits from 2 to 20 TrN/year. The calculations showed a significant sensitivity of the ozone and hydroxyl contents to the produced NO_x for different heights. The necessity for heightening of the accuracy in estimates of the NO_x production by lightning and for using in models not the climatic data but the physical parameterizations allowing the consideration of local peculiarities of thunderstorm activity and feedbacks is substantiated [*Smyshlyaev et al., 2010b*]. To study the evolution of polar stratospheric clouds and their influence on the gas composition of the polar atmosphere, the chemical-climatic model was supplemented by a special thermodynamic microphysical block [*Smyshlyaev et al., 2010a*]. Model experiments and a comparison of the numerical estimates with observational data showed that the occurrence of denitrification in the Antarctic and its absence in the Arctic are the main factors determining the differences between formation of the full-grown ozone hole in the Antarctic and only episodic ozone “mini-holes” in the Arctic.

The impact of charged particles of space origin on stratospheric and mesospheric ozone is described in the monograph [*Krivoluzkii and Repnev, 2009*]. Getting to the polar atmosphere, charged particles ionize it, what leads to an increase in the atmospheric contents of nitrogen and hydrogen oxides. Therewith, each pair of ions formed at deceleration of solar protons in the atmosphere produces 1.25 moles of nitrogen atoms (which convert to nitric oxide molecules) and about 2.0 moles of OH radicals [*Krivoluzkii and Repnev, 2009*]. Then, these components effectively destroy ozone in chemical catalytic cycles. In the period of intense geomagnetic disturbances in October-November 2003 (including the proton flare at the Sun on October 28), the data on the chemical composition of the atmosphere were obtained with the MIPAS instrument installed at the ENVISAT European satellite. These data allowed for the first comparison of the model calculations with the observations of a number of chemical components in the period of geomagnetic disturbances. At present, in the framework of the specially organized international project HEPPA (High Energetic Particle Precipitations in the Atmosphere), a detailed comparison of the results of satellite observations with the results obtained from calculations by several three-dimensional models, including the CAO model [*Repnev and Krivoluzkii, 2010*]).

Preliminary results of this comparison showed a rather good agreement; however, there are some discrepancies that require additional studies (e.g., the models somewhat overestimate the response of the components of nitrogen "family"). The estimation of the contribution of relativistic electrons to the variations of the chemical composition of the polar atmosphere in the periods of geomagnetic disturbances is also of great importance.

In [Ozolin et al., 2009], the one-dimensional ion-photochemical model of the atmospheric gas composition is presented; this model describes the formation of the ionospheric D-layer. The calculations showed that, after powerful proton flare in the mesosphere of polar caps, the NO_X and HO_x concentrations increase. For the period after such a flare in October 2003, the model calculations give the 40% and 70% decreases in the ozone concentration in the middle and upper mesosphere at 75° S and at 70° N, respectively. The results of modeling of variations in the NO_X and O_3 concentrations after the powerful proton flare in October 2003 agree well with the data of satellite measurements.

4. Conclusion

The All-Russian conference "Development of the system for atmospheric composition monitoring" organized by IAP RAS and the Russian Hydrometeorological Center was held in Moscow in October 2007. The specialists from 48 scientific organizations as well as the representatives of the Moscow Government, the World Meteorological Organization and several public organizations were participated at the conference. The reports presented at the conference (159 in total) and their discussion gave a clear estimation of the state of the Russian monitoring system for atmospheric composition (including the state of ozone networks) and the existing problems. Significant physical and moral deterioration of the measurement equipment, inadequate development of the measurement quality control system and data processing and transmission equipment and the losses of qualified specialists in recent years was marked. Warring about the state of the national monitoring system, the conference participants prepared and accepted the general principles of its modernization and development which are accentually defined and enlivened the ozone study in the following years.

Some progress has been made in the expansion and modernization of the observational system. New stations were constructed, including the territory of the former Soviet Union. The large international experiments on the unique mobile platforms were regularly carried out: TROICA mobile laboratory, M-55 "Geophysics" and AN-30 aircraft laboratories. The work began on the creation of the Yak-42 based Russian laboratory and the system for the ozone layer monitoring from the space. The numerical simulation is successfully developed that contributes to the arrival of new powerful computers in the country. The Russian Government attention increase to the problems of the ozone layer and climate changes cause the great optimism. The “Climatic doctrine” was accepted. The documentation for the creation of “The single information center for monitoring, assessment and prediction of the climate change” is developed.

In 2010 the scientific community celebrated 100 years since the birth of the founder of the atmospheric ozone studies in Russia, Professor A.H. Hrgian (1910-1993). The school created by him and his students occupy a worthy place in this field of the science. New young scientists come at this school. The All-Russian Conference which was held in Nizhny Novgorod in May 2010 and was dedicated to the memory of AH Hrgian showed their great potential.

In the present review only the main results according to the authors apinion were included. The other results can be found in the papers which are not quoted in the review but given in the list of the publications and are also of considerable interest.

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Climate

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The objective of this review is a general information about results of climate studies with participation of Russian scientists to the International association of Meteorology and Atmospheric Sciences for the XXV General Assembly of the International Union of Geodesy and Geophysics (see references). Previous similar review was presented in (*National Report…, 2007; Mokhov, 2009*).

Essential part of key results of Russian climate studies during last years in the area of climate changes and assessment of their impacts for Russia was published in (*Assessment Report …,* 2008a-d*; Changes of Environment and Climate*, 2007-2008; *Climate Change,* 2007a,b). Since 2009 information about climate studies and associated activity in Russia is regularly presented in monthly bulletin "Climate Change".

Important step associated with climate problem was done in Russia with acceptance of the Climate Doctrine of the Russian Federation (*http://archive.kremlin.ru/eng/text/docs/2009/12/*).

1. Climate system and its changes from observations, reanalyses and paleoreconstructions

Significant weather and climate anomalies have been noted during last years, particularly in Russia (*Alekseev et al., 2007; Alekseev et al., 2009; Alekseev et al., 2010; Anisimov et al., 2007; Assessment Report …, 2008a; Bogdanova et al., 2010; Dobrovolsky, Istomina, 2009; Gorbatenko et al., 2007; Gruza, Rankova, 2009; Kabanov, 2009; Kiktev et al., 2009; Kitaev, 2010; Mokhov, 2009a; Pavlov, 2008; Shmakin, 2010; Zolotokrylin, 2008*).

According to Rosgidromet (*http://www.meteorf.ru*) the mean numbers of dangerous hydrometeorological events with significant economical and social losses for last 5 years (2006-2010) and for previous 5 years (2001-2005) were 2.3 and 1.6 times larger than that for the period 1996-2000. The maximum number for such events was noted in 2010. Last summer was especially extreme in European part of Russia (see, for instance, (*Shakina, Ivanova, 2010*)). Extreme summer heat wave was related with formation of strong blocking anticyclone with total duration about two months. Extreme weather and climate anomalies associated with blocking activity in the atmosphere were noted in Russian regions also in winter seasons during last years (in winter 2009-2010, particularly).

Important support to global and regional climate studies from observations is based on different reanalyses data (*Akperov et al., 2007; Akperov, Mokhov, 2010; Golitsyn et al., 2007; Gorbatenko et al., 2009; Kanukhina et al., 2007; Murav'ev et al., 2010; Rudeva, 2008*) and also on paleoreconstructions and historical data (*Climates and Lanscapes …, 2010; Datsenko et al., 2010; Datsenko, Sonechkin, 2008; Ivanova, 2009; Khon et al., 2010; Klimenko, 2008; Sidorchuk et al., 2008; Vakulenko et al., 2007*).

Special attention was paid to climate changes and associated changes of carbon cycle (including methane cycle) in the Arctic (*Alekseev et al., 2007b,c; Alekseev, Nagurny, 2007a,b; Golubev, 2010; Semenov, 2008*).

Essential contribution to climate variability is related with different oscillations in climate system at various spatial and temporal scales. Alongside with regular cycles, from diurnal and annual cycles to Milankovitch cycles, there are various quasi-cyclic processes like Quasi-Biennial Oscillation, El Nino / Southern Oscillation and Atlantic Equatorial Mode, North Atlantic and Arctic Oscillations, Atlantic Multidecadal Oscillation and other ones (*Bezverkhny, Gruzdev, 2007; Frolov et al., 2010; Gruzdev, Brasseur, 2007; Ivanova, 2009; Kozlenko et al., 2009; Sitnov, 2010*).

2. Theory of climate and climate system modeling

Different aspects of climate system modeling are considered in (*Assessment Report …,* 2008a,b*; Modern Problems …,* 2010*; Anisimov,* 2009; *Demchenko, Kislov,* 2010*; Diansky et al.,* 2010; *Eliseev,* 2008; *Gritsun, Branstator,* 2007; *Khon et al.,* 2010; *Meleshko et al.,* 2007; *Mokhov,* 2008; *Perevedentsev,* 2009; *Rutter et al.,* 2009; *Sarkisyan, Sundermann,* 2009; *Shakina, Ivanova,* 2010; *Sidorenkov,* 2009; *Smyshlyaev et al.,* 2010; *Tarko,* 2010; *Volodin et al.,* 2008; *Wang et al.,* 2007; *Zherebtsov et al.,* 2008). A number of publications is devoted to model studies of specific climatic mechanisms and processes and to diagnostics of their changes (*Eliseev, Mokhov;* 2008; *Kulyamin et al.,* 2008; *Mokhov, Eliseev,* 2008; *Mokhov et al.,* 2008; *Petoukhov, Semenov*, 2010; *Semenov et al.,* 2009; *Smyshlyaev et al.,* 2010; *Volodin,* 2008; *Zakharov et al.,* 2009; *Zherebtsov et al.,* 2008a,b; *Zilitinkevich, Esau,* 2009).

Models of different complexity are used for global climate simulations, including the most detailed coupled models of general circulation of atmosphere and ocean, Earth models of intermediate complexity, radiative-convective models, energy balance models and conceptual models (*Chernokulsky et al.,* 2010; *Demchenko, Kislov,* 2010*; Diansky et al.,* 2010; *Eliseev et al.,* 2009; *Ginzburg et al.,* 2008; *Malyshkin, Mokhov,* 2010; *Mokhov,* 2009; *Muryshev et al.,* 2009; *Volodin et al.,* 2010).

Advance of climate models is related with the development of interactive climate system components (*Arzhanov et al.,* 2008; *Bortkovskii et al.,* 2007; *Eliseev et al.,* 2009; *Ginzburg, Zavalishin,* 2008; *Golubyatnikov, Denisenko,* 2010; *Khairullin et al.,* 2009; *Machulskaya, Lykossov,* 2009; *Smyshlyaev et al.,* 2010; *Yakovlev,* 2009). Simulations of global climate models combined with the carbon cycle, including methane cycle, are analyzed in (*Denisov et al.,* 2010; *Eliseev et al.,* 2007; *Eliseev et al.,* 2008; *Mokhov et al.*, 2008; *Volodin,* 2007) and simulation of photo-chemical processes, particularly with an interactive ozone cycle (*Galin et al.,* 2007; *Gruzdev, Brasseur,* 2007; *Gruzdev et al.,* 2009; *Frolkis et al.,* 2007; *Smyshlyaev et al.,* 2010;*Titova, Karol,* 2010).

Alongside with the development of global models, the development of regional climate models is necessary for adequate understanding and simulation of climatic processes and their changes with the analysis of distribution functions for possible conditions on the basis of ensembles of numerical realizations. One of such regional climate models was developed at the MGO (*Nadyozhina et al.,* 2008).

3. Global and regional climate change simulations with an assessment of natural and anthropogenic factors

Results of assessment of possible climate changes, in particular for Russian regions, are presented quite widely in (*Assessment Report* …, 2008; *Changes of Environment and Climate*, 2007; *Changes of Environment and Climate*, 2008). Model estimates of global and regional climate changes are discussed in (*Alekseev et al.,* 2009; *Ananicheva et al.,* 2010; *Anisimov et al.,* 2008; *Dobrovolsky,* 2007; *Eliseev et al.,* 2008; *Eliseev et al.,* 2009; *Golitsyn et al.,* 2007; *Golubytnikov, Denisenko,* 2009; *Govorkova et al.,* 2008; *Kattsov,* 2010; *Kattsov et al.,* 2007; *Khon, Mokhov,* 2010; *Khon et al.,* 2007; *Khrustalev et al.,* 2008; *Kiktev et al.,* 2009; *Kislov et al.,* 2008; *Kitaev et al.,* 2008; *Loeptien et al.,* 2008; *Malevsky-Malevich et al.,* 2007; *Malinin,* 2009; *Meleshko et al.,* 2008; *Mokhov et al.,* 2008; *Mokhov, Chernokulsky,* 2010; *Pavlova et al.,* 2007; *Shakhova et al.,* 2010; *Sherstyukov,* 2007; Sorteberg yet al., 2007; Volodin et al., 2010).

4. Climate change impacts and problems of adaptation and mitigation

The problem of adaptation to climate changes was declared as a key current problem by the World Climate Conference-3 (*http://www.wmo.int/wcc3/*) as well by the All-Russian VI meteorological congress (*http://www.meteo.imd.ru/*) in 2009.

Climate change impacts and problems of adaptation and mitigation taking into account tendencies of development of world economy, energy and appropriate strategy for Russia are discussed and analyzed in (*Assessment Report ...,* 2008; *Chernokulsky et al.,* 2010; *Bedritsky et al.,* 2009; *Dobrovolsky, Istomina,* 2009; *Eliseev et al.,* 2009; *Eliseev, Mokhov,* 2009; *Eliseev et al.,* 2010; *Fortov, Makarov,* 2009; *Frolkis, Karol,* 2010; *Groisman et al.,* 2009; *Gulev et al.,* 2008; *Izrael,* 2008; *Izrael et al.,* 2007; *Izrael et al.,* 2009; *Khon et al.,* 2010; *Kislov et al.,* 2008; *Klimenko,* 2007; *Klimenko, Tereshin,* 2010; *Makarov,* 2009; *Meleshko et al.,* 2010; *Mokhov,* 2008; *Revich, Maleev,* 2010; *Ryaboshapko,* 2010; *Semenov et al.,* 2007; *Sirotenko, Pavlova,* 2010; *Zoidze et al.,* 2010).

Problems of optimal adaptation of Russian economy to hazardous climate impacts Hydrometeorological security are analyzed in (*Bedritsky et al.,* 2009). Changes of population health in Russia in conditions of changing climate are considered in (*Revich,* 2008; *Revich, Maleev,* 2010). Impacts of possible climate changes on production of agro-ecosystems, in particular on agriculture in Russia, are assessed in (*Sirotenko et al.,* 2007; *Sirotenko, Abashina,* 2008; *Sirotenko, Pavlova,* 2010; *Zoidze et al.,* 2010). Economic perspectives of the Northern Sea Route under climate change are discussed in (*Khon et al.,* 2010).

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Dynamic Meteorology

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Scientific works, which have been carried out in dynamic meteorology by Russian researchers over 2007 – 2010 and will be discussed in this review, can be conditionally related to the following topics: “General dynamics of the atmosphere”, “Large-scale processes and the weather forecast”, “Mesoscale processes”, “Turbulence in the boundary layer” and “Mathematical problems of climate and ecology”.

1. General Dynamics of the atmosphere

In many problems of dynamic meteorology, dynamics of the atmosphere can be described by an ensemble of interacting eddies and waves of various scale in the approximation of an ideal fluid. Interest in wave motion is associated primarily with the fact that the waves are a source of instability leading to a significant restructuring of the overall dynamic picture (in particular, to the development of cyclones, typhoons, tornadoes, and sand devils). In the paper by Romanova and Yakushkin (2007) methods for investigating the evolution of wave disturbances in density stratified shear flows of ideal incompressible fluid are reviewed. Equations, by which motion under consideration can be described, are Hamiltonian, and written in terms of semi-Lagrangian variables are of integral-differential form. This allows us to study both continuous and discontinuous solutions. In the cited paper, two dynamical systems are considered. One of them is used to describe the gravity waves in shear flow, developing in the unperturbed medium with sharp gradients of density and flow velocity (the simplest example is the Kelvin – Helmholtz model). Another dynamical system describes the shear and gravity-shear waves in two-dimensional flow with a sharp gradient of vorticity. In the paper, the results of solving the problem of the disturbances dynamics in the flow with a continuous distribution of vorticity, obtained by considering linear wave dynamics in a narrow layer with a constant gradient of the undisturbed vorticity and linear interaction of disturbances in the two layers of this type, are presented. The approach makes it possible to study in detail this interaction near the critical level and the formation of structures such as "cat's eye".

The paper (Romanova, 2008) is devoted to the study of resonant wave interaction of discrete and continuous spectrum. Gravitational-shear wave produced by the jump of density and vorticity of undisturbed flow, and a wave on a weak jump of vorticity, similar to a wave of a continuous spectrum, are involved in the interaction. Based on the three-layer model in the form of a Hamiltonian system of equations of the perturbations dynamics, the evolutionary system for the amplitudes of interacting waves is obtained. In the case of the linear approximation (weak coupling of the waves) conditions on the problem parameters are found, for which there is instability. It is shown that the inclusion of a cubic nonlinearity in the evolution system leads to the stabilization of perturbations in the case when the coefficient in the corresponding expression for the nonlinear term is positive.

A number of eddies in the atmosphere (such as tropical cyclones, tornadoes, and sand devils, as well as horizontally oriented vortices in the planetary boundary layer) has a pronounced spiral structure. In Kurgansky (2008) it is proposed to consider the downward flux of helicity (in the upper part of the atmospheric boundary layer) as a measure of the intensity of atmospheric vortices. Using the general balance equation for the helicity, the author of the cited publication defines the flux as a product of the cube of maximum wind speed and bandwidth, swept by the maximum wind under the movement of vortex. It turns out that for intense vortices (in the mature phase) the helicity flux determines the rate of vorticity destruction by turbulent friction. The article presents the results of a comparative (with respect to values of the helicity flux) analysis of dust vortices on Earth and on Mars, and tornadoes. It is found, in particular, that the giant dust vortices on Mars correspond to terrestrial tornadoes, although because of differences in air density on both planets, their dynamic impact is of more than 100 times weaker than for tornadoes.

There are three main range of atmospheric turbulence (Glazunov et al., 2010): macroturbulence with horizontal scales from hundreds of kilometers to the planetary (≈ 10^4 km), mesoturbulence (with scales of kilometers to hundreds of kilometers) and microturbulence with scales less than a kilometer. Throughout the spatial macroscale range atmosphere can be considered quasi-two-dimensional (ratio of vertical to horizontal scale $\varepsilon < 10^{-2}$) and quasi-geostrophic fluid (the Rossby-Kibel number $\mathrm{Ro} = U / lL \leq 1$, l - Coriolis parameter, U - the characteristic velocity scale, L - the characteristic spatial scale). However, the question to what extent the spatial spectrum of atmospheric macroturbulence determined by its quasi-two-dimensionality, and on what – quasi-geostrophity, is extremely important because of the substantial difference in the mechanism of formation of these two types of geophysical turbulence (see, e.g., Tung and Orlando, 2003). Data analysis of aircraft measurements at middle and high latitudes and at altitudes of 9 to 14 km, showed that one-dimensional spectra of the horizontal wind speed and temperature are approximately of the same form in the scale range from 2.6 to 10^4 km (Nastrom and Gage, 1985). The slope of the spectral distribution was close to -5/3 (not -3 or more, as follows from the theory of two-dimensional turbulence) in the high wavenumber (mesoscale) part of the spectrum (10-500 km). At greater scales, these distributions are characterized by the law (k is the wavenumber).

Internal gravity waves generate anisotropic temperature inhomogeneity in a stably stratified atmosphere in the range of vertical scales of several meters to several kilometers. Because of the effect of buoyancy, the vertical direction in the presence of density (in particular, temperature) stratification is singled out, while the horizontal field of temperature inhomogeneities on a scale not exceeding 100 km, can be regarded as locally isotropic (Gurvich and Kuharets, 2008). Numerous experimental studies of vertical spectra of temperature showed that a wide range of vertical wave numbers k_z are subject to the law of degree "-3". In the publication of Gurvich and Chunchuzov (2008) a model of three-dimensional spectrum of temperature inhomogeneities, generated by internal gravity waves in the atmosphere is proposed. According to this model, the vertical spectrum is described by a power law distribution with exponent "-3" and the horizontal spectrum has three asymptotic regions, two of which are subject to the law of degree "-3", and intermediate one is characterized by an exponent, varying from -1 to -3 depending on the rate of decrease in anisotropy with increasing vertical dimension of temperature inhomogeneities. The paper by Gurvich and Kuharets (2008) shows the results of experimental studies of spatial oblique and vertical spectra of temperature fluctuations in stably stratified troposphere at altitudes of 2-8 km (flights were conducted over northern European Russia) and in the wavenumber range from 5×10^{-4} to 3×10^{-2} rad/m. Quantitative estimates of the parameters of these spectra, calculated from field measurements indicate that the temperature large-scale (vertical scale greater than several hundred meters) inhomogeneities are strongly elongated along the Earth's surface (horizontal size exceeds the vertical about 20 times). Anisotropy of the inhomogeneities decreases with a decrease in their vertical dimensions, reaching values of 1.5 - 2 on a scale of 10 m or less.

Atmospheric macroturbulence can be characterized by several key scales. The first is the scale of energy injection into the system. It is commonly assumed that the energy comes into the system due to baroclinic instability, i.e., the instability in the domain of most unstable wavelengths in the sense of Lyapunov. The second important scale in turbulence theory is the scale of the wavelength at which energy is dissipated. Strictly speaking, energy dissipation in the atmosphere is carried out on the Kolmogorov scale, which is negligibly small in magnitude for large-scale turbulence. For macroturbulence one should allocate intermediate scales, on which the energy sink occurs. This primarily refers to the planetary boundary layer, where there is a flux of energy from macroscales to the Kolmogorov scale.

In the work of Ponomarev et al. (2008), an approximate system of equations describing the quasi-viscous incompressible fluid flows and taking into account dissipative effects is obtained on the base of expansion in powers of the divergence of the two-dimensional velocity field. A special case of these equations is the quasi-two-dimensional model with Rayleigh (linear) friction. It is shown that a three-dimensional flow pattern, which is manifested in the effective interaction of vortices with horizontal and vertical axes, determines the nonlinear nature of friction. In the paper cited the parameterization of this interaction in quasi-two-dimensional equations with a nonlinear friction is presented and a comparison of theoretical results with laboratory experiments on the excitation of a spatially periodic fluid flow is carried out. In the paper (Ponomarev et al., 2009) an experimental study of eddy currents, created by magneto-hydrodynamic method in a thin layer of rotating fluid in a laboratory setting, developed in A.M. Obukhov Institute for Atmospheric Physics RAS, is carried out. To interpret the results of the experiment an analytical approach is developed that led to the conclusion that the circulation in the vertical plane determines a mechanism for non-linear friction, which leads to a redistribution of cyclonic and anticyclonic vortices outside the boundary layer.

Two-dimensional turbulent motions belong to physical process, the study of which is not simplified by decreasing the dimension of space. A characteristic feature of two-dimensional turbulence is the transfer of energy from small-scale motions to large-scale. In addition to the Kolmogorov spectral region with the law $k^{-5/3}$ due to the conservation of enstrophy (in the absence of viscosity) should be a spectral range that obeys the degree of "-3". In (Tseskis, 2008) to describe the properties of two-dimensional turbulent flow of an incompressible fluid the Karman-Howarth equation is used for the correlation function $B_{LL}(r) = \overline{u_L(\mathrm{x})u_L(\mathrm{x+r})}$, where u_L - the projection of velocity on the straight line joining the point x and $\mathrm{x+r}$, while the overbar denotes statistical averaging. A special attention is paid to the choice of function $T(k)$ associated with nonlinear terms in the equations of motion and characterizing the flux of energy in $k-$space. It is assumed that the number of crossings of this function with the $k-$axis should coincide with the number of quadratic conservation laws. In three-dimensional case the quadratic integral is only one and a single intersection T with the axis of wave numbers is confirmed by experimental data. This approach allowed to describe the inverse energy cascade, as well as the formation of coherent structures due to the achievement by spectrum a $\delta-$function shape. Coherent structures, which are bounded by closed streamlines vortex formation, prevent the spread seized their impurity, which prevents the use of classical theory of turbulent diffusion.

The paper (Gledzer, 2008) is devoted to the problem of stability of the zonal axisymmetric solutions of quasigeostrophic equations of atmospheric dynamics in the hydrostatic approximation with linear friction and Newtonian cooling. The external influence on the atmosphere is given by the background horizontal temperature gradient. The main parameter that determines the nature of instability of the Hadley type regime is the Rayleigh number Ra. It is found that for large values of Ra and small values of some parameter τ_φ, which has the dimension of time and characterizes the relative importance of the Earth's rotation effects, it is usual baroclinic convective instability, while for small Ra and large times τ_φ - the centrifugal instability.

In the framework of the quasigeostrophic approximation is also investigated in the paper (Kalashnik, 2009) the problem of stability of stratified rotating fluid flow with constant vertical and horizontal velocity shear as one of the variants of Eady problem (Eady, 1949). To solve this problem, an approach based on the description of the disturbances dynamics in moving with the flow coordinate system is used. The paper shows that the inclusion of the meridional velocity shear of the zonal geostrophic flow leads to a qualitative change in the dynamics of Eady waves (wave solutions with zero potential vorticity), which manifests itself in the alternation of the stages of a smooth oscillatory behavior in time with the stages of an exponential (explosive) growth of finite duration. Along with the dynamics of individual Eady waves, it is investigated in the cited paper the generation of these waves by the initial perturbation, given in a form of single spatial Fourier harmonics. This generation process is resulted in excitation of non-modal waves with time-changing horizontal and vertical wavenumbers and potential vorticity different from zero.

Study of the dynamics of jet flows of stratified fluid is one of the fundamental problems of hydrodynamics. In Druzhinin (2008) the development of instability of such flows is studied using direct numerical simulation. It is considered initially cylindrical jet with a Gaussian velocity profile in a stably stratified (with a linear density profile) environment. If initially a small perturbation of the velocity field is specified with a wide spectrum range, then exponential growth of the selected quasi-two-dimensional mode occurs. In this case, the spectral peak associated with this mode, is shifted to lower wave numbers compared with the maximum of unstable spiral mode of unstratified jet. The instability growth rate is proportional to $\sqrt{\mathrm{Ri}}$ where $\mathrm{Ri} = g\Delta\rho L / \rho U^2$ is the global Richardson number (here g is the acceleration of gravity, ρ - the characteristic value of density of the fluid, $\Delta\rho$ - the vertical change of density on the scale L). In the process of development of the instability a vortex flow structure, consisting of bipolar quasi-two-dimensional vortices, which are located in the horizontal plane near the jet axis and accompanied by the internal waves emission, is formed. At sufficiently large times the growth of instability is "saturated" and then the velocity and density fluctuations are damped by the action of viscous forces.

A rotating stratified fluid in a gravitational field is characterized by inertia-gravity waves that in horizontally inhomogeneous shear flows can be trapped within the shear layer. With these localized waves is often associated intense wave activity observed in the areas of atmospheric fronts and jet streams. The paper (Kalashnikov, 2008) deals with the theoretical analysis of the structure of the trapped symmetric perturbations. It is shown that the location of the trapping region is determined by the vertical stratification of the atmosphere. If characteristic value of the Brunt-Väisälä frequency $N = (-g / \rho \partial \rho / \partial z)^{1/2}$ is (in the Northern Hemisphere) more (or less) the inertial frequency l , the capture occurs in a region with the anticyclonic (cyclonic) velocity shear and at the same time frequency of trapped waves is smaller (larger) l.

Kalashnikov and Visheratov (2010) have considered the regime of cyclostrophic balance (balance between pressure gradient and centrifugal force), which is characteristic for the dynamics of intense atmospheric vortices such as tornadoes and sand devils. In this article, to describe the motions in the core of an axisymmetric vortex a class of exact self-similar solutions of the gas dynamics equations is found. It includes the solution for the velocity components, which is linearly dependent on the distance from the axis, and the solution for the temperature, which is quadratically dependent. It is shown that for small violations of cyclostrophic balance the oscillations of thermohydrodynamic fields with a frequency proportional to the angular velocity of rotation occur in the vortex core. Such oscillations can be regarded as a source of infrasound radiation from tornadoes registered in observations. If the initial deviation from the balance state is large enough, the oscillations are non-harmonic and in conditions of prevailing centrifugal forces lead to a significant decrease of temperature on the vortex axis.

Currently, much attention is paid to the stability analysis of dynamical systems based on the approach associated with the use of characteristic Lyapunov exponents. If parameters of medium under consideration have a random nature, there is a randomness in physical fields. Averaging of these fields over the ensemble of random parameters smoothes out the qualitative features of individual realizations. The statistical averages, which characterize the "global" scale of domain of the stochastic processes realization, often do not say anything about the details of their development within it. However, there are physical processes that occur with probability one, called coherent (Klyatskin, 2005) and a "statistical coherence" can be considered as an organization of a complex dynamic system with statistically stable parameters. In application to stochastic dynamical systems, Lyapunov exponents are averaged over the ensemble of random parameters. The publication Klyatskin (2008) shows that the results obtained in this way the average values coincide with the curve of a typical implementation for the lognormal distribution of positive non-stationary in time characteristics of stochastic dynamical systems solutions.

Although complete statistics contain all information about a dynamic system, in practice, one can investigate only some of the simplest statistical characteristics associated with the simultaneous and one-point probability distributions. There are methods of statistical topography (see, for example, Isichenko, 1992), allowing on the basis of such information about the system to describe the main quantitative and qualitative behavior of its individual realizations. In Klyatskin (2008) methods of statistical topography are applied to the problem of statistical description of diffusion and clustering of particles, as well as of the passive tracer concentration, in random hydrodynamic flows.

2. Large-Scale Processes and the Weather Forecast

It is known that in the past five decades, the most important inter-annual and decade variations in weather regimes in the middle latitudes of the Northern Hemisphere were due to the phases of the North Atlantic Oscillation (NAO). In the same decades in the same latitudes extremely large anomalies of air temperature in the layer from the Earth surface to heights of the middle troposphere are observed. Diagnostic calculations (Tanaka and Matsueda, 2004) have shown that they are not connected with the extreme heat influx anomalies. Often, these anomalies are explained by the enhancement of planetary waves, or attributed to a blocking anticyclone. In papers (Kurbatkin, 2008, Kurbatkin and Smirnov, 2010), an analysis of the dominant modes of low-frequency variability of the atmosphere, the mechanisms of formation of the annual cycle of anomalies and sudden anomalies of planetary and continental scales is presented. For this purpose, data from NCEP/NCAR reanalysis for the period 1959-1998 years and the results of the operational objective analysis of the Russian Hydrometeorological Center for the 2002 - 2007 years are used. In the article (Kurbatkin, 2008), emphasis is made on the role of negative interannual winter temperature anomalies over the continents in stabilization of the annual cycle of current climate, observed in 50 - 60 years of XX century. It is also shown the role in the weakening of annual variation in climate of deformation of the North Atlantic dipole into the west-east planetary wave, observed in 1997 and 2007.

The paper (Kurbatkin and Smirnov, 2010) is devoted to the study of the causes and mechanisms of formation of extremely large anomalies in tropospheric temperature as related to the North Atlantic Oscillation. Used in the paper approach is based on the fact that during the annual cycle the troposphere temperature anomalies of a continental scale can both increase (in response to a direct effect of heat influx) and weak (at the temperature advection, opposite in sign to the heat influx). In the paper cited, the seasonal air temperature anomalies at 850 hPa (T_{850}) in Eurasia are studied by the use of monthly average data of NCEP/NCAR reanalysis for the period 1959-1998 years. It is shown that the negative (positive) phase of the NAO in winter is favorable for conservation at this time the negative anomalies of T_{850} in the east (west) of the continent. However, this dependence is critically disrupted (due to the limited influence of the NAO on T_{850}) about two years before the onset of extreme events. The cited article describes the mechanism of anomalous heat influx as a source of amplification of negative anomalies of T_{850} in the winter and positive - in the summer, limiting the influence of the dominant dynamic mode at certain regions of the continent. In particular, the seasonally "off" of anomalies from the mechanism of heat influx under the influence of large changes in the NAO and the total destruction of the annual cycle of anomalies are demonstrated.

Great interest of researchers is related to mechanisms of interaction between the stratosphere and troposphere in the layer, which consists of the upper troposphere and lower stratosphere. Dynamically, this layer is defined as a layer in which the isentropic surface does not lie entirely in the stratosphere and do not cross the Earth's surface. In winter, large-scale meanders of the tropospheric jet extend up and are destroyed at the stratospheric jet height, resulting in inhibition of the stratospheric jet. In the paper (Borovko and Krupchatnikov, 2009), one aspect of the influence of the stratosphere on the troposphere is investigated. Using atmospheric general circulation model with a simple mechanism for heating, given in the Newton form, the sensitivity of the troposphere dynamics to variations of the polar vortex intensity in the stratosphere is studied. It is shown that variations in thermal stratification in the stratosphere cause noticeable changes in circulation in the troposphere during the intensification of the stratosphere polar vortex: 1) the zonal jet flow in the lower troposphere shifts to the North Pole, 2) surface pressure in the polar region decreases, 3) vertical component of the wave activity flux from the troposphere into the stratosphere is reduced, and 4) the dynamic response of the troposphere on strengthening of the stratospheric polar vortex is well correlated with the positive phase of the North Atlantic Oscillation. In the cited article, it is also shown that the zonally symmetric component of the lower troposphere reaction on perturbations of the polar vortex in the stratosphere may be a result of the baroclinic synoptic-scale waves, even in the absence of stationary planetary waves.

The tropopause height and thermal stratification of the troposphere are determined by the dynamic balance between the radiative processes and dynamical (baroclinic) fluxes of entropy (heat). The question of how dynamic and radiative processes interact to maintain static stability (mean vertical gradient of potential temperature) and mean meridional gradient of potential temperature, is still open. In (Borovko and Krupchatnikov, 2010), it is shown that the change of temperature stratification during the amplification of cooling in the stratosphere affects the top layer of the troposphere, where the stratification is determined by radiative processes. In the lower troposphere, where transient baroclinic eddies make a significant contribution to the dynamics, the local slope of isentropic surfaces remains unchanged and is consistent with the theoretical estimate, derived from the theory of baroclinic turbulence for two-layer model of the atmosphere.

One of the climatic processes of global significance are the quasi-biennial oscillations (QBO) of zonal wind in the equatorial stratosphere at altitudes of about 16-50 km. This phenomenon can be described as a slowly spreading down the western and eastern phase of zonal wind, with a successive period of about 28 months. The main mechanism, by which the QBO impacts on the atmospheric dynamics, is associated with the modulation of the wave activity transport (mostly, by stationary waves) in the extratropical stratosphere, which can lead to sudden stratospheric warming (Dunkerton and Baldwin, 1991) and to interaction of the QBO with other low-frequency processes, such as El Niño (Baldwin and Dunkerton, 1998). There are observed regional connections of the QBO with processes in the tropics, in particular, with the duration of the rainy season and hurricane activity in the Atlantic (Knaff, 1993).

Despite the significance of the QBO, few climate models are now able to reproduce this phenomenon (see, for example, Giorgetta et al., 2006). Ideally, the global general circulation model of the atmosphere must reproduce the interaction of the entire spectrum of equatorial waves with the zonal wind in the stratosphere. The question arises, what requirements must satisfy the model to reproduce the QBO. The main difficulty in solving this issue is to implement a complex mechanism of formation of QBO related to the nonlinear interaction of the mean zonal flow and vertically propagating waves of different scales. This issue was investigated in a series of papers (Kulyamin et al, 2008, 2009; Kulyamin and Dymnikov, 2010; Dymnikov and Kulyamin, 2010), prepared in 2007 – 2010 in the Institute of Numerical Mathematics of the Russian Academy of Sciences (INM RAS).

In the first of the publications in this series (Kulyamin et al, 2008), two mechanisms of formation of the QBO are considered. One of them is associated with the collapse of short gravity waves, and the other represents the interaction of long waves with the zonal flow. Such division is important from the standpoint of the development of climate models, in which the generation of large-scale waves is reproduced explicitly, and the effects of subgrid scale gravitational waves are parameterized. In the cited article, formation of the QBO is investigated on the basis of the mechanism of the planetary equatorial waves interaction with the zonal flow in the equatorial stratosphere, using a simple low-parametric model of evolution of the zonally averaged wind velocity component (Plamb, 1977). With the help of numerical experiments it is shown that this mechanism requires a high resolution model (vertical grid size should be not more than 500 m), because the critical layers in which the main interaction takes place, have a small vertical scale. Naturally, this condition is a requirement for reproducing the QBO by the atmospheric general circulation model (AGCM). However, the results of experiments with low-parametric Plumb model showed that this mechanism is not enough to excite the realistic QBO in global models, and should take into account the entire spectrum of wave motions at the equator. Because in models of coarse resolution the propagation of gravitational waves occurs at subgrid scale, the mechanism of their interaction was set in Kulyamin et al. (2008) using parameterization (Hines, 1997), the choice of which is due to its use in the INM RAS climate model. It turned out that the mechanism of the collapse of gravitational waves is self-sufficient to excite oscillations of the equatorial zonal wind in the upper atmosphere and for a specific choice of model parameters appear realistic QBO.

Thus, the main result of the cited article is the joint low-parametric model to encompass the entire spectrum of equatorial waves, and combining the two mechanisms of formation of the QBO (through the interaction of mean flow with long waves and through the collapse of short gravity waves). In this case, a key role in formation of the QBO period and amplitude in the lower atmosphere play planetary waves, while short gravitational waves transport energy and determine the characteristics of the QBO in its upper layers. This approach was used in Kulyamin et al. (2009) for the construction of atmospheric general circulation model, reproducing realistic QBO of zonal wind in the equatorial stratosphere. For this purpose, as the basis, the INM RAS climate model with a horizontal resolution of 2° latitude and 2.5° in longitude, but rather coarse resolution of 39 levels, was used. At default settings, this model does not reproduce the QBO in the equatorial stratosphere, but reproduces the semi-annual oscillations (SAO) in the upper stratosphere and mesosphere. Modification of the model by increasing the number of levels to 80 and by the choice of vertical grid spacing in the stratosphere of approximately 0.5 km make it possible to successfully reproduce in numerical experiments both the QBO and SAO with characteristics similar to those observed.

The problem of the QBO period formation, its stability and links with semi-annual and annual harmonics was investigated in (Kulyamin and Dymnikov, 2010, and Dymnikov and Kulyamin, 2010). To this end, data of observations reanalysis NCEP/NCAR and ERA40, as well as the results of numerical experiments with atmospheric general circulation model of INM RAS were used. Analytical estimates and numerical experiments with semi-parametric models showed the presence of strong synchronization to multiple periods of SAO in the upper atmosphere (in the transition from QBO to the SAO area) and weak synchronization in the lower layers of the spread of the QBO. In this case, the ability to synchronize with the SAO or the annual cycle is implemented as a mechanism both for the absorption of long waves by mean flow, and during the collapse of short gravity waves. This gives possibility to consider the QBO, SAO and the annual cycle as a unified system of oscillations in the circulation of the equatorial upper atmosphere. INM RAS AGCM successfully reproduced the main spectral characteristics of the QBO and SAO, and the observed features of the QBO period variations. Essential fact in this case is parameterization of internal gravity waves effects and associated vertical diffusion, varying which it is possible to reproduce the QBO with periods from 12 to 36 months.

It is known that large-scale atmospheric circulation over the Siberian region has several features which are due to geographic location (the size of the continent, the influence of the Arctic Ocean), specifics of the land surface and terrain. To study the atmospheric circulation over Siberia, Gorbatenko et al. (2007, 2009) examined the dynamics of cyclones and anticyclones over Western Siberia for the period 1976 - 2006. For this purpose, they used surface synoptic and high-altitude maps, as well as data of NCEP/DOE AMIP II reanalysis, in order to investigate trajectories of pressure systems movement, as well as to calculate the number of systems of different genesis.

Dynamic processes that affect the existence, intensity and duration of atmospheric blocking regimes (blocking), are constantly in the field of attention of researchers. It is generally believed that the blocking is the result of interaction between the amplified waves of synoptic scale that transport the anticyclonic vorticity in the area of blocking, and the quasi-stationary planetary-scale waves. When analyzing the variability of atmospheric circulation, one can consider short-term (with time scales of 2 - 6 days) and low-frequency (over 10 days) processes. The maxima of the low-frequency variability are located in areas with the highest repeatability of blocking situations (Dymnikov and Filatov, 1990). Of special interest is the life cycle of atmospheric blocking, in particular, the stage of their destruction. In Lupo et al. (2007), the three blocking events in the Southern Hemisphere over the Pacific Ocean during the cold seasons are analyzed. Based on the analysis of phase trajectories, it is shown that abrupt changes in large-scale structure of atmospheric flows may lead to rapid decay of blocking. This article contains four different scenarios of such a decay: the weakening of the synoptic "recharge", overly active role of synoptic processes or each of the observed modes in conjunction with abrupt changes in the nature of global flows.

Progress, which has taken place in recent decades in the development of general circulation models, and advances in technology assimilation of satellite observations, caused the interest of researchers to the problem of reproduction and prediction of seasonal climate anomalies. The World Climate Research Programme of World Meteorological Organization initiated projects on comparison of models of the atmosphere in relation to the reproduction of seasonal climate anomalies. In the paper by Tolstykh et al. (2010), the results of reproduction of the atmospheric circulation on seasonal time scales are presented, using global semi-Lagrangian model developed at INM RAS and Hydrometeorological Center of Russia. With this model, ensembles of retrospective seasonal forecasts (25 years for each of the seasons) based on the NCEP/NCAR reanalysis were calculated in the framework of the international experiment SMIP-2/HFP protocol, aimed at assessing the practical predictability on seasonal timescales. A comparative analysis of natural orthogonal components for the 500 hPa geopotential and sea level pressure, calculated for the main seasons using both the model results and reanalysis data, has showed quite satisfactory agreement between them.

The paper (Klimova et al., 2010) describes a method of assessing the statistical structure of short-term forecast errors of the temperature field in the atmospheric boundary layer for the purpose of objective analysis. Numerical experiments to evaluate the covariance of the forecast errors were made with WRF (Weather Research and Forecast, NCEP, USA) model. In the cited article the results of numerical experiments are presented with the aim to evaluate the above mentioned covariance in the atmospheric boundary layer, depending on its stability for the summer and winter periods. It is shown that the dispersion and the vertical correlation length of the forecast errors of the temperature field, as well as the behavior of three-dimensional covariance functions in the atmospheric boundary layer are significantly different in the different stability conditions.

For interaction between forecast models and data, there is an effective approach based on variational principles using the methods of assimilation and combinations of forward and adjoint problems for the process models. To date, two directions are under development. The first direction may include optimization methods, leading back to the method of weighted least squares (the Sasaki method and Kalman filter). The second trend is based on the classical variational principle with the application of Lagrange adjoint problems.

It is known that for the linear dynamics the optimal method of sequential data assimilation is Kalman filter (KF). However, in the case of nonlinear models of large dimension, the implementation of KF encounters serious difficulties. Firstly, if the dynamic model has a state vector of dimension N, then the covariance matrix of errors has dimension of N^2. This requires the storage of large data arrays and a large amount of calculations. Secondly, the use of KF with nonlinear dynamics requires linearization to obtain the evolution equation for the covariance of errors. This introduces errors in the forecast of covariances, which, in the unstable case, can grow. Using the schemes of high order closure makes this method practically inapplicable in the problem of data assimilation. Therefore, the recent widespread received another method of sequential data assimilation, namely ensemble Kalman filter (EKF), which allows to remove the restrictions of deterministic KF.

In Klimova (2008a, 2008b), methods for data assimilation, based on ideas of EKF in the assumption that the random forecast errors have the ergodicity property, are proposed. In this case one can obtain an algorithm, in which the probabilistic averaging is replaced by temporal averaging (π-algorithm). The author investigated the applicability of the π-algorithm in the problem of data assimilation for a simple one-dimensional advection equation. Using this simple equation allowed to compare this algorithm with the classical KF algorithm, and consider different approaches to practical implementation.

In the article (Penenko, 2009), new methods of variational data assimilation are proposed and the inverse problems for identification of model parameters are suggested. The explicit inclusion of uncertainties requires the Tikhonov regularization. For these purposes, the formulation of variational principles includes functionals expressing the total measure of uncertainty. The author notes that such an arrangement of data assimilation methods “switches on” the feedback from data to the model at the whole range of assimilation. This is a new fundamental element of methodology, since in traditional methods of assimilation the feedback is included, as a rule, only at the initial time of the assimilation "window". For practical applications, of great interest are methods for sequential data assimilation in real time. Here, the window of assimilation is equal to the time discretization step of the model, and the algorithm is realized without iterations. For a discretization of models and functionals the additive-averaged splitting schemes and discrete analytic monotone schemes for convection-diffusion operators are used. To implement these schemes, algorithms with parallel organization of calculations are proposed.

3. Mesoscale Processes

Polar mesoscale cyclonic eddies (Polar lows), formed in the cold season on the ice-free sea surface, is a bright feature of the atmospheric circulation in the high latitudes. Their typical size ranges from several tens to several hundreds of kilometers. In the paper by Mokhov et al. (2007), Polar mesocyclones are analyzed using data from the image archive of 253 vortex structures found over the water area of North-European Basin, Barents and Kara Seas in the period from 1981 to 1995. Despite the fact that there are considerable interannual variations of the parameters of these cyclones, significant climatic trends were not revealed. It was also found that the cumulative distribution of recurrence of Arctic mesocyclones over the regions under consideration can be fairly well approximated by an exponential function in the size range from 50 to 400 km.

Currently, quite a lot of attention is paid to the problem of tropical cyclones in relation to the observed climate change: whether to increase their number and intensity in a warmer climate? A curious fact here is the fact that tropical cyclones occur only if the sea surface temperature is not below 26 ^{0}C. In (Golitsyn, 2008, 2009), tropical cyclones, as well as polar mesocyclones with "explosive" (within hours) development, are considered as a unified hydrodynamic structure in the form of intense vortices, appearing above the ocean in an atmosphere of a rotating planet. Energy source for these eddies is the top layer of the ocean, and atmosphere must be colder than the surface water and not saturated with moisture up to 100%. In the polar regions the ocean gives heat in the form of sensible heat flux, and in the tropics, the main role plays latent heat flux. In the cited papers, Golitsyn has used arguments of the similarity and dimensions theory, so that on the basis of climatological data, aerodynamic formulas for near-the water surface-layer and the convective velocity scale in a rotating fluid to assess the buoyancy flux, as well as separately fluxes of sensible and latent heat. It turned out that in the tropics during hurricane winds $U \geq 33$ m/s and under climatological relative humidity 80% the total heat flux for a water surface temperature of $T_s \geq 26$ ^{0}C becomes close, and even exceeding, the value of 700 W/m^2. By equation Clausius – Clapeyron, at lower values of T_s the latent heat flux into the atmosphere is significantly reduced. For the penetration of convection above the boundary layer along with intense fluxes of buoyancy must take place substantially weakened static stability of the atmosphere and the absence of significant vertical wind shear. In polar regions, for the formation of explosive mesocyclones the total heat flux should be roughly twice as large than in tropics, due to the much smaller role of latent heat, more geostrophity and greater stability of the atmosphere.

According to modern ideas, one of the possible mechanisms of formation of regular and quasi-regular vortex chains of synoptic scale (circumpolar cyclones and anticyclones, in particular) is the instability of barotropic Rossby waves. In the paper (Ishioka and Yoden, 1995) it is shown that, depending on parameters of the circumpolar jet, in the coarse of a barotropic instability realization periodic, quasi-periodic or chaotic regime of planetary waves generation is formed. An important issue here is chaotic advection and diffusion of passive tracer particles in the chains of vortices. The article (Shagalov et al., 2010) is devoted to the study of generation of spectrally narrow packet of Rossby waves, which generate vortex chains in a zonal flow with a shear velocity profile. For the analysis, an asymptotic approach based on the selection of a narrow critical layer, in which the formation of vortex chains occurs, is used. It is shown that under supercritical increase the development of secondary instability leads first to Lagrangian chaos (there is chaotic motion of particles), and then (for further growth) to the randomization of the vorticity field. It is also studied the motion of passive tracer particles in a steady mode of self-consistent generation of Rossby waves and their associated chaotically modulated vortex chains. In the paper cited it is shown that under supercritical increase a so-called anomalous diffusion occurs, which, compared with the conventional diffusion, leads to more efficient transport of passive tracer along the chains of barotropic vortices.

In numerous experimental studies of impurity diffusion in a turbulent atmosphere a significant contribution of the ordered (convective) flows to the total vertical transport is indicated (see, for example, the review in the article by Zilitinkevich et al., 1999). In (Kuharets et al., 2009) the vertical transport of passive tracer in the medium in the presence of a turbulent and convective mixing is theoretically studied. It is shown that there is an effect of mutual influence of the turbulent and convective transport mechanisms. This effect manifests itself, inter alia, that the presence of convection weakens the turbulent transport, which is due to a "trapping" of impurity particles by vortex structures, and leads to its anisotropy, even in an isotropic turbulent velocity field.

In papers (Gorbatenko and Konstantinova, 2009, Konstantinova and Gorbatenko, 2010) the features of convection over Siberia due to severe weather are investigated. The main goal of such research is to develop a method for estimating the probability of the development of mesoscale convection into hazardous weather. In the cited publications, the temporal and spatial variability of parameters characterizing the convection on a number of signs (temperature stratification, moisture content of the lower atmosphere, its energy potential and rapid changes of wind with height) are analyzed. To study convection and severe weather caused by its development, data on the atmosphere state, obtained by using upper-air sounding of the atmosphere are employed. In the article (Ananova et al., 2007) for the study of convective clouds, along with the traditional observation data the radar characteristics of squall clouds at the south-east of Western Siberia are included into consideration. Recurrence of maximal height of cumulonimbus clouds in the presence of squall, the height of the zero (^{0}C) temperature isoline, the radar reflectivity at three levels and the maximum reflectivity, and integrated criterion of thunderous danger are investigated. The values of the radar characteristics of clouds in squalls under different synoptic situations are determined.

Forest fires are a significant factor impacting on the gas and aerosol composition of the atmosphere and are responsible for the marked regional changes in the environment, and may also affect human health. In addition, large quantities of aerosols emitted into the atmosphere contribute to the formation of clouds and thereby affect the circulation. In the paper by Aloyan (2009), a regional hydrodynamic model based on the coupled solution of problems of atmospheric dynamics in a humid atmosphere and kinetic processes of condensation and coagulation is used to study atmospheric circulation in the conditions of forest fires. A special attention is paid to the description of convective processes, taking into account the heat flux from the combustion zone. It is shown that the heat of condensation leads to an increase in elevation of the soot particles.

The influence of the megalopolis on the temperature regime of the atmospheric boundary layer is, in particular, that over the city the so-called "heat island" is formed whose existence was confirmed by measurements at meteorological masts and television towers, as well as by balloon-radiosonde observations at suburban upper-air stations. In the paper by Kadygrov et al. (2007), the data of temperature measurements made with the microwave radiometer at three sites, one of which is located in the centre of Moscow (megalopolis), and two others outside it - in Dolgoprudny (suburb) and Zvenigorod Scientific Station of the IAP RAS (background) are analyzed. Analysis of measurement data showed that the perturbations, contributing into the megalopolis daily and seasonal variability of the atmospheric boundary layer temperature, are damped with height, but remain statistically significant up to a height of 600 m.

The main feature of the problem of urban air quality over an inhomogeneous surface is a wide range of spatial and temporal scales of processes defining this quality, among which are the size of the city (tens of kilometers), where the primary emission of air pollutants takes place, and micro - and mesoscale, on which secondary air pollutants are formed and scattered. The dispersion of pollutants is highly dependent on the structure of the atmospheric boundary layer and its interaction with the background flow and the underlying surface. For numerical simulation of such a system with strong nonlinearity, the turbulence model requires high spatial resolution, taking into account the chemical transformation of pollutants.

Due to the increase in the intensity of road traffic, an organization of small enterprises with uncontrolled emissions of hydrocarbons, of particular relevance to most cities in Russia became the problem of air pollution by formaldehyde. In the paper by Shlychkov et al. (2010), it is attempted to reconstruct fields of formaldehyde concentration in Tomsk with a numerical model and the use of observational data. The wind regime over the orographically heterogeneous territory in Tomsk and the surrounding area was determined on the basis of diagnostic calculations by single-layer mesoscale model, the basic equations of which are obtained by the composition of statistical and hydrodynamic methods, and based on the hypothesis of "vertical" similarity of the hydrodynamic fields in the surface layer. To calculate the distribution of formaldehyde on the territory of the city, the three-dimensional equation of advection and diffusion of a passive tracer is used. By calibrating parameters, the adequacy of calculated characteristics to the measured concentrations of formaldehyde at observation posts is ensured. The model can be used to obtain estimates of the relative contribution of individual enterprises or groups of sources (including emissions from motor vehicles) in the general pollution of urban atmosphere, as well as a component of expert systems or support systems for management decision-making, particularly in developing preventive measures to help improve urban air quality.

In the article (Penenko et al., 2007), the set of models of the mesoscale transport of pollutants, including a deterministic one in the Eulerian formulation and the deterministic-stochastic model in the Lagrangian approach, is described. The results of comparative experiments on the simulation of pollutant transport in areas with complex geometry are presented.

In a series of papers (Balin et al, 2007, Potemkin and Makukhin, 2007, 2008), the results of comprehensive research of spatial distribution of aerosol fields with the use of laser sensing and local control from the ship on the Lake Baikal are presented. It was found that the average total concentrations of polycyclic aromatic hydrocarbons (PAHs) on Lake Baikal are close to background, and spatial distribution is very non-homogeneous. From a joint analysis with two-dimensional lidar spatial sections of aerosol fields, specific trends in the spatial fluctuations of these quantities are identified. In addition to instrumental studies, model calculations of the PAHs distribution based on the numerical solution of non-stationary semi-empirical equation of turbulent diffusion of impurities are performed. The comparison with experimental data showed that basically the calculated concentrations are close to the measured values. The analysis of the concentrations of nitrogen oxides, measured over the water area of Lake Baikal in the summer of 2005 and compared to the meteorological conditions during the same period, is performed. Using a numerical model of propagation and transformation of pollutants, areas of high pollution by nitrogen compounds in the region of Lake Baikal are identified. The analysis of the situation involving the spread of smoke plume from forest fires in the north-west coast of the lake has been carried out.

The article (Kurbatskiy, 2008) shows that nonlocal mechanism of turbulent heat transport in the atmospheric boundary layer over a rough surface is manifested in the form of bounded areas of counter-gradient transport of heat. These zones are identified by analysis of balance items in the equation for the temperature fluctuations variance on the basis of calculating the exchange coefficients of momentum and heat with a model of "gradient diffusion". In this case, the counter-gradient heat transport in local areas is caused by turbulent diffusion or a term of the triple correlation divergence in the balance equation for the temperature variance.

In recent years, increasing attention has been devoted to the processes of heat and mass transfer between the atmosphere and inhomogeneous land with different types of interface between two media. Traditionally used Monin-Obukhov parameterization does not give in many cases a satisfactory agreement with the data of field experiments. The paper by Panin and Bernhofer (2008) is devoted to analyzing the data of measuring the components of the heat balance over different land surfaces, the results of which indicate that the sum of sensible and latent heat fluxes is systematically smaller than the difference of the radiation balance and heat flux in the soil, and the imbalance increases with increasing heterogeneity of landscape. This fact may indicate the important role of internal boundary layers and associated atmospheric microcirculation in the parameterization of subgrid effects in large-scale models. In the cited paper, empirical formulas are presented for the correction of measured or calculated (based on the aerodynamic method) turbulent heat fluxes over natural (heterogeneous) land surface.

4. Turbulence in the Boundary Layer

One of the main features of turbulent motions in the atmospheric boundary layer (ABL) is a wide spatial-temporal spectrum of turbulent fluctuations, very long wavelength and low frequency of which can reach the size of several kilometers and have a time scale of several hours. It is also important that the boundary layer is characterized by the formation of long-living large-scale quasi-ordered structures (large thermals, having the form closest to the hexagonal Benard cells, convective rolls, extended spiral vortices of different nature), which define a significant part of the integrated transport of momentum, heat and moisture. In turbulent motion, average flow and velocity fluctuations are in continuous interaction throughout the whole range of scales. As a rule, even if there are semi-ordered structures, the flow can not be uniquely divided over on the small-scale and large-scale components, since the energy spectrum of velocity fluctuations in turbulent boundary layers has not pronounced minimum.

LES (Large Eddy Simulation) is a powerful tool for investigating the non-stationary three-dimensional dynamics of large-scale vortex structures in shear flows (including stratified by density) at very high Reynolds numbers (in particular, of order 10^9 for the atmospheric boundary layer). An important factor of development of eddy-resolving models is a consistent choice of parameterization of small-scale turbulence and the numerical scheme. This kind of model is presented in the paper by Glazunov (2009a). It uses the space-filtered Navier-Stokes equations, mixed localized turbulent closure of the dynamic type and the conservative scheme of fourth order accuracy. A substantial part of the nonlinear interactions in the large (but still represented on the grid model) wavenumbers is replaced by a dissipative term, which is justified in the case of dominance of the direct energy cascade in three-dimensional turbulent flow. Dynamic turbulence closure automatically adjusts the sink of the kinetic energy of small-scale eddies, so that this model not only reproduces the structure and energy of large-scale components of turbulent flow, but also gives the possibility to estimate the spectral energy density of velocity fluctuations at large wavenumbers.

However, it was found that in the LES-model with explicit filtering the inverse cascade of energy, predicted by dynamic closure, is determined by the interactions of resolvable scale fluctuations with of similar scale "sub-filter" harmonics. On the other hand, the reversibility of filter allows for any time to get out from forecasted velocity its "reconstructed" analogue, more accurately reflecting the small-scale structure of the flow (Glazunov, 2009b). In this paper, the model was verified through a series of long-term numerical simulations to reproduce the turbulent flow in a channel bounded vertically by two identical infinitely extended rough plates. The motion of fluid in the channel was supported by directed along its axis external force, given in the form of constant pressure gradient. The results are compared with data of laboratory experiments and the results of direct numerical simulation (DNS). It is found that a posteriori reconstruction of the simulated velocity field provides a much more accurate reproduction of the statistical characteristics of model solutions.

The effect of rotation on the intensity and structure of turbulent fluctuations is found for a long time ago (see, for example, in an article by Johnston et al., 1972, the experimental data, confirming the suppression or enhancement of turbulence in the shear boundary layer, depending on the direction of rotation). In the article (Zikhanov et al., 2003), a series of calculations with LES-model of the neutrally-stratified upper ocean layer has been conducted for different directions of the shear stress vector on the surface. The results showed a strong dependence of the intensity of turbulent processes on the flow direction. Using eddy-resolving model of the atmospheric boundary layer, Glazunov (2010) has studied the effect of the Earth's rotation on the structure of turbulence and the dynamics of quasi-ordered eddies. Numerical experiments for neutrally stratified turbulent Ekman layer with a large computational domain (21 km in both horizontal directions and 3 km vertically) and grid step of ~ 40 meters (about 20 million grid points) allowed to reproduce explicitly both a small-scale three-dimensional turbulence and large-scale rolls of up to several kilometres size. It is found that the presence of meridional component of the angular velocity of the Earth's rotation leads to a significant increase of the intensity of velocity fluctuations in neutrally stratified turbulent flow in the eastern and north-easterly winds and a weakening of the intensity of fluctuations in the western and south-westerly wind. This, in turn, causes significant changes in the mean velocity profile. It is shown that these changes are associated with the large-scale fluctuations that are comparable in scale with the thickness of the turbulent Ekman layer. It is also found that in the bounded in height neutrally stratified ABL and in conditions of its stable stratification the dependence on the wind direction is significantly reduced.

With the help of LES-model in the paper (Glazunov et al., 2010) the thermal Rayleigh-Benard convection in a doubly periodic channel with solid walls has been investigated as an analog of multi-scale atmospheric turbulence (in terms of reproduction of the spectral properties). The "mesoscale" ratio of its horizontal dimensions to the vertical one (25.6 in both directions) has ensured the existence of large-scale quasi-two-dimensional flow, and the size of uniform grid of approximately 42 million grid points has allowed to explicitly reproduce the dynamics of small-scale three-dimensional turbulent component. Analysis of the results of numerical experiments showed that the convection starts with small-scale, chaotically placed, uplifting and downward thermals, which combine to form convection cells of irregular shape (including, and deformed hexagonal cells) of approximately the same size, comparable to the distance between the walls. Then, the cells begin to merge together and become stronger as long as the size of the biggest anomalies does not reach the size of the model computational domain. At any time, small-scale anomalies are observed on the background of large cells.

Decomposition of the investigated turbulent flow in the barotropic and baroclinic components has allowed to propose the following scheme for the kinetic energy transformation in the system. The kinetic energy enters the system by converting available potential energy in the baroclinic kinetic energy at the scale of large thermals (through the vertical velocity component) and redistributed on the same scale through the pressure gradient in the baroclinic components, determined by the horizontal velocity components. Due to nonlinear interactions and without substantial dissipation and generation the baroclinic energy is transferred toward smaller scales, forming a first inertial interval with spectral distribution close to the law $k^{-5/3}$ (k - wave number). In the interval of wave numbers associated with a nearly vertical size of the computational domain, there is a substantial transformation of the field of baroclinic velocity fluctuations, providing the energy conversion from barotropic to baroclinic and back, with positive, in the mean, contribution to the energy of averaged over the entire thickness of the layer flow.

The energy of the barotropic component extends from its source, mostly towards large scales, creating a spectral dependence of the $k^{-5/3}$ form, and to a lesser extent, toward smaller scales, that as a result of a cascade of enstrophy leads to the k^{-3} distribution. The rest of the baroclinic kinetic energy, which is not converted into a barotropic component, is transmitted through direct cascade of nonlinear interactions in the direction of smaller scales, where it dissipates (in the case of eddy-resolving model - due to dissipative contribution of closure, and in case of a real turbulent flow - due to the forces of molecular viscosity).

Herstenstein et al. (2008) have studied in the Boussinesq approximation two-dimensional convective flows of viscous incompressible fluid in an infinitely extended layer between two horizontal planes when heated from below. To this end, direct numerical simulation of these flows was conducted, using the Bubnov-Galerkin method for the non-stationary Navier-Stokes equations. The problem is considered in two formulations with different boundary conditions on horizontal boundaries. In the case of the so-called "free" conditions, the vertical velocity, shear stress of friction and temperature shall vanish at the horizontal boundaries. In the formulation with the "stiff" conditions, non-slip condition is used instead of vanishing shear stress. The calculations were performed for different values above the critical level $r = \mathrm{Ra}/\mathrm{Ra}_{\mathrm{cr}}$, where $\mathrm{Ra} = g\beta H^3 \delta T / \nu\chi$ is Rayleigh number (H - thickness, δT - the temperature difference at the boundaries of this layer, β, ν, χ - the coefficients of thermal expansion, kinematic viscosity and thermal conductivity), $\mathrm{Ra}_{\mathrm{cr}}$ - critical Rayleigh number, depending on the type of problem (equal to 657.5 and 1708, respectively).

A special attention is paid to the spatial spectra calculated for the high-supercritical case (with $r = 26000$ in the problem with free boundary conditions) and relatively small $r = 6000$ (in the problem with stiff conditions). In the region of low wavenumbers spectra are close to the Kolmogorov spectrum $k^{-5/3}$, and in the high wavenumber branch the spectral curve is formed by a distribution close to the law

k^{-1}. For the kinetic energy fluctuations in this area holds the spectral law k^{-3}. This "coexistence" of power laws, k^{-1} and k^{-3}, indicates the presence of the inertial range of forward enstrophy cascade.

Processes of turbulent interaction between the atmosphere and the ocean surface are crucial in the theory of tropical storms and polar lows. One of the characteristics of this interaction is the drag coefficient C_d of the sea surface. Traditional aerodynamic formulas obtained on the basis of generalization of experimental data for wind speeds less than 30 m/s, give higher values C_d due to strong winds. In the paper (Powell et al., 2003), it is shown, based on the aggregation of measurements with the incident within tropical cyclones GPS-probe, that the drag coefficient decreases when wind speed reaches 30 - 35 m/s. Possible reasons for this effect may may be a change in the shape of the sea surface in the energy-carrying waves, accompanied by the appearance of a sharp leading edge and the separation of the atmospheric boundary layer (Kudryavtsev and Makin, 2007), as well as the mechanism associated with the presence of spray in the flow formed by wind disrupting the steep ridges of waves (Lykossov, 2001, Andreas, 2004).

In the paper (Troitskaya and Rybushkina, 2008), to determine the aerodynamic drag of the ocean surface due to strong winds, it is proposed a quasi-linear model of the wind boundary layer, based on the solution of Reynolds equations taking into account the effects of the viscous sublayer. In this model, the effect of reduction due to strong winds is explained as due to the fact that the wind generation of waves causes the transfer of momentum from wind to waves, resulting in great reduce of turbulent stress near the surface. This leads to a decrease in the eddy viscosity near the surface and deformation of the wind velocity profile. Comparative analysis of calculation results and experimental data for a wide range of wind speeds allowed the authors cited above article offer a simple parameterization of the drag coefficient for use in numerical models of the wind and waves forecast.

One source of aerosols in the atmosphere is the land surface, from which, under certain conditions, soil particles can be loaded into the atmosphere (for example, during dust storms and dust whirlwinds). Experimental data and theoretical estimates indicate that the separation of particles from the soil surface may occur due to turbulent stress under conditions, when the friction velocity exceeds a critical value (see, e.g., Barenblatt and Golitsyn, 1974). In the article (Gledzer et al., 2010), asymptotic expressions for the mass concentration of fine aerosol are obtained based on field measurements in the Caspian desert and estimates of hydrodynamic parameters in thermal viscous layer near the soil surface. It is assumed that the removal of aerosol from soil is proportional to the air velocity at the top of the thermal layer, which is determined by a friction velocity and temperature deficit in this layer. As a possible mechanism for removal of aerosol, the model of the air dynamics in the porous layer of soil with the assistance of Darcy's law is considered in the cited article.

Papers (Kurbatskiy and Kurbatskaya, 2008, 2009) present the results of investigation of the structural features of stably stratified boundary layer over the urban surface. For this purpose, a modified three-parametric model of turbulence for a thermally stratified atmospheric boundary layer, based on tensor-invariant parametrizations for the stress and pressure correlations between pressure and temperature, is used. Turbulent fluxes of momentum and heat are calculated using the explicit algebraic models, which in a unified manner describe the state of convective mixing, stably stratified regime and the transitions between them. Comparison of simulation results with observational data and with results of other models showed that the proposed model can reproduce the most important features of the turbulent boundary layer over an urban surface, as well as the effect of roughness on the global structure of the wind fields and temperature over the city.

It is now commonly recognized that in the stably stratified atmospheric boundary layer flows, turbulent mixing exists, if the gradient Richardson number $\mathrm{Ri}_g \gg 1$ and the inverse turbulent Prandtl number Pr_t^{-1} decreases with increasing thermal stability of the flow. In the paper (Kurbatskiy and Kurbatskaya, 2010), it is shown that the above three-parametric model of turbulence, which takes into account the effect of stratification in the expression for the time scale of the scalar field, is able to reproduce the known from experimental data and LES-simulation dependence of the Prandtl number on the Richardson number, as well as counter-gradient heat transport in very stable boundary layer.

5. Mathematical Problems of Climate and Ecology

In 2007 - 2010 years, intensively was carrying out the scientific direction associated with the development of the mathematical theory of climate based on the use of methods of dynamical systems theory. One of the main objectives of such a theory is to develop a methodology for assessing the sensitivity of the climate system to small external forcing, which would give a constructive method for calculating the climate changes under the influence of these factors. The definition of "climate" is introduced as a set of states passed by the climate system for a sufficiently long period of time (in practice, over 30 years was adopted). The problem of global and regional climate change is treated as a problem of sensitivity of the statistical characteristics of solutions to equations describing the dynamics of real climate system. From a mathematical point of view, the problem of climate sensitivity is a problem of the sensitivity of the climate system attractor (the set of states in phase space, on which an evolution of the system takes place) and its invariant measure (equilibrium distribution of system states on the attractor) to changes in system parameters (Dymnikov and Filatov, 1990, 1997). When studying the response of the climate system to small external forcing, it is assumed that the climate system dynamics is on its attractor, and for its qualitative analysis one can use models that are more or less successfully describe the current climate.

But it is important to bear in mind that the typical models of the climate system have the property of chaos, due to the presence of positive Lyapunov exponents, and dissipation, so that their attractors are of fractal topological structure.

A perspective method for assessing the sensitivity of climate models and the real climate system to external forcing is to construct an approximate response operator based on the fluctuation-dissipation relations (FDR), which relate the response operator of statistical characteristics of the model with its unperturbed statistical characteristics (Dymnikov and Gritsoun, 2005). This means that the operator of the system response can be calculated solely using the unperturbed trajectory of the system and, consequently, the sensitivity of certain characteristics of the real climate system to changes in external parameters can also be calculated directly from observations. FDR-technology of the response operator construction requires the calculation of multi-dimensional covariance matrices of the system and their inverse ones, which is a complex computational task.

The paper by Gritsun and Branstator (2007) has demonstrated how this technology can be used to construct the linear part of the response operator, based on data obtained by the (nonlinear) atmospheric general circulation model. To this end, a model CCM0 of National Center for Atmospheric Research (NCAR, Boulder, USA) was integrated in the "Permanent January" mode for 4 million days. Patterns of the stationary response in the temperature field and stream function to perturbations in the heat source, calculated using the FDR-technology and directly (with the help of the model SSM0) have shown quite good agreement with each other. It was also found possible to formulate and solve the inverse problem, namely to find the disturbance that would be optimal for a given response. In the article (Gritsun et al., 2008), the FDR method of constructing the response operator is generalized to the case of the climatic characteristics that are not parameters of the system state, and represent some of their functionals, such as the mean rainfall, the average divergence in the upper troposphere or low-frequency variability of the stream function. In particular, there are constructed optimal tropical disturbances, causing maximum changes in the variability of synoptic eddies in the mid-latitudes. It should be noted, however, that a major limitation of FDR method is the requirement of statistical equilibrium of the unperturbed system, which is impossible if the right side of the system contains an explicit dependence on time. Recently generalized fluctuation-dissipation relations (Majda and Wang, 2010) provide a theoretical possibility of constructing the operator response in this case also.

Apparently, at present the only method of investigating the attractors of multidimensional climate systems is a numerical approximation of the corresponding sets (Dymnikov and Gritsoun, 2001), for example, the calculation of global Lyapunov exponents (as indicators of the measure of trajectories instability on the attractor) and the dimension of the attractor of the system (as a measure of the complexity of its dynamics). Promising way to describe the fractal attractor of the system can be based on its approximation using simple basic sets, such as periodic orbits. Solving problems, relating to the existence of periodic solutions in phase space of atmospheric models and links between the characteristic modes of circulation and the properties of the model phase space, as well as possibility to approximate circulation by means of periodic motions are discussed in a series of papers (Gritsun, 2008, 2010a, 2010b).

In the first of this series of articles, several methods are formulated and implemented for a barotropic model of the atmosphere to search for periodic orbits of the model by which over 1500 periodic solutions of the model were found. Calculated orbits have a wide range of periods (4 to 200 days) and the different characteristics of stability (from 2 to 30 unstable modes). The following article (Gritsun, 2010a) addresses the problem of approximating the invariant measure and the statistical characteristics of the barotropic atmosphere model with the help of its periodic orbits. The possibility of such an approximation is based on the ideas of dynamical systems theory, which asserts that in some special cases (e.g. for hyperbolic systems) periodic orbits determine the measure of the system. In this case, the orbits are taken into account according to the weight determined by the characteristics of their instability. The paper shows that under a proper method of averaging it is possible to reproduce the probability density distribution of points in phase space with an error not exceeding 10%. In the final article of the above cycle, the method of generalized FDR was used to construct the approximate response operator for the model CAM3 of NCAR. To this end, a numerical method for constructing the response operator is proposed and preliminary calculations have been carried out to simulate the model response on to equatorial thermal disturbances.

In the years 2007-2010, a research was also conducted to improve and develop methods for solving problems of ecology in a changing climate and environmental quality (Penenko and Tsvetova, 2007, 2008, Penenko, 2010). The peculiarity of this class of problems is that it is necessary to consider a wide range of interacting processes on long time intervals in areas of different scales with uncertainties in external and internal sources of disturbances. It must also consider the feedback, when changes in climate are caused by anthropogenic and natural influences. Relations between the sensitivity and functionals of generalized estimates give a constructive basis for the formation of backward and forward links between the various elements of the modelling system. The sensitivity functions arised in this case synthesize a solution to the direct, adjoint and inverse problems for mathematical models of hydrodynamics, transport and transformation of pollutants, and calculating the sensitivity relations of the atmosphere quality functionals. Penenko and Tsvetova (2007, 2008) have proposed a method of ecological forecasting, taking into account the changes in climatic factors. On the basis of orthogonal decomposition, it is selected from multidimensional and multicomponent databases, containing information on the functions of the state, describing the atmospheric processes over a long period of time, the set of subspaces, ranging in scale of disturbances. The leading part of subspaces, which accounts the climate-scale processes, is an informative basis for the formation of hydrodynamic background when calculating forecast scenarios of changes in air quality. For testing methodology, the database of NCEP/NCAR reanalysis for more than 50 years was used. In the cited article the results of scenario calculations to assess the risk of air pollution in the Far East of Russia and adjacent territories of China and Korea are presented. In the paper (Penenko, 2010), a concept of environmental prediction is presented, which is based on variational principles in conjunction with the methods of data assimilation and on an assessment of risk and vulnerability of territories with respect to anthropogenic factors. This allows to assess the impact of uncertainties on the quality of the forecast.

This review would not been possible without the input and encouragement of large number of Russian scientists.

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Meteorology of Middle Atmosphere

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Some new results, which illustrate middle atmosphere structure (temperature, winds and tides) and its dynamics based on observations and numerical simulations, are presented in this report. One of the focus of data analysis is long-term changes and trends. It was shown also, that cosmic factors (cosmic rays and solar UV variations) may induce important changes in atmospheric chemical species (first of all in ozone content), temperature and circulation. Polar regions are under forcing of energetic particles near solar maximum, and corresponding ionization of the air leads to the borning of additional nitrogen and hydrogen oxides influencing on ozone layer. Reader can find the details in original paper using the list of references.

1. Circulation in a middle atmosphere and its changes

On the basis of empiric model of average monthly srednezonal'nogo of prevailing horizontal wind is expected height-latitudinal distributing of eylerova of prevailing average monthly vertical wind and proper mass function of current for vertical and ageostrophic meridional winds [1]. Calculations are conducted for the central months of basic seasons of year: for January, April, July and October. The distinctive feature of the got distributing of meridional and vertical winds is a cellular structure of height-latitudinal circulation. For meridional wind cell-type structures are concentrated mainly in low breadths: between 40 degrees of North and South breadth. In vertical wind they approximately are evenly up-diffused on a breadth. The mechanisms of forming of similar structures and problem of their design come into question in the global numeral models of atmosphere.

Basic fashions interannual and dolgoperiodnykh variations of circulation of stratosphere and troposphere, general maintenance of ozone (OSO), and also their connections with the anomalies of temperature of surface of ocean (TPO) of the North hemisphere probed in [2]. Found out considerable correlations of interannual variations of OSO in area of Labradora and north Atlantiki with the changes of stratosphere whirlwind of Arctic. The origin of strong stratosphere rises in temperature is related not only to strengthening of westerliess on 500 gPa n the middle breadths of Atlantiki, but also weakening of wind of troposphere above the north of East Siberia and strengthening above Far East. In years with strong stratosphere rises in temperature there are anomalous cold the winters in Eurasia, especially in East Siberia and north-eastern China. There are considerable correlations of anomalies of TPO of extratropical areas of the Pacific and Atlantic oceans with interannual variations of circulation of troposphere and stratosphere, thus the dynamics of stratosphere is stronger related to the anomalies of TPO Pacific ocean. The mechanisms of dolgoperiodnykh changes come into question in interactive application ocean-atmosphere-ozone layer.

With the purpose of study of processes of mass-transfer through an extratropical tropopause the analysis of bottle data is conducted about ozone and aquatic steam, LAUTLOS got during a campaign. For the analysis of origin of air the masses and calculation of streams through a tropopause a trajectory model was used. It is rotined that troposphere air the masses get to the stratosphere on ~2,5 km above the level of tropopause. The depth of exchange can be determined both vertical streams in troposphere and change of level of tropopause [3].

The parameters of semi-diurnal wave are in-process [4] got in area of mesopause on the basis of measurings on Maymata (63^0S., $129{,}5^0$E.) of fluctuations of intensity and rotation temperatures of emissions of OH(6,2) and front atmospheric page of oxygen of O2(0-1), excited on heights ~87 and ~95 km, accordingly. A database, got from October for March in 1999-2005, was used. Amplitude of the wave on height of a 95 km is equal 8K and on ~2Ê more than on a 87 km. Except for November 12-sentinel oscillation on height of a 95 km is LED on a phase oscillation on height of a 87 km.

2. Quasibiennial Oscillations

In [5] was considered the problem of design of Quasibiennial Oscillations QBO) in an equatorial stratosphere. On the basis of littleself-reactance models two mechanisms of (QBO) excitation of are considered: through co-operating of planetary waves with a middle flow on critical levels and through the mechanism of bringing down of gravity waves. Possibility of receipt of analogue of QBO is rotined with the use of each of these mechanisms, the areas of values of parameters which it is possible at are considered, dependences of period and amplitude of maximum cycle are studied on the parameters of models. More realistic picture turns out at the joint including of both wave sources. The relative role of waves of different scales is investigational in forming of period of vibrations of zonal wind. Terms, necessary for reproducing of QBO in GCMs .

In accordance with the results of the first part on the basis of models, developed in INM RAN, marketability in them mechanisms of excitation of QBO is investigational from co-operation of planetary waves with a middle flow and bringing down of gravity waves [6]. The update version of model of INM RAN is created 2^0 x $2{,}5^0$ x 80 with a vertical high-res on the base of 39-level model of general circulation of INM RAN. The good reproducing of modern climate is rotined by both models, marketability mechanism of excitation of vibrations of zonal speed is shown on an equator through bringing down of gravity waves in a 39-level model and realization of both mechanisms of excitation in the model of 20 kh 2,50 kh 80. The results of spectrology of wave activity are resulted on an equator and the processes of forming of QBO are in detail investigational in these models. In the update version of model it was succeeded to reproduce KDK of zonal wind on an equator very near to information of supervisions.

3. Effects of extra-atmospheric influences

The one-dimensional ion-actinic model of gas composition of atmosphere, describing education D-region ionospheres, is built [8]. On its basis the calculations of vertical types of concentration of electrons and ions are conducted, and also small gas constituents to the height a 86 km for unperturbative terms and after a powerful sun proton flash (SPE) at the end of October 2003 SPE results in the considerable increase of NOx in the mesosphere of arctic breadths. In the lower mesosphere of arctic caps the relation of mixture of NOx increases on 20-50 ppbv, and in overhead – on 100 ppbv and more. The high levels of NOx can be saved during a few weeks, producing long-term, but the small diminishing of ozone is comparative in a lower mesosphere. The basic diminishing of ozone is caused short-term growth of NOx after SPE and also short-term in the conditions of the lighted up mesosphere. After SPV in October, 2003 model calculations give diminishing of concentration of ozone on 40% in a middle and overhead mesosphere on 75^0 S, and on 70% on those heights on 70^0 N. The results of design of changes of NOx and O3 after SPE in October, 2003 well correspond with information of the satellite measurements. Comparison of results of calculations on a complete ion-actinic model and on a model with the parameterizations of the sources of HOx and NOx shows an enough good coincidence for HOx, NOx and O3, and for CLO there is noticeable divergence, especially in a lower mesosphere (on a 60 km a model twice understates formation of CLO after SPE).

From data about the streams of sun protons, measured by series of GOES, the most powerful proton events (SPE) of 23th cycle of sun activity are chosen and speeds of ionic composition of the atmosphere are expected in these periods in the high breadths of north hemisphere. In supposition, that every pair of ions brings 1,25 molecules over of nitric oxide to education, 2,0 molecules HOx. Calculations rotined that the most strong ionization and destruction of ozone was caused by SPE 14.07.2000, 08.11.2000, 04.11.2001 gramme.,28.10.2003 [9]. Speeds of ionization of the South arctic atmosphere after SPS of October, 27, 2003 are expected from data about the streams of electrons and protons, measured on satellites GOES 10/11 and POES 15/16 for electrons and protons separately [10].

On the basis of spectral supervisions of emissions of mesopause on Zvenigorodskoy of observatory in 2000-2007 seasonal dependences of response of intensities of radiation of OH (6-2) and molecular oxygen of $O_2(b^1\Sigma^+{}_g)$(0-1) are got, and also temperature and index of closeness of atmosphere on a 87 km on a change sun activity. For all seasons of year the response of these descriptions on sun activity is positive. But in a winter period a most response is observed in intensity and temperature, the least in the indicator of closeness (relation of intensities OH (7-3) and (9-4), characterizing the conduct of swaying temperature). Basic mechanisms, stipulating influence of sun activity on descriptions of mesopause, are considered. The conduct of internal gravity waves is investigational with periods from 0,33 to 7 h depending on sun activity [11].

An interactive three-dimensional chemistry-climatic model, uniting the models of gas composition and general circulation of lower and middle atmosphere, is used for the study of direct influence of changes with sun activity of streams of sun radiation on heating of stratosphere and subsequent changes of temperature and maintenance of ozone in troposphere and stratosphere. Variations of temperature tell on speeds of chemical reactions, that is examined as the first type of indirect influence of sun activity on atmospheric composition. In addition circulation of atmosphere, influencing on the transfer of gas admixtures, changes at the change of heating. This effect is examined as the second type of indirect influence of sun activity on gas composition of atmosphere. Calculations rotined that both types of indirect influence in order of size are comparable with the direct effect of influence of sun activity on atmospheric gases [12].

4. Researches of temperature and composition of middle atmosphere

A) Temperature

On the basis of average monthly vertical types of temperature in area of heights a 25-75 km, certain from data of the rocket sounding on the stations about Heiss Island, Volgograd, Tumba and Molodezhnaya, located accordingly in the high, middle and low breadths of north hemisphere and in high breadths South, approximation of latitudinal, seasonal and height changes is got.[13]. The analysis of the got results allows to do the followings conclusions: 1) Average annual subzero trend of temperature (averaging on a height a from 25 to 75 km) after 1964-1994 made -0,3 K/year. His maximal value was observed in overhead part of mesosphere (-1 K/year). 2) The most considerable seasonal changes of trend took place higher 55 km. 3) the most expressed latitudinal motion of trend was observed in a mesosphere. Distinction of trends in this area for winter and summer terms on poles made near 0,5K/ year, thus for summer terms the absolute values of trend were less than, than for winter.

Results lidar observations of vertical distribution of temperature over Tomsk in 2008-2010 with accent on research of displays of winter stratospheric warming are resulted in [14]. The revealed warming were the most long for all experience of supervision since 1996 They have begun on January, 15th and have come to the end of February, 2010. It there were also the most powerful warming at which the temperature in separate nights reached to 36^0C,

and level of stratopause felled down to 37-38 km. Measurements of a high-rise temperature profile were spent to 2004-2009 by lidar (λ532 nanometers) near Yakutsk ($61,7^0$ N, $129,4^0$ E) [15]. The analysis of winter stratospheric warming with attraction of the data of aerological sounding has shown 2005-2006 that warming observed every year are caused диссипацией the planetary waves extending from below upwards. Also consist of the several short-term localized warming, thus it is modulated by a planetary wave with wave number 1 and with the period about 90 days.

Generation of internal gravitational waves at a flow revolts with an air stream of a ridge of Kopet-Dag a condition of the bottom thermosphere. For issue of 557,7 nanometers at speed of a stream of ~35 km/s the radiation temperature increases on ~5K, the height of a maximum of a radiating layer decreases on ~2,5 km [16].

The mechanism of changes of temperature of atmosphere at the expense of vertical convergence and divergence air streams [17] is offered. These streams form meridional circulation cells. On the basis of the equation of sources of heat for a case adiobatic process numerical estimations of efficiency of the mechanism are received. It is shown that at mesosphere heights this mechanism can create change of temperature with efficiency of an order 10 - 3K/with and can explain existence of a warm mesopause in the winter and cold in the summer. Confirming experimental data are presented.

The analysis of a technique of definition of rotary temperature of hydroxyl issue is presented in [18]. It is shown that use by different authors of factors of intensity (force of lines) the lines of rotary structure of strips of a hydroxyl based on various theoretical calculations, leads to a divergence of values of defined temperatures for area of radiation IT (~87 km) to 14K, considerably exceeding an error (2-3K) measurements. Use of set of such data at the analysis of a temperature mode can lead to distortion of character of long-term changes of temperature of a mesopause. The analytical expressions are resulted, allowing to calculate the regular amendment for temperatures at which definition various factors of intensity were used. It is necessary to consider also considerable seasonal variations of dependence of rotary temperature from level of oscillatory excitation of a hydroxyl. At the publication of results of measurements of rotary temperatures of hydroxyl issue it is necessary to specify what factors of intensity since what moment of time were applied, what strips

IT were used at supervision and during what periods of time, measurements were spent to what seasons and at what widths. Only in this case reduction of the saved up data to uniform helio-geophysical conditions is possible.

B) Composition

The review of the new information on a chemical compound of a stratosphere and the mesosphere received during different seasons in both hemispheres by means of satellite devices is spent MIPAS, SCIAMACHY, GOMOS, HIRDLS, TES, OMI, MLS. In supervision there were some powerful solar proton flashes (Union of Right Forces). Ionization by solar protons has led to formation of additional quantities of oxides of nitrogen and hydrogen and destruction of ozone of polar average atmosphere. Comparison of measurements to modeling calculations allows to check up representations about photochemical processes in atmosphere and processes of interaction of atmosphere with space plasma [19].

The chemical-climatic model of the bottom and average atmosphere was used for estimations of sensitivity of gas structure of atmosphere to speed of storm production of oxides of nitrogen within the limits of natural uncertainty of production from 2 to 20 TgN/god [20]. Modeling experiments have shown that thus concentration of oxides of nitrogen in the top troposphere and the bottom stratosphere can change in 2-3 times, change of the maintenance of ozone at some heights exceeds 100 %; also concentration of a hydroxyl essentially changes. Results show an urgency of increase of accuracy of estimations of speed of formation of oxides of nitrogen at lightning categories and uses in models of gas structure and the general circulation of atmosphere not the climatological data, and physical paraterizations, allowing to consider local features of course lightning effects and feedback arising thus.

The estimation of concentration O2 at heights of 90-120 km on measurements of absorption of solar UV-radiation on companion "Koronas-F" is resulted in [21]. Concentration O2 at these heights has appeared in 1,3 times more than in model Jacchia-77. Level of solar activity poorly influences concentration O2 at these heights.

According to land measurements of the general content (OS) NO2 in a vertical column of atmosphere at stations of network NDACC the analysis of daily and annual variations OCNO2, its reduction under the influence of products of eruption of a volcano of Pinatubo, change in a 11-year-old cycle of solar activity and linear trends OCNO2 [22] is made. The difference between evening and morning values of OS during all seasons has maxima in vicinities 40^0 N and 45^0S. Seasonal maxima of a difference in these widths aren'ted in the summer in northern hemisphere (joint venture) and in the end of spring - the beginning of summer in southern. The annual maximum of OS in extra-tropic latitudes of both hemispheres is observed in first half of summer, and an annual minimum – in the winter.

The maximum annual values in the joint venture have on a vicinity 400 с.ш., and in ЮП – on a belt 5^0-60^0SH. Reduction of OS after eruption of Pinatubo poorly depends on width and is in limits of 20-25 % on evening measurements and varies with width from ~25 % in high widths to ~35 % in middle latitudes under the morning data. Values of OS in middle latitudes above during a minimum of solar activity (a difference in 12 % on the item of Zvenigorod). In high and polar widths a difference statistically незначима. Distribution of annual estimations of trends approximately антисимметрично concerning equator with positive in SH and negative values in the joint venture in averages and low latitudes. The maximum values of trends make ~10 % for 10 years. In high and polar latitudes annual estimations of trend are statistically non-significant.

Results of the analysis of measurements of general maintenance NO2 within 25 years are presented in [23]. Its average monthly and annual sizes as a whole have grown on ~6 %. The indicator of a linear trend has made 0,23 % a year. Average annual value is equal (3,18 ±0,05) 1015 per/sm^2, amplitude of seasonal variations – (2,39 ±0,04) 1015 per/sm^2. The spectral analysis has revealed compound fluctuations with the periods from 6 till 253 months. The simple statistical describes time changes of average monthly and annual maintenances NO2 with average square-law deviations of ~4 and 1 %, accordingly.

About maintenance NO2 in a vertical column of atmosphere of device OMI on companion EOS-Aura comparison of the data is spent to the period from October, 2004 till October, 2007 with results of land measurements at Zvenigorodsky scientific station (55,7^{0}N., 36,8^0 E.). The correlation factor between results of land and satellite measurements of a stratospheric "uncontaminated" part of general maintenance NO2 makes ~0,9. Device OMI data on the average on (0,30±0,03) 1015 cm^{-2} or on (11±1) are less than %, than the land data at a root-mean-square divergence of 0,6 1015 cm^{-2} [24].

During two international field campaigns in the Western Africa (August, 2006) and Central America (August, 2007) 11 vertical profiles of water steam with the high permission in the top troposphere and a stratosphere from a board of a meteorological sounding balloon the Russian optical fluorescent hygrometer FLASH-B [25] are received. Layers with the raised humidity in the bottom stratosphere over the Western Africa to level of 4500 potential temperatures are found out. The analysis of satellite cards light temperatures, balloon measurements of ozone and aerosol dispersion and trajectory modeling show communication between layers with the raised humidity and the phenomena of convective breakdowns tropopause in which result the air cold and impoverished by ozone gets to the bottom stratosphere (to 18 km and above) together with ice particles in the size 0,5-10 microns which quickly sublimate, locally increase concentration of water steam. Values and vertical structure of water steam you areas tropopouse and an average stratosphere essentially differ over the Western Africa and Central America.

At heights of 20-60 km since December 2003 till May, 2004 work [26] is devoted studying of spatial and time variations of concentration of ozone. Results of measurements by means of microwave spectrometers to Apatity and in Kiruna (Sweden), and also with the help balloon ozonozonds in Sodankjulja (Finland) and on stations Koldvej (Spitsbergen) are used. These synchronous measurements have revealed occurrence meridional asymmetries in the maintenance of ozone above 20 km in polar widths. "The warm" winter in a stratosphere and polar whirlwind poorly expressed on a vertical could be the reason. Fall of density of ozone (an order of 30-50 %) at heights of 25-40 km in first half of April, 2004 at all four stations is revealed.

As a result of long-term supervision on Kola peninsula in a stratosphere of Arctic regions connection of character of variations of the maintenance of ozone is established with behavior and structure of a winter polar whirlwind [27]. During winter seasons with well developed polar cyclone and duration of stable existence not less than 1,5-2 months extremely low concentration of ozone at heights of 20-25 km, connected visible with its chemical destruction were observed. So in the beginning of March, 2005 concentration of ozone at height has reached of 25 km of values of ~1±1012/cm^3. On the other hand during the destructions of a whirlwind accompanied by powerful stratospheric warming, almost double growth of quantity of ozone in the range of heights of 20-40 km is registered. Data on chemical loss of ozone in the Arctic polar cyclone according to device SAGE-III in exclusively cold winter 2004/2005 are resulted in [28]. Low temperatures (below a threshold of formation of polar stratospheric clouds of 1 type) were observed in a stratosphere continuously from the beginning of December, 2004 to the middle of March 2005 г in a layer with potential temperature from 350 to 625К. From January, 1st on March, 15th, 2005 on изэнтропических levels 450-500К about 60 % of ozone it has been destroyed. The average volume of air weight with favorable for formation of polar stratospheric clouds (and chemical destruction of ozone) reached sizes 56 106 км3 that approximately on 25 % it is more before observed values. Chemical ozone losses in a polar cyclone during the winter-spring period have reached 2004/2005 record value 116±10 DU. at the border of a cyclone it was even more: 128±10 DU.

5. Atmospheric emissions

Ordering of the data about regular variations of intensity of issue of atmospheric system of molecular oxygen on the basis of materials of long-term researches is spent in [29]. Empirical approximations of variations are presented to the night period of days, lunar variations, seasonal variations, variations with solar activity and also latitudinal dependences, long-term changes and correlation with issue of 557,7 nanometers and oscillatory temperature of a radiating hydroxyl.

On the basis of supervision of Issues of a hydroxyl (a strip (6-2)) and molecular oxygen (a strip (0-1) atmospheric system) on the Zvenigorodsky observatory in 2000-2008 their regular night and seasonal changes are received. In case of a hydroxyl intensity of radiation goes down during all or the first half-fault of night that it is possible to explain influence of a chemical drain of atomic oxygen Night changes of intensity of radiation O2 to the visible are modulated basically by atmospheric inflow. Features of a seasonal course of both issues are the considerable spring minimum making 25-55 % from their mid-annual values, and an appreciable minimum (10-30 %) in December. The annual course of issue O2 (b1 Σ) is defined in the big degree by seasonal behavior of the maintenance of atomic oxygen in the field of its layer. In case of a hydroxyl in a seasonal course of its issue not the smaller role is played by changes of temperature [30].

6. Aerosol of the middle atmosphere

Within a week c 17 on June, 23rd, 2009 over Kamchatka silvery clouds at heights of 80-85 km were observed. Companion Aura has registered on June, 22nd temperature fall at these heights to ~135K [31].

By data about aerosol dispersion to heights of 75-80 km during the period from November, 2007 till December, 2009 it is received that during a summer season (April-October) there are no layers with raised by scattering, since November there are indignations in shape profiles with raised scattering at heights of 60-75 km and 30-50 km. Indignations reach Maxima in December-January and in stratospheric warming [32].

From October, 2007 till October, 2008 over Kamchatka peaks of aerosol dispersion at heights of 35-50 and 60-75 km regularly were registered. Attempt to explain their existence by influence gravio-photoforez (occurrence photoforetical forces at the aerosol particles which are in the field of electromagnetic radiation visible and / or the IR-range) [33] becomes.

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Physics of Clouds, Precipitation, and Weather Modification

(Review for the period 2007-2010)

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1. Cloud physics

1.1. Observations and Investigation of different cloud types and precipitation characteristics

The Main Geophysical Observatory of the Russian Federation Hydrometeorological Service has published "Russian hydrometerological encyclopedia dictionary" in 3 volumes /1/ where considerable attention is given to terms, definitions, and interpretations of physical processes in clouds.

The Russian State Hydrometeorological University of the Ministry of Education of the Russian Federation has published an illustrated manual "Clouds: Genesis, Classification, and Identification." The manual presents the international cloud classification adopted by the World Meteorological Organization. /2/.

The Central Aerological Observatory published a collection of papers on cloud physics /3/. This memorial issue is dedicated to Prof. S.M. Shmeter, Doctor of Physics and Mathematics. The papers cover a wide range of science problems that were among those addressed by S.M. Shmeter and are primarily devoted to cloud physics and intended weather modification. Apart from some original studies of the last years, the book includes reviews of long-term theoretical investigations and field observations. Some of the papers address the dynamics of the atmosphere and turbulence, atmospheric aerosols in large city environs, assimilation of satellite-borne data, climate, and some other problems. In 2007, manuals and reference books on cloud physics, air masses, and fronts /4/, as well as supplements to weather forecasts /7, 9/ were published. In /8/, the authors evaluated humidity fields and temperature distribution over a mountainous area in Iran. Atmospheric precipitation amount and chemical composition in the center of the European part of Russia have been studied / 10 /.

The Earth cloud theory has been extended to include some new results /5/. The relation between different factors in the process of cloud and cloud field formation was discussed /6/. Is was established that the input of the thermal radiation factor – dry unstable thermal stratification in the ground layer – to the formation of all types of clouds, including cumuli, does not exceed 20-30%. The main role in cloud formation /6/ belongs to the dynamic factor, i.e. synoptic-scale vertical motions, variations of their speed with height, and vertical temperature gradient increase with time. Reaching a state of moist-unstable saturation is largely governed by the dependence of a moist-adiabatic gradient on air temperature and pressure.

Experimental case studies of different cloud forms in diverse geographical regions have been carried out. Paper /131/ analyzes the development of a cumulonimbus cloud with its upper boundary above 18 km, based on radar observation in India. Also analyzed, based on radar data, is the movement of cumulonimbus in Canada (Alberta Province). Some applied research has been fulfilled to meet the demands of different branches of the national economy / 12, 23, 24, 36, 52/.

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1.2. Convection, convective cloud characteristics, and cloud water content

Convective processes, convective cloud characteristics in various regions /13-17/ and cloud water content /18-22/ have been investigated using different experimental and theoretical methods. Building upon radar observations /13/ of the evolution and hierarchy of cumulonimbus clouds in different regions of the world, a concept of a mesoscale convective system life cycle has been framed. The concept asserts that separate cumulonimbus clouds organize hierarchical mesoscale clusters that occur in cycles and persist throughout thir lifetime in certain places of a system taken as a single whole. The appearance of dominant clusters results in quasi-periodical oscillations of the maximal intensity of a precipitation field wavelike spatial structure. The methodological principles of the concept are applied according to an objective precipitation systems classification by their morphological and evolution features.

Regional estimates of the input of daytime convection in the Volga basin /15/, of a convective atmospheric potential /16, 17/ and water content of convective clouds in different evolution phases /18-22 ~~6-10~~ / have been obtained. In /15/, the estimates of the daytime thermal convection input to summer precipitation formation in two regions of the Volga basin are presented. It is shown that the input of a thermal radiation factor to precipitation formation has been underestimated due to inaccurate choice of day and night time limits. For the regions under study, these limits were taken to be 10:00 and 22:00 Moscow Time, respectively /15/.

A method and the first results of radar studies of reduced (height-integrated) and an integral (volume-integrated) cumulonimbus water content /18-22/, as well as peculiarities of the distribution of integral water content and structure of hail /20 / and shower /21/ clouds have been discussed. It is established that in the North Caucasus, reduced water content in hail clouds varies between 8 and 50 g/m^2, in shower clouds between 0.5 and 12 kg/m^2, in nimbostratus it is generally less than 0.5 kg/m^2, and in drizzle clouds less than 0,05 kg/m^2. Basic water content of hail clouds in an evolution phase is found in their supercooled layer, in a maturity phase – in the layer from the ground up to 8-10 km, and in a dissipation phase - in the surface layer. The ratio of the supercooled to the warm portion of reduced water content makes it possible to estimate the extent of cloud hail hazard and the phase of cloud development. It is shown that the volume of hail clouds varies within the interval of 10^3 to 5 X 10^4 $км^3$ and their integral water content within 10^5 to 6 X 10^6 t. Hail localization volume is 5-25 % of the total cloud volume, its input to integral cloud water content being 30-60%. Precipitation formation rate in thick hail clouds is 1 X 10^4 X 10^5 t/min., their integral cloud water content decreasing at the same rate beginning with the dissipation phase. Time variation of integral cloud water content and repeatability of the values of integral water content over the whole cloud and over its supercooled layer are discussed in /22/. The data on and perspectives of using pilotless aircraft by CAO to monitor the atmosphere are presented /23/.

The interaction between physical processes in convective clouds /25/ and convective cloud evolution in situations associated with heating due to explosion or fire /26/ have been studied, using numerical simulation. The numerical model in /26, 125/ adequately describes the evolution of a droplet cloud developing under extreme conditions with high-power thermal sources on the ground or in the atmosphere. This model helped investigate the features of a cloud life cycle and phases depending on the ambient humidity distribution and on the duration, temperature and radius of the thermal source. It is shown that an instant source of energy (explosion) leads to the development of a convective flow in the form of a thermal, a durable thermal source (fire) produces a convective flow in the form of a jet above it. The evolution of and precipitation formation processes in clouds, associated with both forms of convection, have been studied in detail. Paper /27/ describes a method of predicting convective cloud development and related hazardous phenomena, building upon a comprehensive non-stationary numerical model of a small-sized convective cloud. The potentials and effectiveness of this method in thunderstorm forecasting are shown. Temperature profiles on thunderstorm cloud days for the period 1991-1999 have been summarized / 27/.

Some new theoretical results /28/ pertaining to the theory of convective vertical jets over heat sources and momentum have been obtained. Free convective jets and mixed-type situations have been considered, with the input of water vapor buoyancy effect allowed for. The existence of a universal conservation law, valid for any implication hypothesis, has been proved. A straightforward criterion of the possibility of barrier layers penetration by jets has been derived. An analytical solution has been found which describes a moist-adiabatic ascent of a jet above a condensation level. Jet influence on the transport of passive pollutants has been estimated. A model of the horizontal spreading of warm air brought by a jet to below an intense barrier layer has been suggested. Convection due to heat release by a thunderstorm discharge has been estimated /29/.

A work series has been fulfilled in modeling convection processes /30 126. /. The results of the numerical simulation of the intensive convection over the European territory of Russia in summer 2007 /32/, using non-hydrostatic model WRF-ARW, are described. The computations were made on four nested grids with 27-, 9-, 3-, and 1-km horizontal steps / 31/.

Paper /32/ presents the most important Main Geophysical Observatory research outputs in convective cloud physics and intended cloud modification for the last decades. These refer to the conventional research directions such as numerical modeling of natural and induced convective cloud development, laboratory modeling of cloud water phase transfer, investigation.

Apart from that, some new directions have developed. Thus a new instrument has been constructed to measure glaze-and-ice formations, the effect of fulleroid nanoparticles on water drop freezing explored, and a procedure of using Meteosat measurements to obtain convective cloud characteristics developed. The study of a coronal discharge effect on phase and microstructure of cloud water transformations has continued /33/.

A theory of hail cloud microstructure formation allowing for the interaction of dynamic, thermodynamic, microphysical and electric processes has been developed at the High- Mountain Geophysical Institute. Changes in hail hazard from clouds of different types depending on artificial crystal seeding location and concentration, the geometry of crystal source positioning, and cloud evolution phase at the start of cloud seeding have been investigated. It has been theoretically proved that introducing artificially produced ice crystals to a cloud makes it possible to control the number of large hailstones forming in it. Improved agent seeding patterns have been suggested. The role of the interaction between dynamic and thermodynamic processes in the formation of cloud precipitation particles has been studied /34-36/. The influence of climate changes on weather phenomena characteristics associated with cloud formation, precipitation and thunderstorms has been explored /37-38/.

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1.3. Experimental studies, measurement instruments and procedures, data processing techniques, field observational data on clouds and precipitation, and instruments for cloud observations

Paper /39/ describes laser observations of the atmosphere fulfilled by the Central Aerological Observatory. Laser sounding of the lower cloud boundary (LCB) has provided /40/ horizontal distributions of LCB height, radiation scattering factor gradient in the cloud boundary area, and that of the vertically averaged scattering factor. The energy spectra of the fluctuations of these parameters have been evaluated. It is shown that the shape of these spectra is qualitatively very similar to that of the spectra measured with an airborne lidar at the upper cloud boundary. This similarity even remains unchanged despite the highly inhomogeneous LCB characterized by discontinuity of its height and fallout of precipitation /40/.

Clouds have been studied using radar /41-43, 47/ and radio thermal sounding /44, 45/. Radar cloud characteristics in squalls in southeast Western Siberia are presented. The occurrence of the maximum height of cumulonimbus clouds in squalls /41/, zero isotherm height, radar reflectivity at three levels and a maximum one as well as a comprehensive thunderstorm hazard , have been investigated. Cloud radar characteristic values with squalls under various synoptic conditions, have been determined. The results obtained will help improve squall prediction methods /41/.

In /46/ the development of methods to evaluate cloud microstructure characteristics from radar measurements as applied to hail clouds analyzed. For applied purposes, paper /47/ discusses possibilities and peculiarities of using weather radar data and numerical simulation results to produce short-term and very-short-term forecasts of heavy and shower rains in St. Petersburg area in order to improve the efficiency of its water sewerage system.

Based on a 20-year sample of ground observations, radio sounding data and objective analysis, the conditions for freezing precipitation (FP) at Nizhni Novgorod airport have been investigated /48/. The upper cloud boundary was estimated from radio sounding data. It is found that the mean monthly FP occurrence from October through February is not more than 0.44%. During 20 years, only 113 FP events were observed, i.e. less than 6 events per year on average. FP fall out mainly during night and morning hours and only very rarely in the afternoon at air and ground temperatures not higher than 0°C and not lower than -2, 0°C. Surface wind mostly blows from the south or southwest, while, according to radiosonde data, in a 4-km ground layer its direction changes with height clockwise from the southern quarter to the western or northern one. In the boundary layer with FP, lower-level jets, mainly from southwest, are often observed in clouds. Warm cloud or sub-cloud jet occurrence is no more than 20%. Most typically, FP fall from wholly cold clouds. Based on objective criteria of fronts, synoptic situations, advection, and baroclinity, it is shown that freezing rain nearly always occurs in frontal zones, while drizzle is nearly as frequent at the fronts and under air-mass cloud conditions. Both FP types mainly occur in high-baroclinity zones and under heat advection. The results obtained can be useful for the development of an objective method of FP forecast /48/.

Aircraft studies /49/ of the microphysical structure and properties of As-Cs cloud systems in the Arctic have been fulfilled. The data were obtained over the Sea of Beaufort on board US NCAR C-130 aircraft lab, using one of the most advanced instrumentation systems designed to investigate microphysical cloud structure. The clouds were found to consist of several layers of limited horizontal extension. Spherical crystals prevailed. Their concentration to decreased as the height decreased. Their measured size spectra reveal their considerable dissimilarity of the crystals. The spectra parameterization fulfilled used gamma-distribution for particles less than 50 μm and exponential distribution for those over 50 μm /49/.

Possibilities for creating an information analytical system of cloud and cloud cluster identification to analyze weather phenomena in the lower and middle troposphere have been considered. A combined approach has been suggested, consisting of numerical modeling of cloud clusters and obtaining reference samples for comparison with the actual cloud distribution /43/.

Comprehensive investigations of cloud characteristics have been fulfilled using satellite-borne information /50, 51/. Methodology of studying cloud structure characteristics has been analyzed, which is based on the spectral coefficients of solar radiation reflection, obtained on board the International Space Station with optical instruments for the Earth remote sounding, by comparing experimental results and model computations. A program package has been described which is used to determine the directed coefficient of cloud reflection (albedo) of incident solar light, allowing for cloud microstructure. A feasibility of creating an information analysis system of cloud and cloud cluster identification, aimed at analyzing weather conditions in the lower and middle troposphere, has been considered. A combined approach has been suggested, which includes numerical simulation of cloud ensembles and obtaining reference samples to compare with an actual cloud distribution /51/.

Some new data processing techniques have been developed. In /52/, a technique providing detailed temperature and precipitation for regions with sparse network coverage is suggested. It is devised to correct archive data, allowing for topographic, reflection and other properties of the surface. A detailed distribution of temperature and precipitation monthly means has been obtained for the Lena basin characterized by irregular and sparse meteorological data coverage.

Methods and techniques to measure and analyze cloud and precipitation parameters have been investigated /53-55/. Automated precipitation measurement techniques and instruments have been developed to reveal meso- and microstructure of cloud and precipitation fields /56, 57/.

A pilot setup has been developed /57/ to study saturated water vapor condensation with diverse condensation nuclei, and also, in the presence a static electric field and a current of charged particles (electrons).

The automated system of parameterization and identification of cloud forms, created by the Institute of Experimental Meteorology of SI RPA ‘Typhoon’,/58

20/, has provided new data on Cu, Sc, Ac, Cu+Ac, Cu+Sc, St, As, Cs, based on cloud irradiation in a 8-13 μm range. The results obtained will constitute the basis of the meteorological radiation classification of cloud forms being developed which differs from the commonly accepted visual meteorological classification by an objective assessment of cloud irradiation parameters at any time, 24 hours a day, provided by the automated system. Paper /59/ suggests a method to determine cloud movement direction and speed using data on cloud field irradiation in a 8-13 μm range.

In 2007-2010, “Typhoon” fulfilled a work series to establish an instrumental and methodical basis providing space-borne observational systems with data for the validation of theoretical models of optical radiation propagation in the atmosphere /60/. It has become possible with a system of “Typhoon” ’s model setups to acquire a complete dataset for the verification and validation of theoretical models describing optical radiation propagation in cloud media with different microstructure features. The data can be used to improve observation conditions, provide timely detection and assessment of hazardous hydrometeorological and other natural and anthropogenic phenomena, as well as the consequences of ecological disasters.

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1.4. Tropospheric aerosol, cloud condensation nuclei, ice nuclei

In the period 2007-2010, data on tropospheric aerosol microstructure and condensation characteristics was obtained in diverse regions of the Russian Federation. The measurements of atmospheric aerosol concentration and size spectrum and the concentration of cloud condensation and ice nuclei, made at the Central Aerological Observatory near Moscow in 1994-2009 /61/, have been summarized .The relation between aerosol characteristics and weather in Moscow environs has been investigated and aerosol particle size spectrum, mostly connected with meteorological processes, has been determined /62/. The measurements of submicron aerosol mass concentration and condensation activity, carried out at Zvenigorod site of the Institute of Atmospheric Physics of the Russian Academy of Sciences, 50 km west of Moscow, in the period 2001-2006 /63/, have been analyzed. For this location, the role of transport over long distances in aerosol variations /64/ has been evaluated and, based on a 19-year series of observations of submicron aerosol concentration, its variability over a year period has been investigated /66/. The data on the mass concentration of submicron aerosol and soot, obtained in Western Siberia in the period 1997-2006 /65/ have been summarized. The data of the monitoring of ion aerosol composition in the atmosphere of the lake Baikal region in 2002-2004 /67/ has been analyzed. Seasonal features of the mass concentration variability of submicron aerosol and soot have been studied, based on the 1997 - 2008 measurements at the site of the Tomsk Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences / 68/. The results of water surface aerosol studies by the weather ship "Rift" during its 29th Astrakhan-Derbent-Aktau research trip in autumn 2008 have been published /69/. Data on the number and mass concentration of submicron aerosol over the White Sea was obtained during the 53rd research trip of "Academician Mstislav Keldysh" weather ship in August-September 2007 /70/. Atmospheric aerosol microstructure in the mainland-ocean transitional zone in the Far East region has been investigated on the basis of three-wavelength lidar sounding /71, 72/. A scheme of tropospheric aerosol parameters retrieval from lidar sounding data has been suggested /73/. During the period 2007-2010, an experiment to study aerosol and surface air chemical composition along the Trans-Siberian railway, using a car lab and reflected to as "Troika" was being continued. Data on the total concentration /74, 75/, particle size spectrum /74/ and chemical composition /76/ of aerosol and on soot aerosol characteristics /77/ have been obtained. A mathematical model of gaseous minor species and aerosol transport on a region and a city has been constructed /78/.

A fine fraction of atmospheric aerosol in the ground layer /79, 80/ and in the free atmosphere /81/ has been investigated. The process of condensation nuclei formation due to radiation has been studied in the laboratory / 82 /. The space-time variability of the zones of 3-20 nm particle formation over Western Siberia has been studied within the framework of the project YAK-AEROSIB/POLARCAT and the relative role of different mechanisms in nanopaticle generation has been evaluated /81, 83, 84/.

Further studies of the influence of industrial cities on the physicochemical characteristics of atmospheric aerosol have continued. The role of Moscow in atmospheric aerosol formation in its environs and the megacity influence on the concentration of ice nuclei and cloud condensation nuclei have been studied /85, 86/. The influence of the city of Tomsk on the chemical and dispersion composition of atmospheric aerosol has been investigated /87/. Mass concentrations of submicron and soot aerosol in the ground layer have been measured in locations with heavy anthropogenic loading (Beijing, Moscow, Almaty, and Ryazan') and in small resorts /88/. Theoretical papers /89, 90/ have investigated into homogeneous /89/ and heterogeneous /84/ nucleation of droplet and ice embryos.

The smoke from forest fires on the territory of Russia was the subject of a large number of studies. The influence of forest and peatbog fires on atmospheric aerosol characteristics in Moscow environs, observed in autumn 2005, has been analyzed /91/. Aircraft measurements of the characteristics of particles in smoke plumes from summer forest fires in Siberia have been obtained /92/. During the heavy forest and peatbog fires in central Russia in summer 2010, detailed data were obtained on smoke particle concentrations in Moscow environs /93, 94/, mass concentration of aerosol in Moscow /95/, and aerosol optical thickness of the atmosphere in periods of its maximal exposure to smoke were obtained /96/. A large number of cloud condensation nuclei were found in smoke aerosol /93/. Smoke particle morphology in Moscow Region /97/ and Krasnoyarsk Territory /98/ has been studied.

The data on soot mass concentration in the water-surface atmospheric layer, obtained in two voyages, St. Petersburg – Franz Josef Land and St. Petersburg – Antarctica – the Southern Ocean , of the research ship "Academician Fedorov" , in the voyage of "Academician Ioffe" from Ushuaya (Argentina) to Gdansk (Poland) and at Bellinsgauzen station in Antarctica, has been published / 99/. Also published are reviews of the studies of the physicochemical properties of soot particles in exhaust from aircraft /100/ and seacraft /101/. Laboratory studies of the condensational growth of smoke particles /102/ have been carried out and investigations fulfilled of changes in soot aerosol structure and optical properties in the process of hydrophylization /103, 104/ have been carried out.

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1.5. Cloud microphysics

The Main Geophysical Observatory has published the first ever atlas of snowflakes with the support of the Fundamental Research Foundation (RFBI) /105/ The atlas contains well-known and generally adopted morphological classifications of ice crystals. Also presented is information about basic physical characteristics of crystals (mass, geometrical size, falling speed) and some information about the relation between the shape of ice crystals and cloud temperature and humidity regime.

Some physical factors – aerodynamic and electrostatic effects on ice cloud particles - governing particle orientation in crystal clouds have been considered. Plate- and column- shaped cloud particles were modeled as oblate spheroids and oblong ellipsoids of revolution /106/. The influence of physical cloud processes on cloud microstructure has been described /107/. Microphysical processes of condensational ice particle accretion and precipitation formation in mixed-phase clouds have been investigated /108/. It is shown that ice particle accretion is not only determined by Wegener-Bergeron-Fideisen (WBF) process. It is humidity in mixed-phase clouds being close to saturation over water that is important. It is this that leads to the appearance of large ice precipitation particles. Droplet evaporation rate in mixed clouds, however, is determined not by pressure difference between water vapor saturated over water and that over ice, but by quasi-stationary sub-saturation. Depending on thermodynamical cloud characteristics, droplets and ice particles can either grow simultaneously or evaporate simultaneously. In such cases, the WBF mechanism does not work. Droplets evaporate with ice particles growing in mixed-phase clouds only within a limited time interval under certain conditions. It is then that the WBF process makes a certain contribution to condensational accretion of ice particles. The estimates obtained show that the WBF mechanism is not the only, and often not the main, reason for large ice particle and precipitation formation in mixed-phase clouds. The role of this mechanism may become more important during intended cloud seeding activities /108/. A review of the work done by Soviet scientists has served as a basis for the discussion of stochastic condensation theory: processes of cloud droplet condensational accretion in a random humidity field /109/. Mathematical modeling of microphysical processes in clouds is under way / 110, 111/.

A model of homogeneous nucleation is considered in /89 in 1.4/ and a model of heterogeneous nucleation in /90 /. Paper / 90/ evaluates the number of viable embryos and the rate of their formation under conditions of spontaneous condensation, spontaneous formation of ice crystals in supersaturated water vapor and supercooled water as well as of direct water vapor deposition on the surface of an ice-forming nucleus and immersion freezing. The computational results obtained are compared with earlier data from different authors.

Convincing evidence is obtained that glory, as conventionally defined, forms in clouds with temperatures below zero as a rainbow of the first order on spherical particles with refraction index 1,81-1,82 and diameter over 20 μm . The new evidence found proves the existence in cold clouds of liquid water in a specific state, namely, amorphous water. A visible size of the glory may be indicative of the maximum size of amorphous water drops, while its additional rings may testify to the presence of some forms of ice crystals /112/. In /113/ are also presented some new conclusions about the properties of liquid H_2O modifications, which are metastable as to the transition to crystalline ice at $T < 0°C$ of ordinary supercooled water and amorphous water, both contained in cold atmospheric clouds. The new experimental data have contributed to the general knowledge of the physical and chemical properties of amorphous water.

In 2007-2010, SI RPA ‘Typhoon’ investigated the scattering of water droplets in order to create instruments to measure them, analyzed light propagation in clouds and fog, and suggested a new formula for water vapor pressure /114-117/. In 114, based on the analysis of errors in the calculations of the radial functions of Mie series, which are a precise solution of the problem of light scattering on spherical particles, a procedure to compute these functions, which is free from the drawbacks of the current schemes, is suggested and validated. In 115, a technique to calculate spherical particle scattering indicatrices in geometrical optics approximation is presented, and the results of their calculation with refraction coefficients from 1.1 to 1.8 are given. In 116, using Mie theory calculations and those with the assumption of geometrical optics, a mechanism of the formation of the natural phenomenon of Gloria, so far hard to interpret adequately, is analyzed. In 117, a new straightforward formula is suggested for the calculation of saturated water vapor pressure, which is applicable in a wide range of temperatures and useful for theoretical estimation of cloud formation processes.

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1.6. Turbulence and air currents in clouds

Turbulence is a major factor in energy and water vapor exchange between the earth (land and sea) and the atmosphere, and thus one of the main mechanisms of cloud formation. So, some studies of the ground layer can be referred to cloud turbulence investigation.Paper /118/ suggests a general approach to the problem of cloud formation based on the analysis of the equation of heat and water vapor balance in a turbulent atmosphere. Recently, much attention has been given to the formation and development of a so-called wave boundary layer over turbulent water surface /119/. The structure of the wave boundary layer is observed to depend on wind direction and off-shore influence, i.e. vortices formed overland.

There are very few publications devoted to experimental studies of turbulence in clouds, which can be accounted for by big technical and financial problems in organizing such experiments. In this connection it is worth mentioning an integrated experiment in tropical convective clouds observations over Cuba /120, 121/. Turbulence and air currents were studied on board an aircraft research lab, while cloud evolution and the aircraft flight were followed with ground-based radar. Data on the spectral characteristics of wind speed flactuations, temperature, turbulent flows of heat and water vapor was obtained and their dependence on cumulus cloud evolution phase was shown. The new data processing and analyzing (wavelet conversion) techniques employed yielded presumably the first ever experimental data on the spectral structure of ambient air involvement in convective clouds. It was shown that eddies over 500 m in size condition heat exchange between a cloud and surrounding atmosphere.

Paper /122/ presents the results of an atmospheric boundary layer observations over the Sea of Okhotsk near Sakhalin Island. The boundary layer was developing above a thermally inhomogeneous surface, which brought about the formation of thick cumulonimbus clouds shower precipitation in winter. The observation were made in an air mass traveling from a cold land surface (-17 .. -20 oC) to a relatively warm (+4 ..+8 oC) sea surface. The underlying surface structure was marked by the changes of its thermal physical properties proceeding along the main current from solid to cracked ice and open water. The observations provided data on the spatial distribution of temperature, humidity, and wind speed, as well as turbulent fluxes of heat, water vapor, and impulse in the boundary layer over a thermally inhomogeneous surface. The first ever evidence was found of the formation of a discontinuous thermal inner boundary layer when stable inner boundary layers alternated with convective ones.

Cumulous cloud evolution in the presence of inversion layers is an important aspect of cumulous dynamics. Papers /123, 124/ suggest criteria of cloud penetration by growing convective clouds. In /125 8 / is presented a model of convective cloud developing at extremely high temperatures near the underlying surface, which may result from either natural or anthropogenic disasters. Paper /126/ reveals the relation between the dynamic structure of thermals and profiles of turbulence parameters in a convective boundary layer.

A method to determine water vapor supersaturation is suggested in /127/, which builds upon the familiar fact of an amplitude asymmetry of temperature fluctuations in clouds.

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1.7. Modeling of Cloud and Microphysical Processes

Several leading institutes of Roshydromet (Main Geophysical Observatory, MGO, Central Aerological Observatory, CAO, High-Moutain Geophysical Institute, HMGI, the Institute of Experimental Meteorology of SI RPA ‘Typhoon’, IEM) have undertaken to develop a 3D model of a precipitation convective cloud /128-129/. The underlying concept is based on the analysis of the state-of-the-art of the physical knowledge of processes in convective clouds and the status of 3D numerical simulation of convective clouds the world over. The essence of this concept is the model division into modules. Each module includes a description of certain physical processes. Electrification processes and intended modification are allowed for. Nevertheless, the earlier models of smaller dimensionality developed by the institutes continue being used in their research (MGO / 130-132/, CAO /133/, “Typhoon” /134/), HMGI /147-151/. At MGO, a 1.5 D model including, as a parameter, a horizontal cloud size modeled by a cylinder, was used to model the development of a cumulonimbus cloud with top boundary over a 18 km height, observed in central India. This model was also used in analyzing physical effects occurring in a long-lived cumulonimbus cloud observed in Alberta (Canada), seeded by a crystallizing agent. Radar observations and numerical simulation showed that the seeding had led to a noticeably smaller hailstone size. CAO and IEM used a Lagrangian approach to model some aspects of possible microphysical mechanisms of modifying warm convective cloud precipitability by hygroscopic particles seeding. The HMGI fulfilled a work series in modeling processes in hail clouds /135-136/and generation of electric particle discharges in thunderstorm clouds /137/. The modeling of processes proceeding in hail and thunderstorm clouds were also discussed in /138-140/.

Numerical and theoretical models of the kinetics of droplet and ice particle formation in mixed-phase clouds have been constructed /141/.

The Russian State Hydrometeorological University (RSHMU) has developed a model of heterogeneous nucleation of ice, based on the assumption of a quasi-static size distribution of embryos /144/. A numerical model of supercooled water solution droplet crystallization is being developed. The model temperatures of homogeneous and heterogeneous crystallization of supercooled droplets are in good agreement with experimental data, which renders the model fit for modeling cloud processes /145-148/. The RSHMU investigations have yielded data on the statistical relation between solar activity and the global amount of clouds. The data show positive values of the coefficient of correlation between cosmic radiation flux (CRF) and the lower layer cloud amount and negative values of the correlation between SRF and the amount of middle- and upper-layer clouds /149, 150/. Experimental studies have been initiated to determine ice crystal fractal dimensionality whose values can be used in modeling the propagation of electromagnetic radiation in clouds /151/.

Apart from other RSHMU studies /152-162/, the modeling of chemical processes in various clouds has been carried out. A thermodynamic microphysical model of the formation and evolution of polar stratospheric clouds has been constructed. This model has been integrated in the chemical climatic model of the lower and middle atmosphere. The model experiments fulfilled have revealed differences between the formation of polar stratospheric clouds in the Arctic and Antarctica /153/. In Antarctica, where a circumpolar vortex is more stable and temperature during the polar night is lower than in the Arctic, polar stratospheric clouds are more long-lived and occupy a larger area governing the intensity of chlorine and bromine activation due to heterogeneous processes. An enhanced amount of chlorine and bromine radicals results in faster ozone destruction in the absence of nitrogen-containing gaseous species (denitrification phenomenon), which could otherwise combine with active chlorine. The nitrification in Antarctica and its absence in the Arctic are the main factor that accounts for the formation of an actual ozone hole in Antarctica and only random “mini-holes” in the Arctic. Papers /163-164/, to a certain extent, refer to modeling atmospheric clouds. Thus in /163/, a 3D problem of convection in an uncompressible fluid placed between two horizontal planes and heated from below is considered. In /164/, the modeling of dust cloud sinking in an unstable atmosphere, due to the force of gravity, is discussed.

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2. Weather modification

2.1. Weather modification (WM) agents and technical aids

Basic WM research in the Russian Federation in the period 2007-2010 was devoted to intended precipitation redistribution, hail protection, cloud and fog dispersal /165/.

Microphysical processes associated with droplet accretion and their size spectrum evolution within an ascending cloud volume (Lagrangian approach) have been modeled and some aspects of possible microphysical mechanisms of hygroscopic particle action on precipitation formation in warm convective clouds have been discussed /166-171/. A method of forecasting convective cloud evolution and related hazardous phenomena, developed on the basis of an integrate non-stationary numerical model and summarized experimental cloud data, has been suggested /172/. Based on numerical computations, a comparative analysis of the effect of hygroscopic salt on condensational cloud droplet accretion has been fulfilled and optimal versions of convective cloud hydroscopic seeding to enhance precipitation have been discussed /173/.

The results of precipitation enhancement experiments fulfilled in Saudi Arabia by Weather Modification Inc. (USA) were discussed. Statistical analysis of the radar measurement data obtained showed that the modification of clouds had lead to considerable changes in cloud characteristics and to enhanced precipitation /175/.

The long-term experimental forest fire extinguishing operations fulfilled by aircraft forest patrol in diverse regions of the Russian Federation, using silver iodide and hygroscopic material, have been analyzed. The results of using cloud modification techniques and technical aids to prevent precipitation during mass festivities in large cities and the results of acting upon an electric cloud state, resulting in a current-conducting cloud-earth channel, have been presented /176/.

The results of over 40 large-scale weather modification operations in large cities have been summarized. Depending on a synoptic situation, the following weather modification techniques could be used: 1) stratiform cloud dispersal; 2) induced preventive fallout of precipitation windward of the protected territory; 3) heavy seeding ("superseding") of the overrunning clouds to reduce precipitation formation; and 4) dynamic destruction of cumulonimbus clouds /177/.

A large series of theoretical and experimental activities have been fulfilled in studying intense convective and thunderstorm hail processes to control them /179-188/.

The existing methods of WM assessment have been improved and some new approaches outlined. Усовершенствованы существующие методы оценки АВ и намечены новые пути оценки результатов АВ In particular, a basically different criterion has been assumed, allowing for a stochastic nature of agent dispersal in a seeded cloud, which adequately provides for successful cloud modification, judged about by the time variation of convective cell parameters /189-199/.

Advanced WM technical aids and agents have been suggested /200-207/. The practicality of modifying atmospheric eddy formations, investigated in the laboratory using video shooting of free eddies generated above a heated surface, are being discussed. The modification technique employed uses obstacles in the form of vertical meshes of different geometries placed along the path of an eddy travels /208/.

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Planetary Atmospheres

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1. Introduction

The report of the National Geophysical Committee on Planetary Atmospheres incorporates the investigations carried out in the period of 2007–2010. These investigations include spacecraft observations and numerical modelling. Numerical modelling relates to the dynamics of atmospheres of planets and large satellites, microphysics of aerosols, and processes in the outer atmospheres. Other investigations are based on the results of measurements aboard the Viking-1 and -2, spacecrafts (SC), Huygens probe descended on the surface of Titan (2005), and others. As previously, most of observational results were obtained with instruments developed with the participation of Russian scientists and installed aboard the Mars Express and Venus Express ESA spacecrafts.

The Mars Express SC is operational in the orbit around Mars since 2004. The Mars Express mission and Russian participation in OMEGA mapping spectrometer, PFS Fourier spectrometer, and SPICAM spectrometer are briefly discussed in the previous IUGG report [Korablev et al., 2009]. The results of these experiments are also summarized in review papers by Bibring et al. [2009], Formisano et al. [2009], Bertaux et al. [2009].

In 2006 Venus Express SC has orbited Venus. Now it is conducting remote global studies of its atmosphere and climate. The spacecraft is an artificial satellite of Venus equipped with science instruments for the studies of the atmosphere, climate and the plasma environment of the planet. It has been launched in October 2005 from Baikonur with Soyuz launch vehicle with Fregat booster. Science observations started immediately after the insertion into the orbit in April 2006 [Titov et al., 2006; Svedhem et al., 2007, 2009]. Russian Co-Is are in most of the experiments of the project. For two instruments (versatile spectrometer SPICAV-SOIR and Fourier-spectrometer PFS) key components were contributed by Russia. Because of the malfunction of the PFS scanner [Formisano et al., 2006], some of its scientific goals are fulfilled with mapping instrument Visible and Infrared Thermal Imaging Spectrometer VIRTIS (Russian Co-Is) [Drossart et al., 2007a]. Many studies of the dynamic of the Venus' atmosphere were carried out by Russian participants of Venus Monitoring Camera (VMC) experiment [Markiewicz et al., 2007].

Venus Express observations include the monitoring of the planet from apocenter, from the ascending branch of the orbit, and also nadir, limb, and occultation (Sun, stars and the Earth) observations in the vicinity of the pericenter. Starting from 2008 two more observation modes were introduced: "pendulum" and the tracking of the chosen locations. The "pendulum" mode allows to increase the duration of dayside observations preventing the overheating of the SC. The second mode allows to keep the chosen location or the latitude range in the field of view allowing effectively observe wind patterns in middle and high latitudes. A dedicated observations strategy is being developed for the VMC camera [Titov et al., 2006; Koschny et al., 2007].

The SPICAV-SOIR (Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Venus – Solar Occultation in the InfraRed) suite on board Venus Express consists of three independent spectral channels: ultraviolet (118-

320 nm, spectral resolution ~ 0.55 nm) SPICAV UV, near infrared acousto-optic (650-1700 nm, spectral resolution better than 1 nm) SPICAV IR, and infrared echelle-spectrometer with acousto-optic selection of diffraction orders SOIR for the spectral range of 2.2-4.3 μm (resolving power ~20000). The instrument is dedicated to a number of studies of the Venus' atmosphere from the surface to the hydrogen corona (~40000 км). The spectrometers can be operated in several observation modes, including nadir, limb and occultations for the vertical sounding of the atmosphere. The instrument is built by three organizations in France, Belgium, and Russia (Space Research Institute, IKI) [Bertaux et al., 2007]. The idea of the high-resolution spectrometer SOIR has been proposed in Russia [Korablev et al., 2002; 2003], and it has been built by Belgian Institute of Space Aeronomy and Belgian industry [Nevejans et al., 2006]. Russia has contributed also to its calibration, operations, and data analysis [Mahieux et al., 2008; 2009].

Many results of the Mars Express experiments are summarized in a special issue of ESA SP [Chicarro et al., 2009] published with a large delay. First results of Venus Express are published in a special section of Nature [Svedhem et al., 2007]. The results of the first phase, "nominal mission" of Venus Express are published in a special issue of Journal of Geophysical Research, which includes about 40 papers [Titov et al., 2008; Titov et al., 2009].

The report is based on the most every results publisher in refereed journals. The results are grouped around the planets.

Due to the large amount of studies following the Venus Express investigations, the current Report by the Commission on Planetary Atmospheres of the National Geophysical Committee is not complete regarding the modelling of dissipation in the outer shells of planetary and satellites [Johnson et al., 2008; Liu et al., 2009; Lichtenegger et al., 2009; Shematovich 2008; Berezhnoy 2010], and also methods [Shematovich 2011], and instruments [Yoshikawa et al., 2008, 2010; Chassefiere et al., 2010] for their studies. Also, the ionosphere studies [Witasse et al., 2008; Ma et al., 2008; Gavrik et al., 2009; Pavelyev et al., 2009], and closely related to Mars meteorology observations of seasonal dynamics of polar caps [Litvak et al., 2007a,b; Kuzmin et al., 2007; Demidov et al., 2008; Evdokimova et al., 2009; Rodin et al., 2010] are not included in the Report.

2. Mars

The climate of Mars is determined by the three main cycles: CO_2, H_2O and dust. The measurements of orbiters and landers over the past thirty years delivered a lot of information about global patterns of these cycles on Mars, but their mutual dependencies are still largely unclear. Long-term monitoring of atmospheric cycles by various instruments of the Mars-Express orbiter allows better understanding of these interactions.

2.1 Study of the Mars water cycle

Comparison of different measurements of atmospheric water vapour

Estimations of the atmospheric and surface water interaction in the Martian climate system are based on experimental data. The understanding of current Martian hydrological cycle is largely based on observations of the seasonal cycle of the atmospheric water vapour, relatively easily measurable quantity, unlike the surface and subsurface reservoirs. For the first time full atmospheric H_2O cycle was quantified in the MAWD experiment on the Viking 1 and Viking 2 orbiters [Jakosky and Farmer, 1982]. Only 20 years later such measurements were repeated by TES on Mars Global Surveyor, which measured the water vapour abundance on Mars in the thermal spectral range for three Martian years from 1999 to 2005 [Smith 2004]. The TES database serves now as a basis for all state-of-the-art climate studies of Mars. Since 2004, the atmospheric water cycle of Mars is being monitored with three spectrometers (PFS, SPICAM, OMEGA) onboard of the Mars Express orbiter, which measure water vapour from the near-infrared to the thermal infrared range. For the first half of 2004 Mars Express experiments operated simultaneously with TES. SPICAM, OMEGA and PFS spectrometers continue to measure water vapour up to now. Also, since 2006 the mapping spectrometer CRISM provides measurements of H_2O onboard of Mars-

Reconnaissance Orbiter. Thus, the water cycle on Mars is studied continuously for more than five Martian years.

Simultaneous measurements allowed to compare for the first time different methods of water vapour retrieval. Many factors affecting on the data treatment have been considering: spectroscopic databases, line broadening in the CO_2 atmosphere, atmospheric models, and the absolute accuracy of the data. It allowed to re-evaluate the uncertainties and discrepancies in the results of various experiments and to assess the existence of inter-annual variability in the atmospheric H_2O. Many works devoted to data processing from different experiments have been published at the time of the previous report [Korablev et al., 2009]. New results are discussed below.

Comparison of observations at 1.38 μm band (see below) with the TES results in the thermal range of 20-40 μm showed systematic discrepancies for all seasons. At the same time, the corrected TES data agree well with the PFS (long-wavelength channel, LW) results obtained in the same spectral range [Fouchet et al., 2007]. Although the SPICAM and TES data overlap for only a short time, the 50% differences apparent repeatedly over three years suggests a possible systematic bias between the two different spectral bands.

The OMEGA and PFS (short-wave channel, SW) spectrometers measured the water vapour in the 2.56 μm band and their results are much less homogeneous. OMEGA data have been used both for the study of regional, local and temporal variations of H_2O (see below) and to measure the seasonal cycle on a global scale [Melchiorri et al., 2007; Maltagliati et al., 2011]. The PFS SW data are larger than the data of PFS LW [Tshimmel et al., 2009]. To reconcile the results of SW and LW channels of PFS one had to assume that the bulk of the water vapour is concentrated near the surface. At the same time, such assumptions were not required to analyze SPICAM and OMEGA near IR data, equally sensitive to the vertical profile.

The main conclusions from the comparison of different experiments are as follows [Korablev, 2008]:

- Correction of the TES results: more than 60% of the data (all measurements with a lower spectral resolution) have been corrected downward by ~30%. An updated database of TES is made available [Smith, 2008].

- Correction of the MAWD data downward by 50%, especially in the summer in the northern hemisphere, and good agreement of these measurements with the SPICAM results, obtained in the same near-infrared 1.38 μm band.

- The most reliable measurements are the data in the thermal spectral range: TES (after correction) and long-wavelength channel of PFS [Fouchet et al., 2007]

- The variability of the atmospheric water cycle was found to be substantially less than suggested before, both from year to year (the observed variations are related only to the variability of dust in the atmosphere), and at long-term (measurements in the Viking's era do not differ from today).

Future works should include the account for aerosol for all near-IR measurements, SPICAM in particular.

Correction of the MAWD/Viking results

During the analysis of the SPICAM/Mars Express data, significant differences in the spectroscopic parameters of the lines and in the number of those lines in the 1.38 μm band between HITRAN 2000 database and HITRAN 2004 and subsequent versions have been indentified. This raises a question about the quantitative reliability of data analysis performed many years ago. The reanalysis of all data of the MAWD (Mars Atmospheric Water Detector) instrument on Viking 1 and 2 orbiters was performed. New maps of the water vapour distribution according to the MAWD have been retrieved taking into consideration new spectroscopic databases and climatology of state-of-art general circulation models [Fedorova et al., 2010]. As a result of this reanalysis, the measured water vapour abundance has been decreased by a factor of two. The polar maximum of water vapour is about 50 pr. μm. Comparison of the distribution of water vapour measured by MAWD and SPICAM showed an agreement for water cycle observations made 30 years ago (MY12-14, in accordance with the Martian chronology proposed by Clancy et al. [2003]) and observations performed in 2004 (MY27- 29) (Fig. 1). It suggests the stability of the water cycle during this period.

Weak interannual variations observed for some seasons, in particular during the southern summer, can be explained both by the natural variability of the water content, and by the contribution of scattering in radiative transfer (variability of the atmospheric dust). Both MAWD and SPICAM data have been processed ignoring the scattering by dust that, as shown previously [Fedorova et al., 2004], leads to the underestimation of the measured near-infrared H_2O abundance.

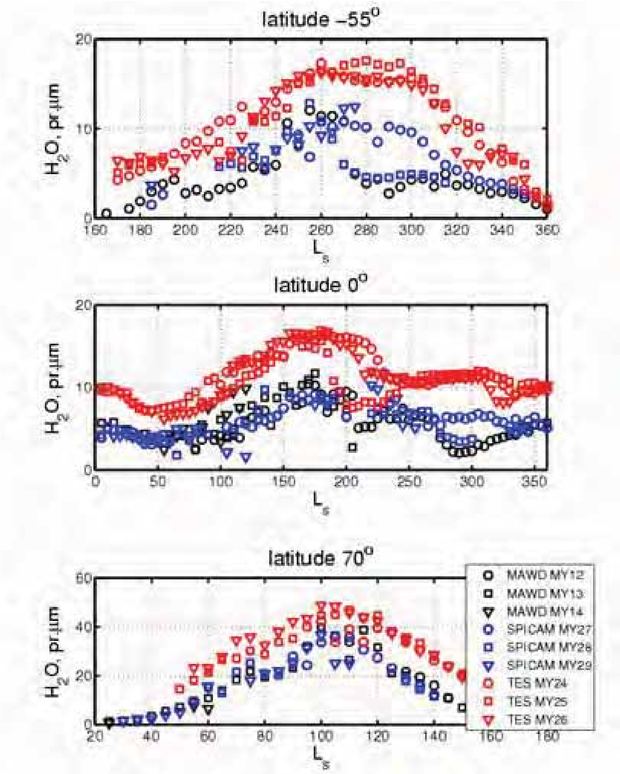

Fig. 1 Comparison of MAWD results for MY12-14 with SPICAM (MY27-29) and TES (MY24-26) datasets for three latitude bins: -55, 0 and 70˚. The data have been averaged in 5˚x5˚ bins (see paper by Fedorova et al.[2010]).

Study of the water vapour in the Martian atmosphere on a local scale with OMEGA/Mars Express data

The behaviour of the atmospheric water over Tharsis volcanoes has been studied by infrared mapping spectrometer OMEGA. OMEGA observations uniformly cover the full Martian year at different times of a day. Observations showed an abnormally high concentration of water vapour (up to 2000-3000 ppm) over the tops of the four volcanoes in comparison with the surrounding plateau. Such behaviour has been observed throughout the year and demonstrated a clear seasonal trend [Maltagliati et al., 2008].

The increased water vapour in the volcanic area suggests that it is not uniformly mixed with altitude and its content increases sharply near the surface. The reasons for atmospheric enrichment over the volcanoes are likely connected to mesoscale circulation. Sharp changes in elevation and thermal inertia on volcanoes are caused by slope winds transporting the water vapour from valleys to the tops, where, at low temperatures, it is either deposited as a frost or adsorbed by regolith. Similar studies are performed over other regions with large elevation differences, such as the Hellas Basin and the Valles Marineris [Encrenaz et al., 2008].

Investigation of the water vapour distribution in the northern polar region in spring and summer with high spatial resolution shows the evolution of the H_2O maximum during the sublimation of the polar cap and its connection with the distribution of hydrated minerals obtained in the same experiment [Melchiorri et al., 2007].

Vertical profiles of water vapour from SPICAM/Mars Express solar occultations

The knowledge of the vertical distribution of H_2O and aerosol in the Martian atmosphere helps answer the questions of Martian meteorology related to their sources and sinks in different atmospheric layers, the interaction with the surface, etc. Only a few measurements related to the vertical distribution of water vapour and aerosol were made before, revealing no global picture of seasonal and latitudinal variations.

For three Martian years SPICAM performed about 600 solar occultation observations allowing vertical profiling of the atmosphere. The spectral range of the instrument includes the carbon dioxide 1.43 μm band, to retrieve the atmospheric density, and the 1.38 μm band to retrieve the water vapour abundance. The atmospheric opacity and the properties and distribution of aerosols with altitude are studied in a whole spectral range from 1 to 1.7 μm. To retrieve the gas densities the optimal estimation algorithm for nonlinear equations has been used.

The observation set of MY28 (summer 2007) allows to trace how the vertical distribution of dust evolves during the global dust storm, which began approximately at Ls= 270° in the southern hemisphere. Prior to the global dust storm (Ls = 250-265°, MY28) the relative content of water vapour agreed well with the general circulation model of Mars, water vapour content decreasing at altitudes of 40-45 km for latitudes 50-60°N and 60 km for latitudes 60-65°S. The relative content below this level was 100-160 ppm. At the same time, we found some systematic differences with the general circulation model. For example, in the southern spring-summer 2008 (Ls = 70-110°, MY29) the beginning of the H_2O activity at middle latitudes has been observed earlier compared with the model that can be explained by underestimation of the turbulent mixing at the evening terminator, or an unusual aerosol activity. In small amounts the water vapour was well mixed up to altitudes of 45 km. At the same time in the northern early summer, the water activity began later compared with the predictions of the model, which may indicate the lack of sublimation in the model, stronger interaction between the atmosphere and the surface, the weak vertical transport [Fedorova et al., 2009; Maltagliati et al., 2010].

2.2 Aerosol

The vertical structure and properties of the aerosol from SPICAM/Mars Express solar occultations

Studies of the vertical profiles of aerosol frequently formed form condensing component (water ice), is closely related to the studies of vertical distribution of

H_2O vapour (see above). The solar occultation data of SPICAM IR (~600 observations) allow good spatial coverage in latitude and longitude in the southern and northern hemispheres for all seasons over three Martian years. Cloud layers have been observed at altitudes from 20 to 60 km with optical depths from 0.001 to 0.01. In the polar region the profiles are concentrated near the surface, while in low and middle latitudes the main aerosol layer extends up to 25-30 km.

During MY28 the global dust storm has been observed. In the southern hemisphere the storm began at Ls = 268-270° at latitudes of about 64°S, while in the northern hemisphere from Ls ~ 280° at latitude 55°N. During the storm dust was elevated to altitudes of 70 km and 60 km for the southern and northern hemisphere respectively (level where the slant optical depth equals 1) [Fedorova et al., 2009].

Interpretation of OMEGA/Mars Express limb scan measurements

Work on retrieval of Martian aerosol property vertical profiles from OMEGA spectrometer data has been continued. The OMEGA limb observations reveal aerosol layers registered in a wide spectral range of 0.4-3.3 microns. A model of optical aerosol properties with a minimum number of variable parameters and possibility to retrieve a set of optical characteristics of aerosol particles (extinction and scattering cross-sections, phase function or phase matrix) has been developed. The model assumes the chemical composition of aerosol to be known. For Mars, the optical aerosol model with three variable parameters is suggested: wavelength, modal radius and a parameter characterized the wide of the aerosol particle size distribution function. The method based on this model allows to retrieve the vertical profiles of Martian microphysical aerosol characteristics from OMEGA limb measurements. The method takes into account multiple scattering in the spherical symmetry atmosphere. Vertical profiles of aerosol number density and modal radius of the particle size distribution function are obtained [Vasilyev et al., 2010].

Numerical modelling of cloud microphysics in the Martian atmosphere

A one-dimensional numerical model with a size distribution of aerosol particles in the Martian atmosphere has been developed. The model reproduces bimodal distribution of ice particles in the clouds, including the main mode (1-2 μm) and the high-altitude fraction (0.2-0.3 μm). The model simulates fog rising in the lower part of the troposphere in the morning. The one-dimensional numerical model, based on the approximation of fractional eddy diffusion, is developed and applied to water ice clouds. This model simulates transport by global circulation system and vortices of different scales [Burlakov, Rodin, 2011].

2.3 Ozone and $O_2(a^1\Delta_g)$ dayglow

Ozone is one of the most chemically active species, indirectly related to the question of the stability of the Martian CO_2-dominated atmosphere. Ultraviolet solar radiation leads to dissociation of carbon dioxide into CO and O and their subsequent recombination occurs as a result of a long, complex triple collision reaction. In turn, the recombination of O_2 from the oxygen atom is quite fast. Thus, the concentration of CO and O_2 in the Martian atmosphere must be consistently high. The measurements also indicate a relatively low abundance of minor species (see below chapter 2.4). The reason is likely a significant role of water vapour in the atmospheric stability. The CO_2 stability is associated with chemical reactions involving odd hydrogen radicals (H, OH, HO_2), because the hydroxyl OH can react with CO and restore the CO_2 content much more effectively due to higher reaction rate. Unfortunately, the distribution of these radicals is difficult to observe directly. One possible way of indirect assessment of the HO_x radicals is to measure ozone in the atmosphere of Mars, since it is effectively destroyed by them and can serve as a tracer of their presence.

Ozone on Mars from SPICAM/Mars Express data

The study of the distribution and seasonal changes of ozone on Mars with the SPICAM spectrometer has been continued. The seasonal and latitudinal variations, vertical distributions have been obtained; the comparison with various photochemical models within atmospheric general circulation model of Mars by LMD has been made [Lefèvre et al., 2004]. It was shown that the photochemical model, which does not include heterogeneous chemistry on the water ice clouds, poorly approximates observations [Lefèvre et al., 2007].

Oxygen dayglow and ozone in the atmosphere of Mars from OMEGA/Mars Express data

2D maps of the O_2 day glow emission at 1.27 μm are obtained by the OMEGA mapping spectrometer in the near IR spectral range, with spatial resolution of the maps ranging from 2 to 5 km/pixel. Detection limit is ~4 MR. In the Martian atmosphere a strong O_2 emission on the day side is produced as a result of photolysis of O_3. About 90% of ozone molecules give rise to oxygen $O_2(a^1\Delta_g)$. At OMEGA spectral resolution the whole O_2 emission falls inside the interval covered by the spectral channels λ_1 = 1.256, λ_2 = 1.271 and λ_3 =1.285 μm. Developed method allows obtaining the quantitative estimation of O_2 airglow intensity from OMEGA spectra despite their low spectral resolution, and investigation of its horizontal distribution, local time and seasonal behaviour. The highest values of emission ~31 MR are observed on the south pole for 11 h < LT < 13 h, during the early spring (186° < Ls < 192° MY27)

In the polar regions observed day-to-day variability, associated with polar vortex turbulences, is of the order of 30–50% as predicted by the model [Lefèvre et al., 2004] and found by SPICAM [Perrier et al., 2006] from UV measurements. In the considered data set a maximum of the O_2 emission is observed between 11 h and 15 h LT in the latitude range 70–85°S during early spring on both hemispheres. During MY28 a maximum of airglow intensity is found between 50° and 60°S for the southern autumn–winter season. Increased O_2 emission observed from Ls=130° to 160° at southern high latitudes may be explained by higher solar illumination during the considered period [Altieri et al., 2009].

In the high latitudes the O_2 emission is usually observed as a region, extended within some range of latitude and longitude. The extension in longitude is connected with variation of the solar illumination and consequently with local time: the emission is maximal around noon, and it decreases in the morning and in the afternoon. The latitude of the emission maximum is determined by two factors: H_2O abundance and the solar illumination. In winter the water vapour abundance decreases with the latitude, leading to the increase of the O_3 abundance, strengthening the O_2 emission. At the same time the solar illumination decreases toward high latitudes, reducing the O_3 dissociation and the O_2 emission.

A higher intensity of the O_2 emission found at high latitudes in the south comparing to the north may be connected with higher intensity of the Hadley circulation during northern winter (perihelion), which transports water vapour from the low latitude more efficiently than in the southern winter(aphelion).

For the first time atmospheric waves crossing the terminator are observed in polar areas during the MY26 (in the north polar region) and MY28 (in the south polar region) early spring. The spatial scale of the waves ranges from 100 to 130 km, and the intensity fluctuations are of the order of 4MR.

The observations of the $O_2(a^1\Delta_g)$ dayglow are important as a passive tracer of Martian atmospheric dynamics at high latitudes [Altieri et al., 2009; Migliorini et al., 2011].

2.2 Other minor constituents

Carbon monoxide in the Martian atmosphere from PFS / Mars Express data

Carbon monoxide is another important component of the chemical cycle of Mars. Its abundance has been studied by the PFS spectrometer using the fundamental (1-0) CO band at 4.7 μm. Calibrated PFS data of year 2004 (Ls ranging from 331°.17 to 51°.61, end of MY26- beginning of MY27) have been used to derive seasonal, temporal, and spatial trends in the CO distribution. The globally averaged CO mixing ratio value derived from this dataset is 11.1×10^{-4}, which is compatible within errors bars, although somewhat higher, with the value of $8\pm3\times10^{-4}$

determined from the ground-based high-resolution observations [Kaplan et al. 1969]. However, the derived CO mixing ratio exhibits large variations from 3×10^{-4} to 18×10^{-4}, which were analyzed statistically to estimate the seasonal and latitudinal variations. The measurements confirm the increase of the CO abundance in the northern hemisphere in the beginning of winter [Krasnopolsky 2007], which is believed to be related to the condensation of CO_2 on the polar cap that leads to the enrichment of the atmosphere with non-condensable species. No *definite conclusion* can be reached about other seasons and latitudes because of limited seasonal coverage [Billebaud et al., 2009].

Modelling of the dissipation of the Martian atmosphere

A model of the photoelectron collision-induced component of the Mars dayglow using recent cross sections and solar flux is developed. The calculation of the photoelectron source of excitation is based on a stochastic solution of the Boltzmann equation using the direct simulation Monte Carlo method. The neutral atmosphere is taken from outputs of a global circulation model, and recent inelastic collision cross sections are adopted. The calculated vertical profiles of the CO Cameron bands and CO_2^+ doublet emissions integrated along the line of sight compare well with the SPICAM limb profiles observed from Mars Express at Ls = 166° during the summer season at northern midlatitudes. The comparison shows agreement to within the uncertainties of the excitation cross sections. Seasonal changes in the brightness and the altitude of the emission peaks are predicted with intensity variations in the range 15–20% [Shematovich et al., 2008].

Estimates of the total thermal and nonthermal losses of hydrogen and the total nonthermal loss of oxygen from the atmosphere of Mars are discussed, and their ratio is analyzed. It is shown that an H to O stechiometric ratio of 2:1 has not been achieved in any of the current models of various authors. The closest ratio, H:O = 4:1, has been obtained in the model of formation of a hot oxygen corona [Shematovich et al., 2007].

3. Venus

3.1 Composition of the atmosphere

Vertical distribution of HDO, H_2O and D/H ratio in Venus' mesosphere from SOIR/Venus Express data

Measurements of the water vapour content in Venus' atmosphere are important for understanding of the planetary climate. In spite of large number of observations performed from orbiters and landers in 1970-1990 as well as from groundbased telescopes, spatial distribution of H_2O on Venus is so far poorly constrained.

In the SOIR experiment water vapour is measured in solar occultation using absorption lines of the gas around 2.61 µm (3830 cm^{-1}) at altitudes 70-110 km; HDO isotope is measured simultaneously in the range 3.58 µm (2715 cm^{-1}) at 75-95 km. It provides determination of HDO/H_2O ratio. Results of observations for one and a half year (from April 2006 to August 2007) have been considered. 54 measurements of water vapour and its isotope were made at different locations from middle latitudes of southern hemisphere to the northern pole of the planet. Analysis of 22 observations nearby Venus' northern pole, captured mainly from the orbit's pericenter has been published. An average value of H_2O mixing ratio is 1.16±0.24 ppm and 0.086±0.020 ppm for HDO (fig. 2). The water vapour is uniformly mixed at altitudes above 75 km. A small decrease of H_2O mixing ratio at altitudes 80-90 km may be linked with a temperature inversion above ~95 km. No significant temporal variations in vertical profiles of water vapour are noted. An average value of the HDO/H_2O ratio appears to be 240±25 time more than on the Earth, and 1.5 times more than the same ratio retrieved for the lower atmosphere on the basis of ground based observations and Pioneer Venus lander measurements – 157±30 (see de Berg et al. [2006] for a review describing the composition of Venus atmosphere before Venus Express mission). The raised concentration of deuterated water may result either from low photodissociation rate of HDO with respect to H_2O or from higher dissipation rate of deuterium atoms with respect to hydrogen atoms. These new results will serve as a basis for dynamical and chemical modelling, and for estimation of contemporary dissipation rate of water from Venus [Bertaux et al., 2007b; Fedorova et al., 2008].

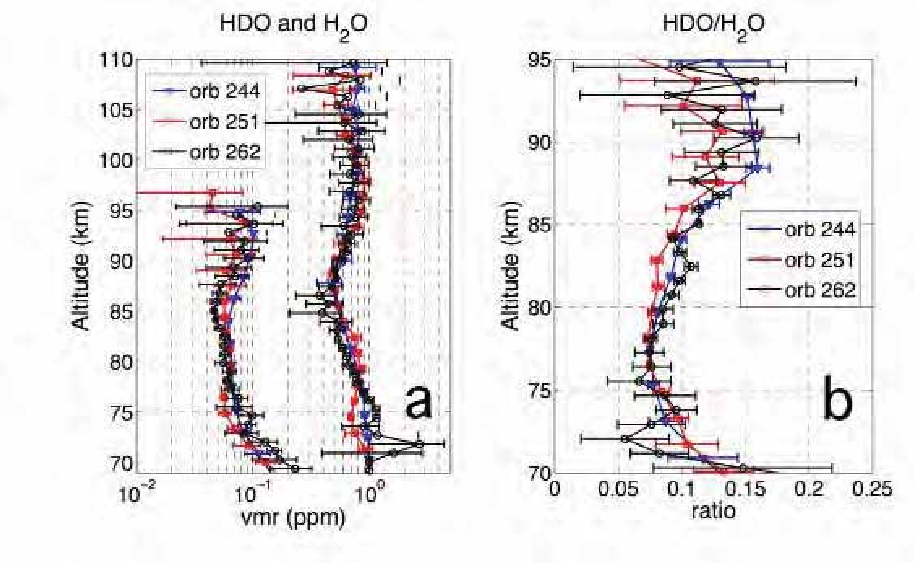

Fig. 2. Vertical profiles of HDO, H_2O and isotope ratio (from Bertaux et al., 2007b).

Water vapor near the cloud tops from VIRTS/ Venus Express dayside data.

Observations of the dayside of Venus performed by the high spectral resolution channel (-H) of VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) on board the ESA Venus Express mission have been used to measure the altitude of the cloud tops and the water vapour abundance around this level with a spatial resolution ranging from 100 to 10 km. This dataset supersedes previous measurements in a combination of good coverage, spatial resolution, and robustness of the method. CO_2 and H_2O bands near 2.5 μm are analyzed to determine the cloud top altitude and water vapour abundance near this level. [Cottini et al., 2011]

These measurements unambiguously proved the absence of high variations of the water vapour abundance near the cloud tops, reported from a number of microwave and radiometric measurements. At low latitudes (±40º) mean water vapour abundance is equal to 3±1 ppm and the corresponding cloud top altitude at 2.5 μm is equal to 69.5±2 km. The cloud top altitude gradually decreases poleward from middle latitudes down to 64 km, while the average H_2O abundance reaches its maximum of 5 ppm at 80º latitude with a large scatter from 1 to 15 ppm. No local time dependence has been observed.

The calculated mass percentage of the sulfuric acid solution in cloud droplets of mode 2 (~1 micron size) particles is in the range 75-83%; in low latitudes the interval is more narrow: 80-83%. The sulfuric acid should be in a deeply supercooled liquid state. The amount of water in vapour always exceeds that in cloud particles, indicating that the water vapour abundance near cloud tops is not controlled by the equilibrium with the sulfuric acid clouds, but forced at this level by other, e.g. dynamical, reasons. The meridional distribution of the water vapour abundance is consistent with global circulation characterized by combined Hadley and polar cells. Simultaneous observations by VMC did not reveal any systematic correlation between the dark UV markings with the local (on the scale of 100 km and smaller) variations of the cloud top altitude or water vapour abundance.

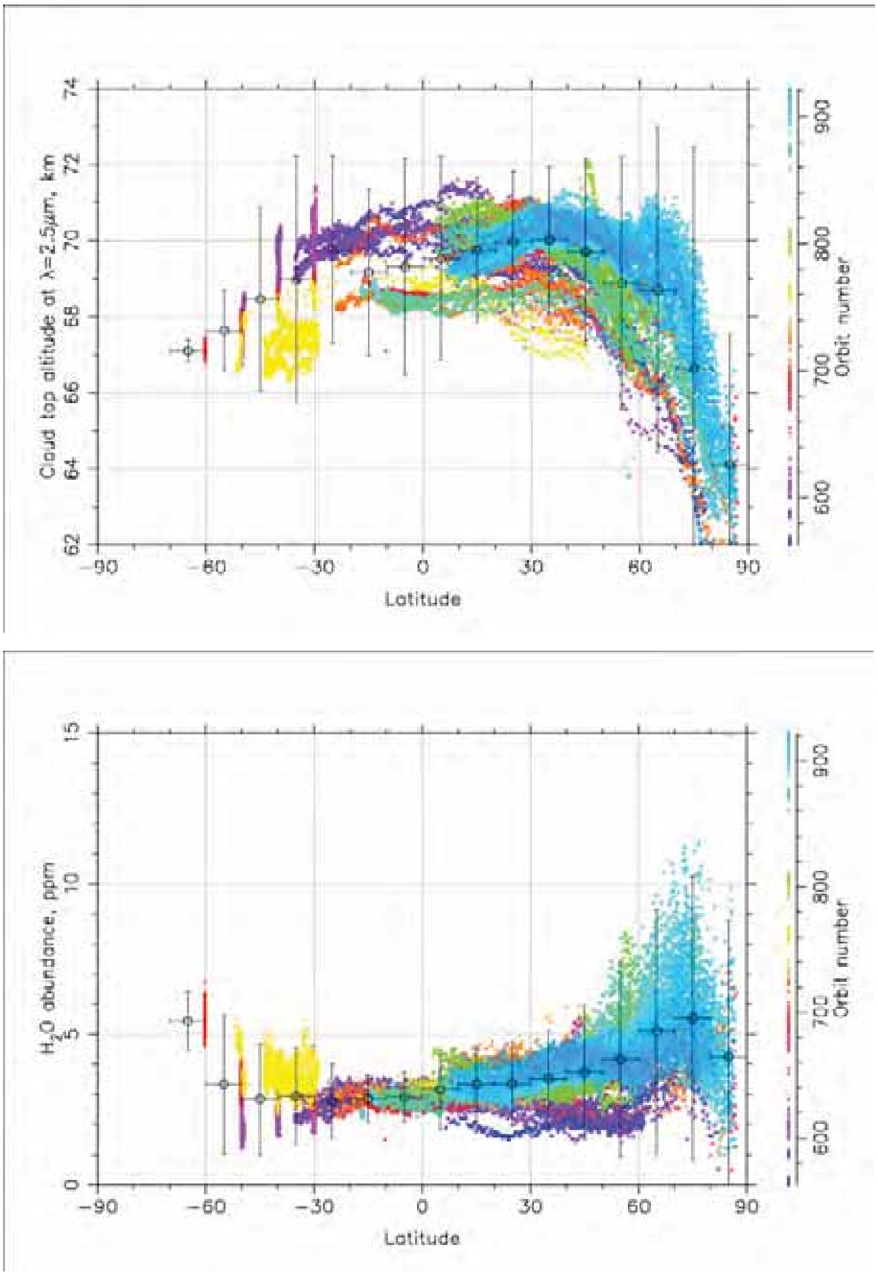

Fig. 3. Water vapour abundance (bottom) near the cloud tops (top) as a function of latitude from VIRTIS / Venus Express data [Cottini et al., 2011].

Composition of Venus' mesosphere from SOIR/Venus Express data

High-resolution spectra by SOIR allow to detect separate absorption lines of minor species. By this mean concentrations of HCl, HF and CO in Venus' mesosphere are measured, and their vertical profiles retrieved [Vandaele et al., 2008]. HCl mixing ratio was obtained as 0.1-0.2 ppm at altitudes 70-90 km; that is less than 0.4 ppm at ~64 km observed 40 years ago by P. Connes from the ground experiment [deBergh et al., 2006], and less than 0.76 ppm at 61-67 km from nowadays astronomical observations [Iwagami et al., 2008]. HF content, estimated as 1-7 ppb, is in agreement with previous results. The presented ranges of mixing ratios reflect variability with altitude and time, not error bars.

Vertical profiles of carbon monoxide content were measured as well. Photodissociation of CO_2 above 120 km serves as major source of CO in Venus' atmosphere; that is why, the essential part of the atmosphere above 140 km consists of the monoxide. Above 90 km profiles match with the VIRA atmospheric model [Keating et al., 2003]. Below 80 km retrieved values of 30-50 ppm are significantly higher than VIRA, but are in agreement with other observations, for example, microwave experiments [Clancy et al., 2003]. It should be mentioned that SOIR profiles are characterized by clear minimum (~10 ppm) at 85 km.

With SOIR spectra upper limits for important photochemical molecules OCS and H_2CO were improved. OCS upper limit is 1.6±2 ppb below 90 km, while for H_2CO it is 3±2 ppb in same altitudes.

SO_2 and SO above Venus' clouds from SPICAV-SOIR/Venus Express data

Sulphur dioxide is one of important component in Venus' atmosphere, because this gas is directly linked with H_2SO_4 clouds that totally cover the planet. Variations of SO_2 content above the clouds (altitudes >65 km, where the gas is dissociated), serve as an indicator of photochemical reactions in the atmosphere and of vertical mixing that delivers SO_2 from lower atmospheric layers. SO_2 abundance measurements of many years above Venus clouds (mainly day-side nadir observations) allow us to assume decennial variations of the content from 0.01 to 0.5 ppm. In parallel, absorption of sulphur monoxide SO was registered in the UV range with continuous concentration ~10% from SO_2 at altitude ~70 km.

Measurements of SO_2 and SO vertical profiles were carried out by SPICAV/SOIR spectrometer in solar occultation regime in spectral range around 4 µm at altitudes 65-75 km (SOIR) and around 215 nm at 90-100 km (SPICAV). 4-µm band of SO_2 is mixed with abundant CO_2 lines that restrict detection accuracy. For some profiles it was possible to retrieve just upper limits of gaseous content. At altitudes of 80-90 km the instrument is not sensitive to SO_2 and SO absorptions. In the lower part of the profiles the sulphur dioxide's mixing ratio decreases with altitude from ~0.5 ppm at ~65 km to 0.05 ppm at 75 km; in the upper part an increase is observed from ~0.1 ppm at ~90 km to ~1 ppm at ~100 km (Fig. 4). Vertical profiles of SO_2 content are equal in the pole at morning and evening. Slant SO_2 concentration increases with aerosol optical thickness [Belyaev et al., 2008, 2011]. Concentration ratio $[SO_2]/[SO]$ varies between 1 and 5 at altitudes 90-100 km.

Sulphur dioxide's measurements in the band 215 nm were also performed in nadir mode by SPICAV spectrometer at several altitudes of northern hemisphere. Analyzing albedo of Venus' clouds at reflection and scattering of solar radiation, SO_2 mixing ratio was retrieved around 0.1 ppm at level ~70 km confirming SOIR results [Marcq et al., 2009]. SO_2 content at 70 km decreases with latitude from equator to pole in accordance with the cloud top decrease [Ignatiev et al., 2009] (see also Fig. 3).

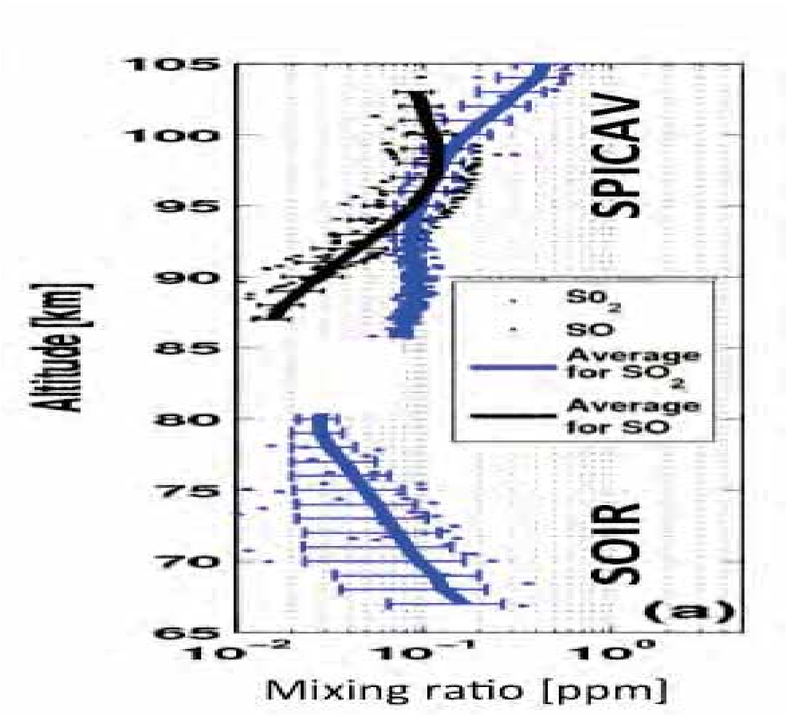

Fig. 4. Vertical profiles of SO_2 and SO mixing ratio. Results from SOIR (SO_2 only) – below 80 km; results from SPICAV (blue SO_2 and black SO) – above 85 km.

New band of isotope CO_2 628 from SOIR/Venus Express data

Spectroscopic lines of an unknown absorber nearby 2982 cm^{-1} (3.3 μm) were found in high-resolution spectra of Venus atmosphere, measured by SOIR spectrometer. They were attributed to the CO_2 isotopologue $^{16}O^{12}C^{18}O$ (628) and correspond to absorption band 01111-00001. Comparing with well-known CO_2 bands, observed by SOIR, and using computations, line strengths of the Q-bench for this band were determined. They occurred to be two orders of magnitude more than it presented in spectroscopic database for vibrational-rotational molecular transactions HITEMP [Bertaux et al., 2008; Wilquet et al., 2008]. Thus, the detected band of the 628 isotopologue was forecasted theoretically, but with high underestimation for the strength. Due to weakness of the band, it has never been observed in the Earth atmosphere; however, it was registered on Mars [Villanueva et al., 2008].

3.2 Airglow

Discovery of hydroxyl airglow by VIRTIS/Venus Express

Night airglow in OH bands was first detected from high-resolution spectra of terrestrial atmosphere in 1948 [Meinel, 1950]. Meinel bands come from vibrational-rotational transitions between vibrational levels of major state from ν′= 1 to ν′= 9. Photochemical modelling [Atreya, Gu, 1994] suggests that hydroxyl might play a key role in reduction of the Mars CO_2-atmosphere, which is dissociated on day-side by the solar UV; however so far only an upper limit for the OH airglow of 50 kR was established [Krasnopolsky et al., 1977].

In limb Venus spectra, registered by imaging spectrometer VIRTIS, hydroxyl was identified from IR Meinel's bands: (2-0) at 1.40-1.49 µm with integral intensity 100±40 kR and (1-0), (2-1) at 2.6-3.14 µm with intensity 880±90 kR (1 R equals to 106 photons). Vertical profiles of the airglow at the limb were retrieved, and spatial/temporal variations were established [Piccioni er al., 2008]. Detection of OH in Venus atmosphere by Venus Express orbiter suggests a modification in present understanding of chemical processes in Venus atmosphere concerning reactions with H, OH and O_3: most probably, ozone plays a major role here, like on the Earth.

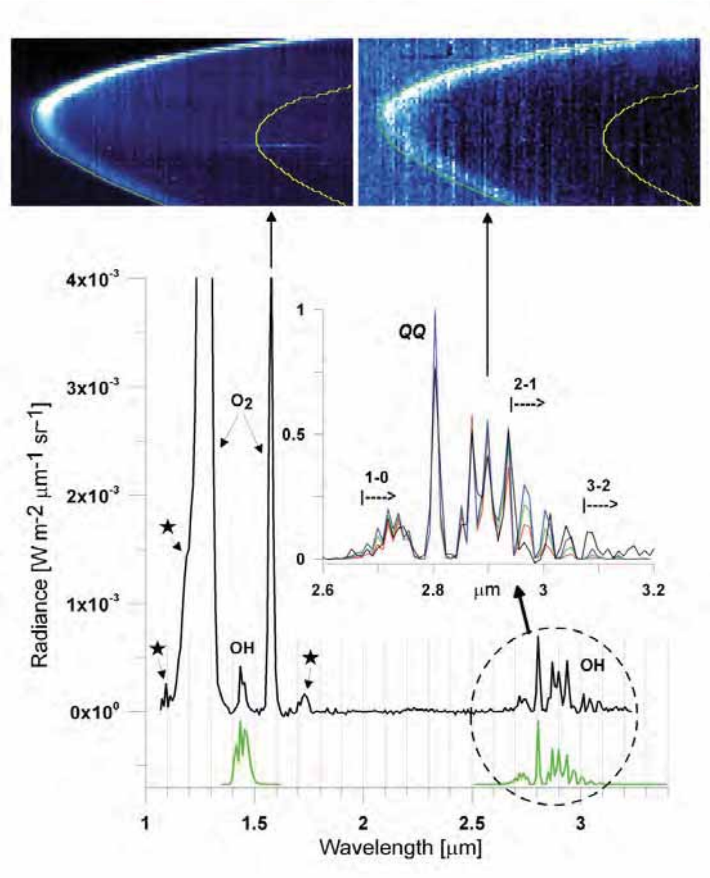

Fig. 5. Airglows of O_2 and OH in the upper atmosphere of Venus (upper images) and a typical spectrum of VIRTIS/Venus Express (lower plots). Limb Venus spectrum is averaged within 90-100 km of altitude and 25 - 35°N of latitude (local time is ~02:00 pm). OH bands at 1.40-1.49 µm (2-0) and at 2.6-3.14 µm (1-0), (2-1) are observed in addition to O_2 bands (0,0) 1.27 µm and (0,1) 1.58 µm. Tracks of thermal radiation from the lower atmosphere are marked by stars at 1.1, 1.18 and 1.74 µm. Synthetic spectra of OH airglow are presented as well [Piccioni et al., 2008].

Considering little water content in Venus atmosphere, the detection of hydroxyl came unexpected. OH glow varies in space and time, but it correlates with O_2(a – X) 1.27-µm emission in intensity and the altitude of the emission peak (96±2 km). Using relative distribution of intensity in OH (1-0) band, rotational temperature was found as 250±25 K that is confirmed by SPICAV results about the warm layer at altitudes 95-100 km [Bertaux et al., 2007] (see below). Measured intensities of O_2 and OH emissions vary from orbit to orbit, possibly depending on the efficiency of chemical reactions, collisional deactivation, physical conditions in atmosphere, and, mainly, on temperature. However, some variations of HO_2, H, O and O_3 contents could play a role as well.

Airglow of molecular oxygen in near IR range on Venus night-side from VIRTIS/Venus Express data

Airglow of molecular oxygen $O_2(a^1\Delta_g - X\ ^3\Sigma_g)$ at wavelength 1.27 μm on Venus night-side occurs as a result of oxygen atoms recombination, which takes place on the day-side at photolysis of CO_2 and CO. Atoms of O_2 are carried on the night-side by global circulation in the upper mesosphere and thermosphere. Gas molecules elevate near the subsolar point, pass through terminators to the night-side, and move down near the antisolar point (SS-AS circulation).

Reactions $\{2O + M \rightarrow O_2^* + M\}$ and $\{O_2^* + M \rightarrow O_2(a^1\Delta_g) + M\}$ in the downwelling flux at the antisolar point result in production of excited oxygen molecules, which emit when returning to the main state. Night emission $O_2(a - X)$ on 1.27 μm in Venus atmosphere was first detected in 1975 [Connes et al., 1979] and later it was observed many times from the Earth, revealing high variability.

Spectrometer VIRTIS (mapping channel VIRTIS-M) allows to observe atmospheric airglows with high spatial and moderate spectral resolution. The strongest nonthermal emission on Venus night-side is 1.27-μm airglow. Spectrally, this line falls into the transparency window of CO_2, and analysing nadir data it is necessarily to consider contribution from the lower atmosphere radiation, scattered and reflected by clouds. At limb measurements oxygen and thermal emissions are spatially separated (Fig. 6) [Drossart et al., 2007b; Piccioni et al., 2009].

Airglow is most intensive on planet's limb. Observations of VIRTIS allowed first time to retrieve vertical profiles of oxygen emission. Features of the airglow are highly variable: intensity, pick position, width of the pick and profile's shape change in space and time (Fig. 6b). Within one orbit decrease of the intensity and increase of the pick's height may be noticed with changing latitude. It happens, possibly, because of the fact that intensity of vertical motion (SS-AS circulation) is stronger in the equatorial region, providing lower downwelling of oxygen atoms with recombination at higher density and temperature. In average, the glow occurs nearby antisolar point that is confirmed by groundbased observations and nadir measurements of VIRTIS (see below).

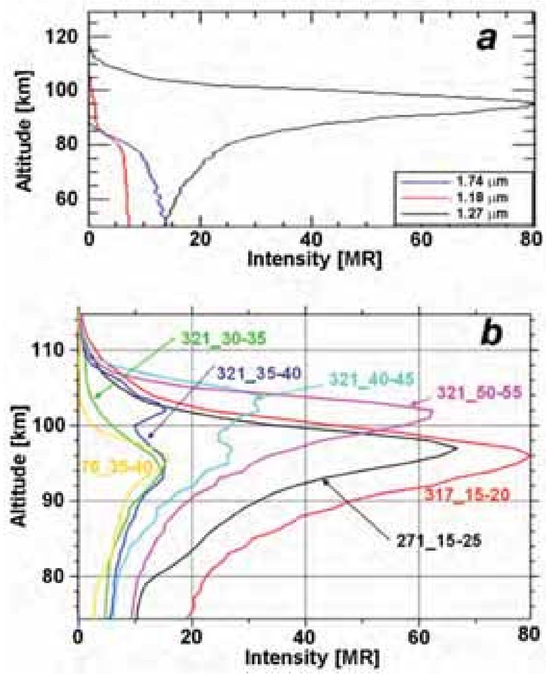

Fig. 6. Examples of O_2 emission profiles at 1.27 µm. a – limb profiles at three wavelengths demonstrate contribution of thermal emission from lower atmosphere. b – O_2 emission profiles at 1.27 µm with removed thermal radiation. Averaging was made within given orbit numbers and latitude range [Piccioni et al., 2009].

Vertical profiles of airglow were retrieved from limb measurements using “onion-peeling” technique. For 42 profiles with latitude coverage from 7°S to 77°N the altitude of emission peak is 97.4±2.5 km. The peak is wider in equator with width 11 km at half maximum, twice as more as in middle latitudes. Average intensity of the peak is 0.52±0.4 MR (the maximum is ~2 MR). Often, a double peak was observed: the principal maximum at 96-98 km and the additional one on 103-105 km. Their presence might be explained by wave processes.

For the first time the night emission band (1-0) of O_2(a – X) was observed in spectrum of another planet at 1.58 µm (Fig. 5.) The intensity reaches 1.2% from the band (0-0) at 1.27 µm, and vertical profiles are almost identical. Simultaneous measurements of those two bands allowed to estimate transition probability A00/A01 = 63 ± 8.

Nadir observations of the night airglow (0–0) O_2(a – X) from Venus Express orbiter allowed to reach high spatial resolution for the southern hemisphere globally from equator to the pole. In further data processing the thermal radiation, which goes from the lower atmosphere and mixes with O_2 airglow, was excluded, as well as O_2 radiation reflected from clouds [Shakun et al., 2010].

Oxygen airglow allows studying processes of atmospheric transport at altitudes 90-110 km (upper mesosphere and lower thermosphere), in the range poorly constrained by observations. Unlike in the mesosphere, where zonal superrotation is present, in the thermosphere the SA-AS circulation dominates with some variable contribution of zonal rotation. Two maxima of O_2 1.27-µm airglow were observed: one in the antisolar point, confirming the hypothesis of SS-AS transfer. The second maximum is shifted from the antisolar point to high latitudes and to evening part of southern hemisphere; this behaviour is not compatible with the mixture of SS-AS and zonal superrotation. The O_2 1.27-µm airglow from nadir VIRTIS observations is strongly variable both on spatial and temporal scales. These variations (and also the occurrences of intense airglow, several times higher than average in any point on the night-side) come from downwelling fluxes at altitude of emission. It tells about complicated and variable nature of circulation in this transition range.

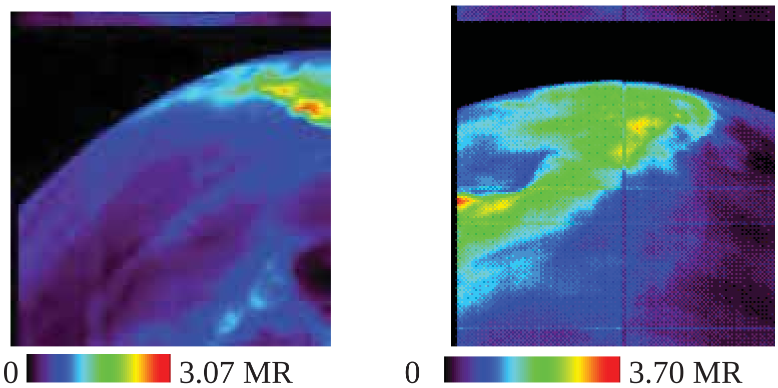

Fig. 7. Two examples of nadir images in the band of O_2 glow, recorded in the southern hemisphere. The equatorial region is on the limb. Oxygen emission, observed along the limb, is not shown because of large difference in intensity.

Non-equilibrium airglow of CO_2 from VIRTIS/Venus Express data

Carbon dioxide's airglow in 4.3 µm, which occurs at local thermodynamic disequilibrium, is typical for all planets of terrestrial band. NIMS spectrometer on-board Galileo spacecraft has first detected this airglow on Venus. The peak of emission intensity is determined, from one hand, by concentration of radiating molecules, and, from the other hand, by collisional quenching. VIRTIS observations from Venus Express allow systematic study of such lightening on the dayside at altitudes of 90-120 km. Airglow peak is located at ~115 km and shifts by ~10 km depending on solar emission angle. A radiative transfer non-LTE model, developed previously for Martian atmosphere, was used for the interpretation. In the frame of the model, observed altitudes and airglow intensities match the standard VIRA model [Drossart et al., 2007].

UV and EUV spectroscopy of the Venus dayglow with OUVS/Pioneer Venus и UVIS /Cassini

The intensities of the OI 130.4 and 135.6 nm emissions were calculated using the soft electron precipitation measured on board the Pioneer Venus (PV) Orbiter. The comparison of calculated intensities with the auroral brightness observed with the ultraviolet spectrometer (OUVS) on board PV was made. For this purpose, a new electron transport model [Shematovich et al., 2008] based on a Monte Carlo implementation of the Boltzmann equation and a multi-stream radiative transfer model to calculate the effects of multiple scattering on the intensity field of the 130.4 nm triplet were used. It was shown that the consideration of the enhancement of the emergent 130.4nm to the 135.6nm intensity by multiple scattering in the optically thick Venus atmosphere increases the auroral 130.4/135.6 ratio by a factor of about 3 [Gerard et al., 2008].

EUV spatially-resolved dayglow spectra obtained by the UVIS instrument during the Cassini flyby of Venus on 24 June 1999 were analyzed. These observations were obtained in the wavelength range 56.3 – 191.2 nm at 0.37 nm resolution; the special resolution at planet was ~500×500 km from distance of 7000 km. Observations were made at high solar activity level. Emissions from OI, OII, NI, CI and CII and CO have been identified and their disc average intensity has been determined. They are generally somewhat brighter than those determined from the observations made with the HUT spectrograph onbard Space Shuttle in 1995 at a lower activity level. A detailed comparison of the intensities of the 834 nm, 989 nm, 120.0 nm multiplets and CO B–X band measured along the slit foot track on the disc with those predicted by an airglow model previously used to analyze Venus and Mars ultraviolet spectra [Shematovich et al., 2008] was conducted. Overall, it was found that the O, N_2 and CO densities from the empirical VTS3 model provide satisfactory agreement between the calculated and the observed EUV airglow emissions [Hubert et al., 2010; Gerard et al., 2011].

3.3 Atmospheric dynamics

Morphology and dynamics of the cloud layer of Venus according to VMC and VIRTIS/Venus Express data

Circulation of the upper cloud layer of the Venusian atmosphere was studied using the images of the cloud structure obtained by Venus Monitoring Camera in the UV, visible and IR spectral ranges. The sequence of UV images obtained by the VMC allows to estimate the displacement of the cloud details and to define the direction and speed of the wind. The significant database of estimated wind vectors with uniform coverage by local time was created. The period of observations envelops more than three Venusian years.

The cloud morphology on the top cloud level (~70 km) changes from chaotic structures with dominance of compact cloudy formations or cells in the low latitudes (<40°) to more regular streaks, indicating quasi-laminar streams in the middle latitudes. In the polar region cloud structures testify to presence of a huge global vortex with a size in some thousand kilometers [Markiewicz et al., 2007]. The observation of the day side of Venus in the UV demonstrates strong variability on a time scale of one day. This variability indicates fast dynamic and microphysical processes within the upper cloud level (fig. 8).

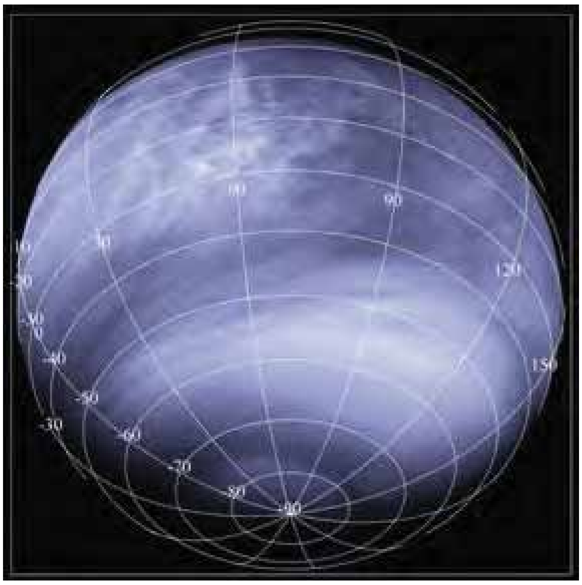

Fig. 8. Venus was observed in UV spectral range (0.365 μm) by the VMC from the distance about 30000 km [Titov et al., 2008].

Zonal and meridional profiles (fig. 9) were constructed by averaging of the whole data set. The speed of the zonal wind is nearly constant and equals to 90±10 m/s in low latitudes, reaches the maximum of ~100 m/s at latitude nearby 47° and quickly falls in high latitudes. The meridional component changes within 10-20 m/s. The accuracy of these measurements depends on latitude. Errors of averaging for the zonal component are 1.5-3 m/s (larger in the region of middle-latitude jet and in the polar latitudes) and about 1.5 m/s for the meridional. Observations demonstrate the dependence of the zonal wind on the solar local time.

The period of the atmosphere rotation on the equator equals to 5 earth days, and decreases to a minimum of 3 days at latitude ~50° (fig. 9a). The retrieved meridional profile confirms the presence of the Hadley cell and allows to define its boundaries. The ascending branch of the Hadley cell is on the equator and descending – in the middle latitude region, at latitudes ~ 50° [Limaye et al., 2009; Moissl et al., 2009].

Solar related dependences were registered for entire data set of wind vectors obtained from VMC images. Position of the zonal speed maximum varies from orbit to orbit from 35° to 55° and depends on local solar time. The value of zonal speed also depends on local time. Diurnal and semidiurnal components are guessed. Considering limitation of sampling by day hemisphere, two maxima of zonal speeds were detected: in the morning, around 8:30 local time, and in the evening, around 16:30, i.e., the maximum speeds are observed near the terminators [Moissl et al., 2009].

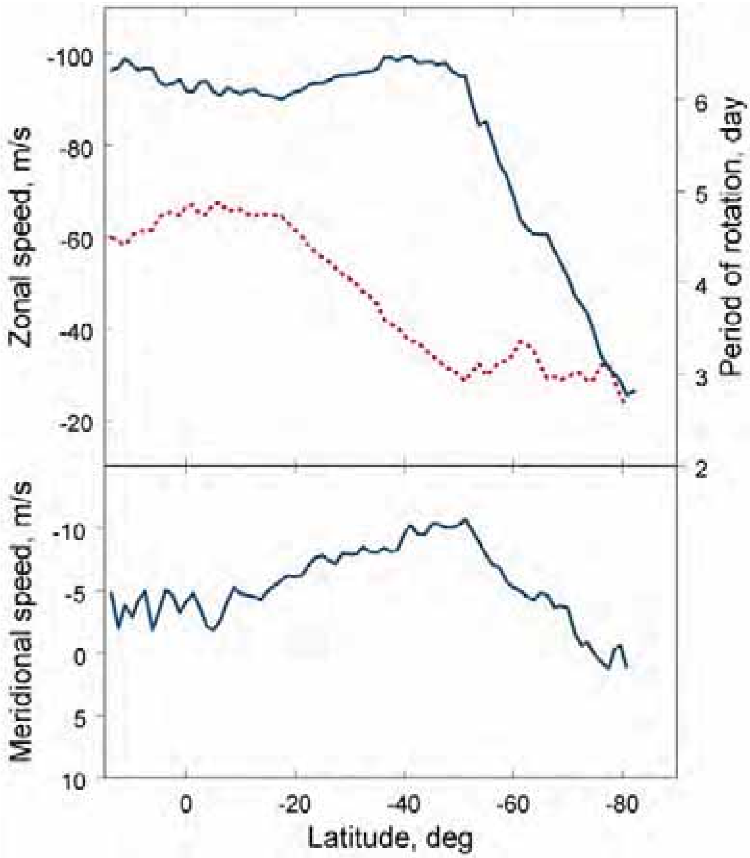

Fig. 9. Average profile obtained from VMC UV images: zonal speed (upper panel, solid line), meridional speed (low panel, solid line; negative velocity denotes movement from the equator to the pole).Dashed line on the upper panel corresponds to zonal period of the atmosphere rotation. The figure is based on ~35000 cloud displacement vectors collected over 6 Venus years.

Structure of the South polar vortex according to VIRTIS and VMC/Venus Express data

Vortex structures in the polar regions also named as “Polar dipole” were observed both in the northern, and in the southern hemispheres. The polar vortex has been found for the first time in the northern polar region by Mariner 10 [Murray et al., 1974] in the UV spectral range. “S” structure of the dipole was observed in the thermal IR-range from Pioneer Venus [Taylor at al. 1980]. The Fourier spectrometer experiment onboard Venera 15 (1983) demonstrated that the upper bound of clouds around northern polar dipole is lower than in surrounding areas, and their temperature is a little higher [Zasova et al., 2006]. These experiments dedicated to thermal sounding have detected the “cold collar” surrounding the polar dipole.

During Venus Express mission the circulation of the polar region is studied by imaging spectrometer VIRTIS. Images of a southern polar dipole in the short wavelength IR-range are obtained with much higher spatial resolution, than earlier. The structure of the southern polar dipole is studied in details (Pioneer Venus and Venera 15 observed only the northern dipole).

Observations in the short wavelength IR-range on the night side provide information on the structure and dynamics of the atmosphere below the main cloud layer. Observations are made in 1.74 and 2.35 µm spectral windows and in the ranges 3.7 and 5 µm, corresponding to different altitude layers. In all ranges global vortex near the pole is observed, confirming existence of the dipole structure through the whole cloud layer. High-altitude polar region with polar dipole rotates closely to solid-body rotation, in the direction of the zonal stream circulation. Atmospheric masses make a complete rotation for 2.5 days. At the altitudes ~ 50 km (1.74 µm) the rotation period in high latitudes is changing from 2.4 to 2.7 earth days. At the altitudes about 63 km (3.7 µm) the rotational speed increases, the period being 1.9 – 2.6 earth days. The period correlates with the size of the polar vortex. The larger is its diameter, the longer is the rotation period, in accordance with conservation of the angular momentum. The rotation centre of the polar vortex normally doesn't coincide with the pole, and is shifted by a few degrees. Both at cloud top level, and in the interior of clouds periodic structures associated with wave activity were observed. The polar dipole demonstrates firm dependence of the meridional speed on the local solar time. At the altitude of 63 km the amplitude of changes of the meridional speed is systematically higher, than at heights of ~50 km [Piccioni et al., 2007].

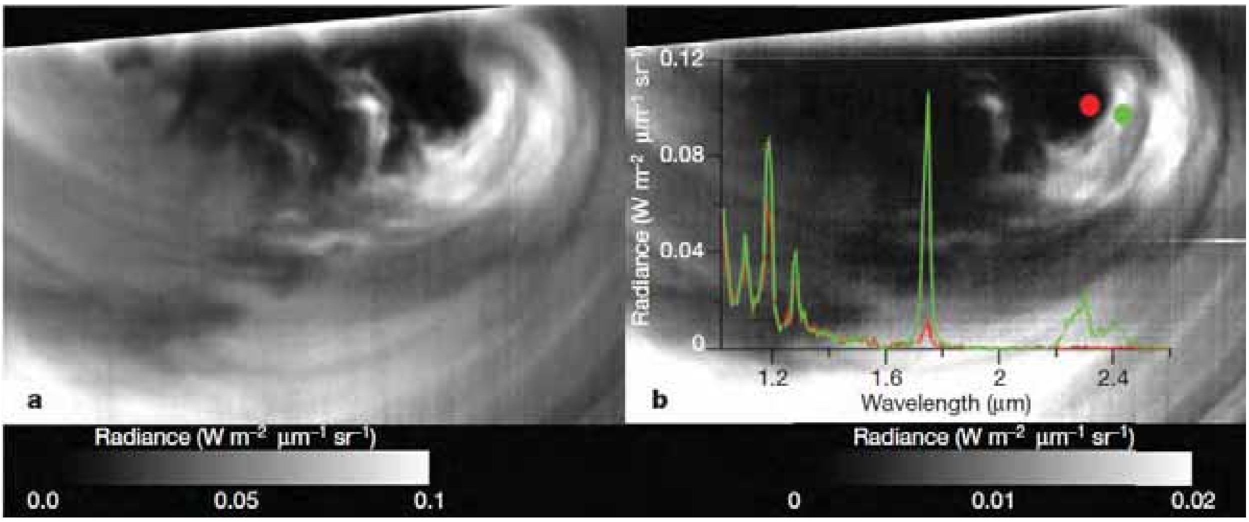

Fig. 10. Night side images of the southern polar vortex of Venus obtained in 1.74 µm (a) and 2.3 µm (b) spectral bands. On the right panel the spectra of the night airglow concerning to the different part of the vortex are presented [Piccioni et al., 2007].

Simultaneous imaging of southern polar regions in the UV and IR ranges shows strong correlation of morphological details. Usually the polar vortex, which eye can be well distinguished in the IR range, is encircled by a dark ultra-violet ring. Probably, this dark ring is formed by the strong jet flow in the polar latitudes. Spiral branches of the vortex begin in zone of the dark ring. Thus the UV contrast details on the disk of Venus are basically caused by the features of thermal structure and dynamics at the upper cloud level [Ignatiev et al., 2009].

The assumption based on the analysis of the movement vectors of atmospheric masses suggests the similarity between the polar dipole and terrestrial tropical cyclones [Limaye et al., 2009].

Cyclostrophic wind: the preliminary analysis of VIRTIS / Venus Express thermal sounding data

Data of the imaging spectrometer VIRTIS allow to study the thermal structure of the Venus mesosphere at altitudes of 60-95 km (see below section 3.4). Using a cyclostrophic approach the wind fields can be retrieved from the temperature fields assuming mean atmosphere. Obtained wind fields have the following basic features: (1) middle-latitude jet is observed, connected with subpolar structure known as cold collar; thermal wind speed in the jet equals to 80–90 ± 10 m/s on the cloud top level (altitude ~70 km) at latitude 50°S; (2) wind speed decreases from the latitude 60°S, approaching zero at 70°S; (3) wind speed over the jet decreases with altitude.

Solar related dependences of the temperature and zonal wind fields are analyzed. At the night side the temperature on the cloud top level decreases by ~15 K, modifying the zonal wind field. The retrieved cyclostrophic thermal wind globally coincides with zonal wind patterns obtained from the cloud tracking from UV VMC images. The differences observed in the middle and low latitudes may indicate the violation of the cyclostrophic balance. [Piccialli et al., 2008].

Atmospheric circulation at the altitude near 100 km according to apparent motions of the oxygen airglow details at the night side observed by VIRTIS / Venus Express

Using the series of images obtained on the night side by imaging spectrometer VIRTIS-M in the singlet oxygen airglow band (see 3.2) and estimating apparent motion of these details, the wind speed is retrieved. In part these apparent motions are connected to real movement of the air masses at the altitudes of 95-107 km corresponding to the peak of the airglow.

The night oxygen airglow is strongly inhomogeneous, and its maximum is usually observed near the midnight meridian. The intensive airglow was sometimes observed in the southern polar region. The structure of oxygen airglow is diverse and strongly variable. Both the small and large scale details of the oxygen airglow can be used for wind tracking. The zonal component of speed varies from –50 to +60 m/s, and the meridional one – from –30 to +30 m/s (error ±10 m/s). Zonal and meridional speeds of oxygen clouds are strongly variable. However the mean zonal stream changes sign of speed near to the midnight. The brightest oxygen airglow takes place at latitudes where the converging meridional streams increasing concentration of the atomic oxygen are observed.

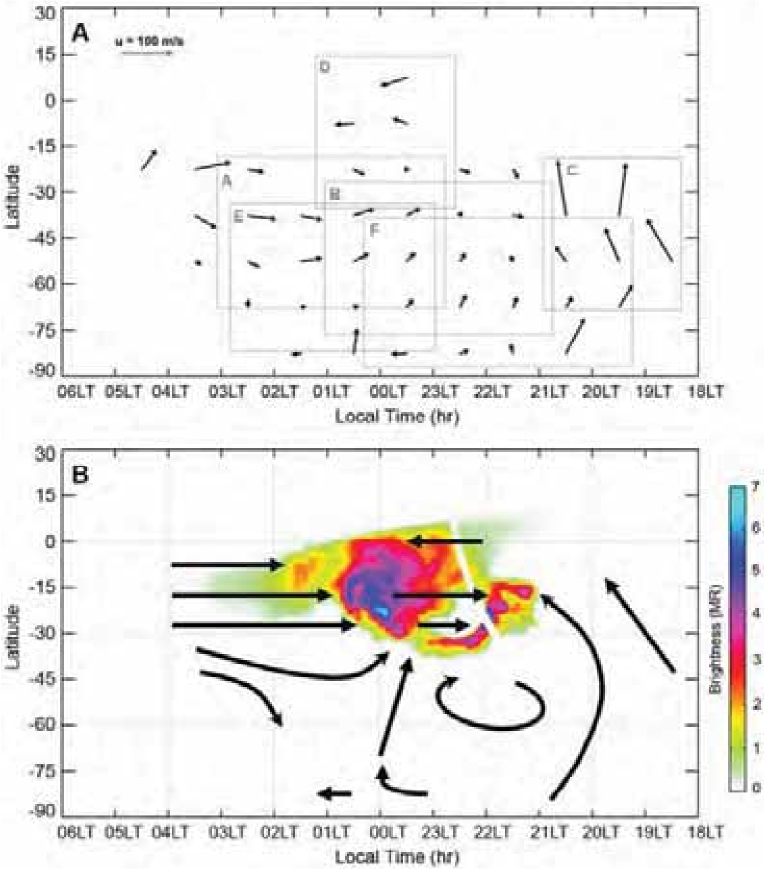

Fig. 11. Mean apparent circulation of the mesospheric oxygen airglow brightness. (a) Averages of all apparent motions tracked on the airglow and also marks the sampled regions. A reference vector of 100 m/s is included on the upper left corner of the map. (b) A schematic model of the mean circulation of Venus mesosphere from these measurements [Hueso et al., 2008].

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3.4 Atmospheric structure

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Venus mesosphere is located between two regions of atmospheric circulation: 4-days superrotation, which is observed on the cloud top, and subsolar-antisolar circulation in the thermosphere (~100 km) with air upflow on the subsolar side and transfer to the night side. A layer of warm air was first detected from SPICAV experiment at extended altitude range 90-120 km of the night side. This layer may come from adiabatic air heating in the downflow, which is compensated by the upflow in the dayside [Bertaux et al., 2007].

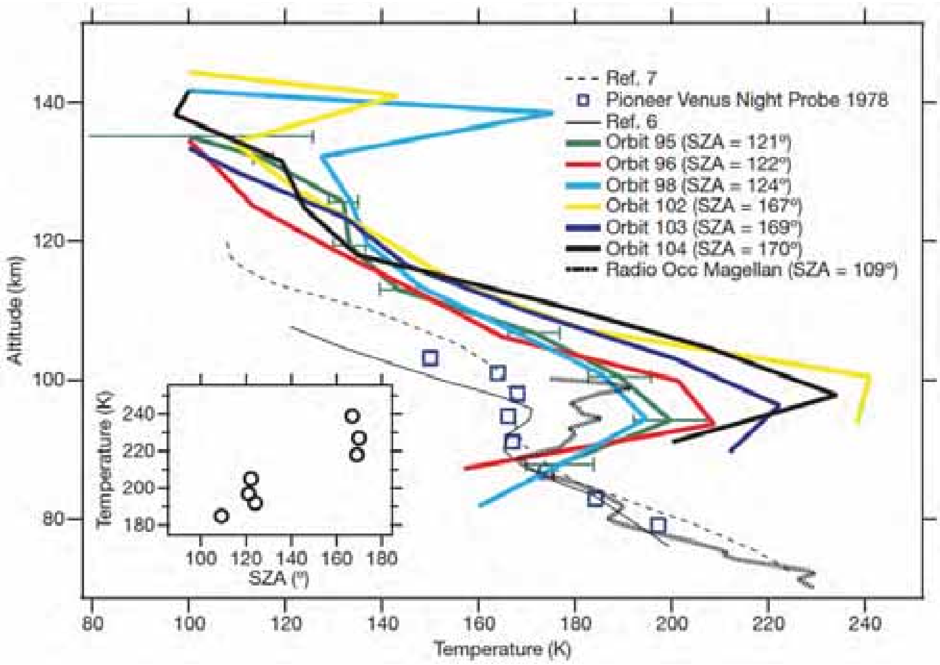


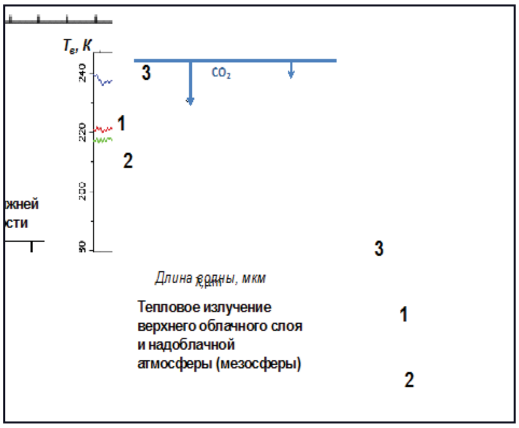
Fig. 12. Temperature profiles of Venus mesosphere in the night side. Thick colour lines are obtained from SPICAV stellar occultations [Bertaux et al., 2007].

Study of mesosphere structure from SOIR/Venus Express data

In the SOIR experiment, which is dedicated to solar occultations in IR range, it is possible to retrieve vertical profiles of atmospheric constituents content, including H_2O, CO, HCl and HF, and some of their isotopes in altitude range 70-120 km (see section 3.1 above). In case of CO_2, vertical profile can be obtained from 70 to 150 km, using several absorption lines. In parallel, rotational temperature can be calculated from the structure of CO_2 line. Technique of such retrievals was developed and demonstrated [Mahieux et al., 2010].

Temperature profiles of mesosphere from VIRTIS VEX observations.

Global investigation of the thermal structure of the Venus mesosphere (from tropopause 55-60 km up to 95-100 km mesopause level) was made for the first time by Fourier Spectrometer experiment on board Venera-15 [Zasova et al., 2007] . One of the main scientific goals of Planetary Fourier Spectrometer on Venus Express was a monitoring of the temperature structure. Unfortunately, this instrument is not operational and partially its scientific goals on thermal sounding are fulfilled by VIRTIS-M mapping spectrometer using the CO_2 4.3 μm band for the temperature retrieval. The vertical profiles of temperature are retrieved above the clouds (65-95 km) and only on the night side (because of unknown contribution of non-LTE on the day side) [Grassi et al., 2008, 2010]. Examples of the VIRTIS-M spectra in the range of the CO_2 4.3 μm band are presented in Fig. 13a. At low latitudes the shape of spectrum (monotonous increase of intensity from the band center to the wings) suggests monotonous decrease of temperature with the altitude from the upper boundary of the clouds. At high latitudes inversion in the temperature profile is observed near upper boundary of clouds, deepest inversion and lowest temperature at 65 km level are observed in the “cold collar” (60-70°S). Absolute values of average temperature fields retrieved from VIRTIS- M (2006-2009) and FTS (1983) [Zasova et al., 2007] usually agree within 5K. This agreement is obtained despite the differences in the spectral range used for the retrieval and in the width of the weighting functions, both factors being optimal for the FTS - experiment. The agreement demonstrates therefore: a) the overall high quality of the absolute radiometric calibration for both instruments, b) the robustness of the retrieval algorithm, and c) the actual minor effect of the uncertainties in the aerosol vertical distribution on the temperature retrieval above 65 km [Grassi et al., 2010]. The main features of the average temperature fields in southern hemisphere (fig. 13b) repeat the fields obtained earlier for the Northern hemisphere: at the 100 mbar (~65 km) level the temperature tend to decrease from the evening to the morning side with a local maximum observed around 20–21LT;



semidiurnal solar related wave is identified at the latitudes of the cold collar, etc.

Fig.13a. Examples of the Venus night side spectra recorder by VIRTIS-M: 1 – typical for low and mid-latitudes, 2 –“cold collar”, 3 – south polar region.

Simultaneous imaging of southern polar regions in the UV and IR ranges shows strong correlation of morphological details. Usually the polar vortex, which eye can be well distinguished in the IR range, is encircled by a dark ultra-violet ring. Probably, this dark ring is formed by the strong jet flow in the polar latitudes. Spiral branches of the vortex begin in zone of the dark ring. Thus the UV contrast details on the disk of Venus are basically caused by the features of thermal structure and dynamics at the upper cloud level [Ignatiev et al., 2009].

The assumption based on the analysis of the movement vectors of atmospheric masses suggests the similarity between the polar dipole and terrestrial tropical cyclones [Limaye et al., 2009].

Cyclostrophic wind: the preliminary analysis of VIRTIS / Venus Express thermal sounding data

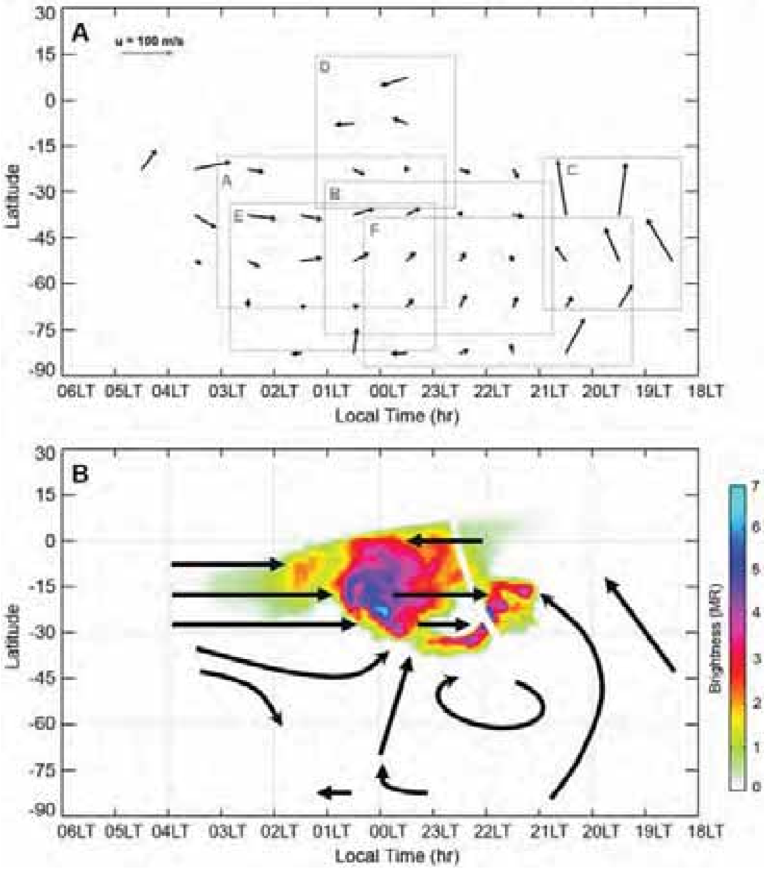
Data of the imaging spectrometer VIRTIS allow to study the thermal structure of the Venus mesosphere at altitudes of 60-95 km (see below section 3.4). Using a cyclostrophic approach the wind fields can be retrieved from the temperature fields assuming mean atmosphere. Obtained wind fields have the following basic features: (1) middle-latitude jet is observed, connected with subpolar structure known as cold collar; thermal wind speed in the jet equals to 80–90 ± 10 m/s on the cloud top level (altitude ~70 km) at latitude 50°S; (2) wind speed decreases from the latitude 60°S, approaching zero at 70°S; (3) wind speed over the jet decreases with altitude.

Solar related dependences of the temperature and zonal wind fields are analyzed. At the night side the temperature on the cloud top level decreases by ~15 K, modifying the zonal wind field. The retrieved cyclostrophic thermal wind globally coincides with zonal wind patterns obtained from the cloud tracking from UV VMC images. The differences observed in the middle and low latitudes may indicate the violation of the cyclostrophic balance. [Piccialli et al., 2008].

Atmospheric circulation at the altitude near 100 km according to apparent motions of the oxygen airglow details at the night side observed by VIRTIS / Venus Express

Using the series of images obtained on the night side by imaging spectrometer VIRTIS-M in the singlet oxygen airglow band (see 3.2) and estimating apparent motion of these details, the wind speed is retrieved. In part these apparent motions are connected to real movement of the air masses at the altitudes of 95-107 km corresponding to the peak of the airglow.

The night oxygen airglow is strongly inhomogeneous, and its maximum is usually observed near the midnight meridian. The intensive airglow was sometimes observed in the southern polar region. The structure of oxygen airglow is diverse and strongly variable. Both the small and large scale details of the oxygen airglow can be used for wind tracking. The zonal component of speed varies from –50 to +60 m/s, and the meridional one – from –30 to +30 m/s (error ±10 m/s). Zonal and meridional speeds of oxygen clouds are strongly variable. However the mean zonal stream changes sign of speed near to the midnight. The brightest oxygen airglow takes place at latitudes where the converging meridional streams increasing concentration of the atomic oxygen are observed.



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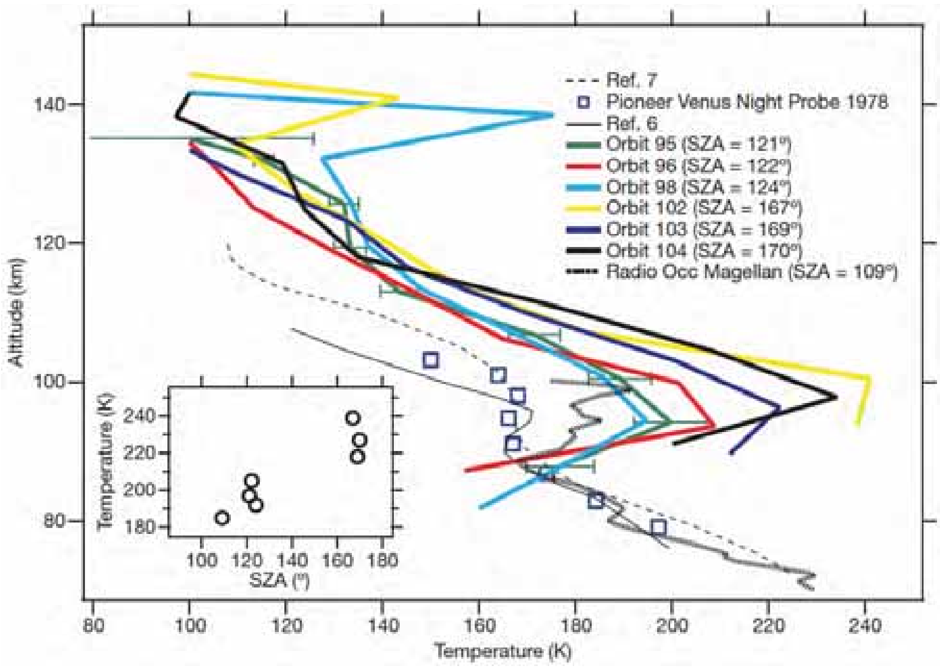

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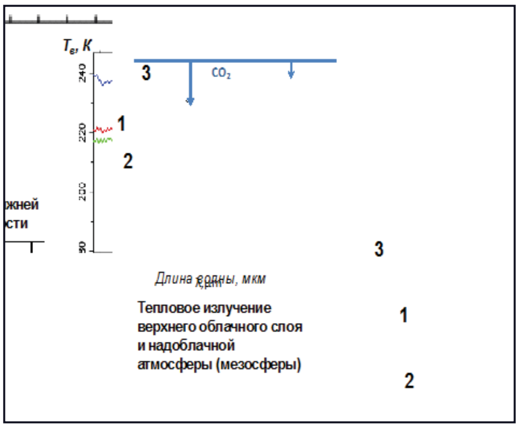

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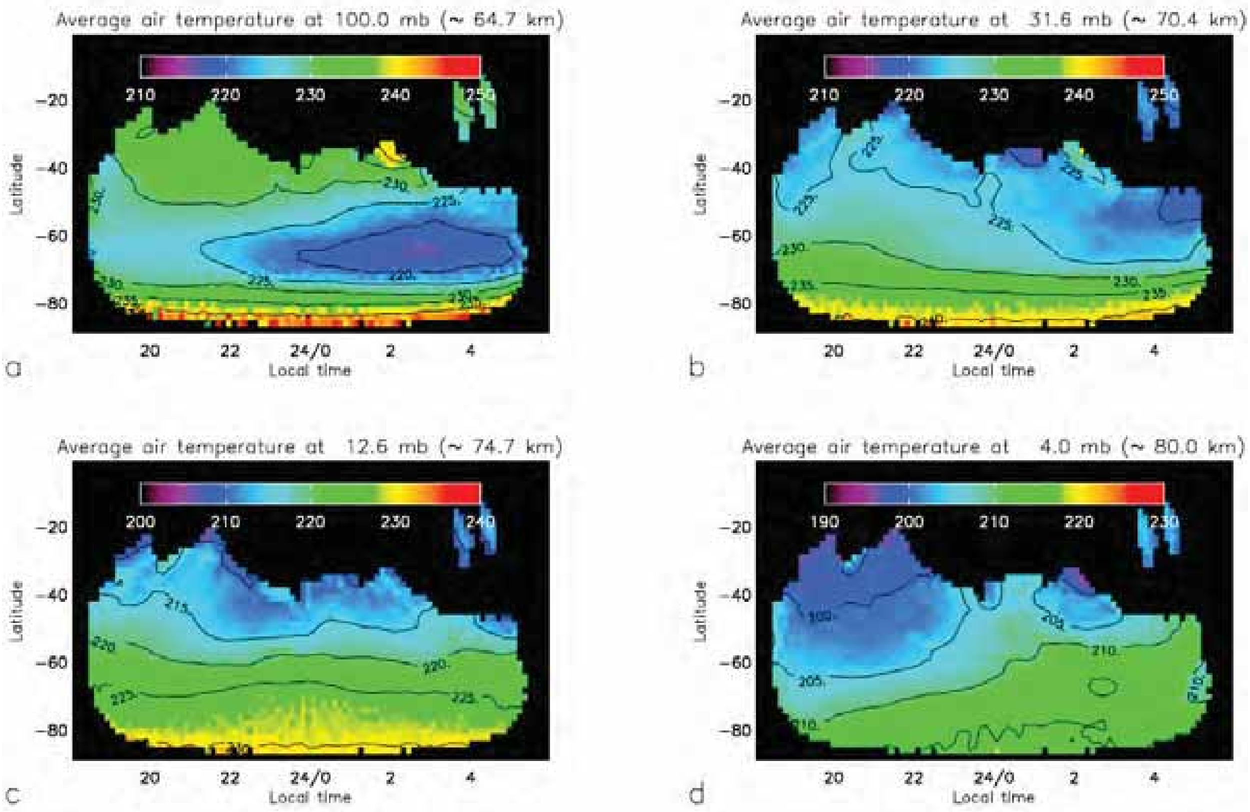

Fig.13b. Average temperature fields of Venus atmosphere on four levels [Grassi et al., 2010].

3.5 Aerosol

Altimetry of the cloud tops and correlation between the atmospheric dynamics, thermal structure, clouds, and the UV absorber from VIRTS and VMC / Venus Express data

Simultaneous observations of Venus by Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) and Venus Monitoring Camera (VMC) onboard the Venus Express spacecraft have been used to map in details for the first time the cloud top altitude and demonstrate that the ultraviolet (UV) markings are not related to gaps in bright clouds but caused by the variations of the UV absorber that related to the thermal structure and dynamics of the atmosphere.

The cloud top altitude, defined as the unit optical depth, is retrieved from the depth of CO_2 absorption band at 1.5 μm. In low and middle latitudes the cloud tops are located at 74±2 km. It decreases poleward of ±50° and reaches 63–69 km in the polar regions. This depression coincides with the eye of the planetary vortex. Fast cloud motion results in variations of the cloud top altitude of about 1 km over few hours. Long-term variations of the cloud top altitude do not exceed several hundred meters in low latitudes and are as large as several km in high latitudes. A weak maximum is observed in equatorial region between the subsolar point and evening terminator, where UV images reveal a high convective activity. Convective mixing brings ultraviolet absorbers from depth, making low latitudes appear relatively dark at these wavelengths. In middle latitudes in the so called 'cold collar', deep inversions suppress the convection and block the supply of absorbers, while cold temperatures create favorable conditions for formation of bright sulfuric acid haze [Titov et al., 2008]. The polar depression in the cloud tops always coincides with the vortex eye observed by VIRTIS at thermal IR wavelength. Moreover, the detailed structure of the altimetry maps shows high correlation with the thermal IR images at 5 μm, although the radiation at 5 μm comes from the levels located by several km lower than at 1.5 μm. Ultraviolet dark spiral arms, which are often seen at about –70^{o} and expand down to even lower latitudes, did not appear to be the gaps in the clouds as it has believed before.

They rather correspond to higher altitudes than the surrounding brighter clouds or to the regions with strong latitudinal gradient of the cloud top altitude. Simultaneous consideration of the cloud top altimetry maps, UV dayside and IR nightside images shows that the UV dark spiral arms and IR features are the manifestations of the giant dynamic structure of the planetary scale polar vortex [Ignatiev et al., 2009].

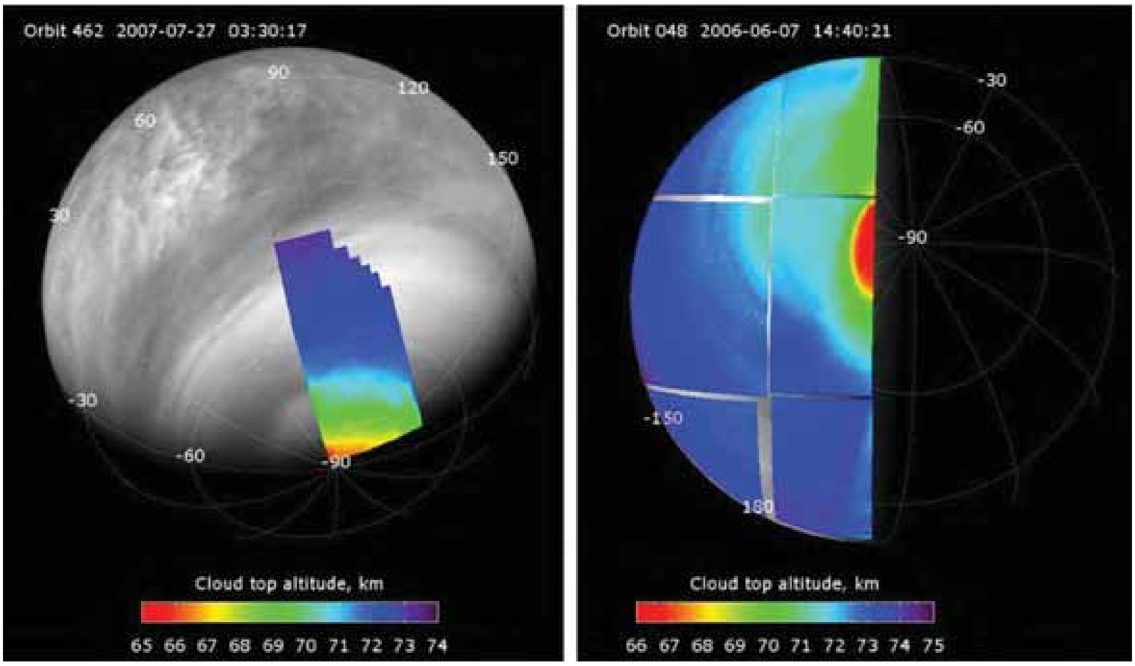

Fig. 14. UV images of Venus taken VMC with superimposed cloud altimetry maps derived from VIRTS data [Ignatiev et al., 2009].

The vertical profiles of upper aerosol haze above from SPICAV-SOIR/Venus Express solar occultations

The three channels of the SPICAV-SOIR instrument (UV, visible-NIR and SOIR) perform simultaneous measurements in solar occultation mode allowing to study the optical properties of aerosol upper haze of Venus in an unprecedented spectral range from 0.11 to 4.4 μm. The vertical profiles of extinction have been retrieved at the altitudes from 70 to 100 km. Due to the wide spectral range the spectral behaviour of extinction gives an unambiguous answer about the size of particles in the assumption on the aerosol composition. In the case of Venus it is a sulphuric acid H_2SO_4 (80% H_2O). The results show a bimodal particle size distribution at altitudes below 80 km with the effective radius of 0.1-0.2 μm and 1.5 μm, which allows to draw conclusions about various processes of formation and destruction of particles in the Venus mesosphere [Wilquet et al., 2009].

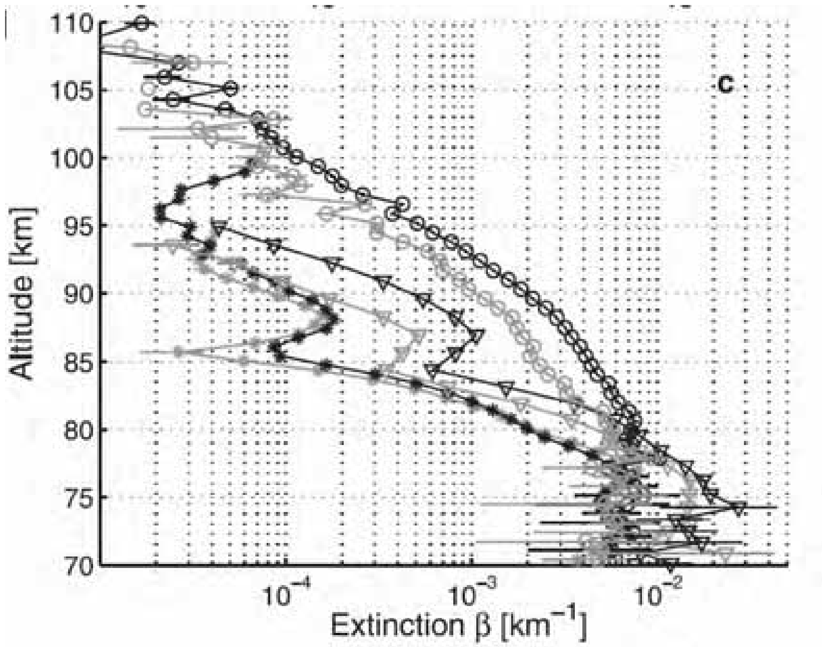

Fig. 15. The extinction vertical profiles of Venus' upper haze at 220 nm (black circles), 300 nm (grey circles), 757 nm (black triangles), 1553 nm (grey triangles), 2345 nm (grey stars) and 3682 nm (grey stars) [Wilquet et al., 2009].

4. Giant planets and their satellites

4.1 Jupiter

Quantitative assessment of the retrieval capabilities of future IR spectro-imagers in Jupiter's hot spots.

Jupiter's atmosphere presents limited regions of relatively thin cloud coverage (the so-called 'hot spots'), which allow the thermal radiation from warmer, deeper atmospheric layers to be transmitted directly to space. Hot spots therefore represent a means for probing chemical composition below the main cloud deck. Planned missions to Jupiter (Juno and EJSM) should host as payload components spectro-imagers operating in the infrared. Their coverage of 5 μm CH4 transparency windows makes them particularly suitable for the investigation of the hot spots. The retrieval performance is evaluated for JIRAM/Juno and the VIRHIS spectrometer proposed for EJSM. These instruments should provide effective constraints on the mixing ratios of water vapor and ammonia between 40 and 70 km below the reference 1 bar pressure level (that is in the pressure range of 3.5-7 bars). Imaging capabilities of the instruments enable a number of studies covering chemical and dynamical aspects of atmospheric evolution [Grassi et al., 2010].

4.2 Saturn

Investigation of Saturn’s aurora

Images of Saturn’s aurora at the limb have been collected with the Advanced Camera for Surveys on board the Hubble Space Telescope. They show that the peak of Saturn’s nightside emission is generally located 900-1300 km above the 1-bar level. On the other hand, methane and H_2 columns overlying the aurora have been determined from the analysis of FUV and EUV spectra, respectively. Using a low-latitude model, these columns place the emission layer at or above 610 km. One possibility to solve this apparent discrepancy between imaging and spectral observations is to assume that the thermospheric temperature in the auroral region sharply increases at a higher pressure level than in the low-latitude regions. Using an electron transport code, we estimate the characteristic energy of the precipitated electrons derived from these observations to be in the range 1-5 keV using low latitude model and 5-30 keV in case of the modified model [Gérard et al., 2009].

4.3 Titan

Numerical simulations of aerosols and comparison with Huygens data

Studies of the Titan aerosol haze microphysical properties based on Huygens lander data were continued. Numerical experiments were carried out using 1D self-consistent microphysical model, taking into account coagulation, photoelectric charging and ion/electron accretion, with model results compared with the atmosphere sounding data along lander's descent path. It is shown that haze size distributions are determined mainly by Coulomb interaction of coagulating particles. Above the tropopause the model predicts a bimodal distribution with characteristic monomer size of ~0.05 mm, which is likely determined by a Coulomb barrier of particles carrying single elementary charge. The observed change in the haze optical properties near the tropopause may be caused by two competing processes: capillary condensation of organic gases in the pores of fractal aerosol particles and surface aging of particles whose lifetime at the tropopause is longer than elsewhere in the atmosphere. Spectra and phase functions of particles obeying up to 3000 have been calculated. Optical properties of fractal aggregates were assessed using discrete dipole approximation in order to obtain additional information on the particles microstructure from Huygens polarimetry data [Skorov et al.,2008; 2010].

General circulation modeling of the Titan atmosphere and interpretation of Huygens data

A non-hydrostatic general circulation model of the Titan atmosphere has been developed for the altitude range 0 – 250 km, based on the complete equation system of the elastic viscous gas dynamics. Simulations were carried out in the relaxation approximation with specified thermal profile. The model reproduces the superrotation of Titan atmosphere, polar vortices, and global patterns typical for thermal tides. Vertical profile of zonal wind component along the Huygens lander descent path has been quantitatively reproduced [Mingalev et al. 2009].

5. Conclusion

As previously, the most of the experimental studies in 2007-2010 have been carried out by groups of Russian scientists involved in the foreign planetary missions, in partcular Venus Express and Mars Express. The work of these satellites is being continued. The European Space Agency plans to support the science operations at least up to the end of 2012. It is estimated that the Mars Express propellant will be sufficient for 3 years. Thereby, the investigations are going on. In parallel, the generalization of the results is started. The studies of Mars atmosphere and climate are to have continuation in the frame of the national project: in November 2011 the launch of Phobos-Soil SC is planned. One of the goals of the project is to study the Mars atmosphere and climate remotely from the orbit [Zelenyi et al., 2010]. In particular, sensitive measurements of methane and other minor constituents of the atmosphere are planned [Korablev et al., 2011]. The future projects dedicated to the studies of the atmospheres of Venus are more ambiguous. European M-class proposal EVE with planned considerable Russian contribution [Chassefiere et al., 2010] has missed selection. Further studies of the planet would be most likely made possible in the frame of the national project Venera-D, planned around 2018.

ACKNOWLEDGMENTS

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Polar Meteorology

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In previous National Report on Meteorology and Atmospheric Sciences prepared by the Commission on Polar Meteorology of the National Geophysical Committee, Russian Academy of Sciences [1, 2] the main attention is paid to works, executed during the period (2003-2006) of International Polar Year (IPY) preparation. This publication is a review of the results of Russian polar studies performed in 2007–2010 in the period of IPY active observation phase (2007-2009). Обобщение The overview of the preliminary results of Arctic environment state investigations obtained by Russian scientists during IPY is presented in [3].

1. Investigations in Arctic Meteorology

The study of meteorological regime and long-term climate variability mechanisms formation in Arctic allows estimate the relative natural and anthropogenic input into the observed climate changes. To solve this problem the spatial and temporal structure of key meteorological parameters variability was considered in Northern polar region on the base of routine observations, reanalyses and model results obtained from global or regional climate models.

Special attention was paid to the estimation of atmosphere - ocean - sea ice - permafrost interactions processes input into the formation of multiyear climate variability in Arctic, as well as of the extreme meteorological conditions over Eurasia.

On the base of meteorological and sea ice observations the set of papers [4-6] analyzes the process of polar regions warming during the XX century, which was interrupted by local cooling conditions. The main causes of this phenomenon according to [6] are a consequence of cyclical nature of climate fluctuations such as decadal and centennial general circulation of the atmosphere and incoming total solar radiation variability. Original Arctic meteorological conditions projections, based on natural multidecadal climate cycle dynamics forecast the surface air temperature decreasing and the Arctic sea ice increasing towards 2030 – 2040th.

Current climate anomalies in the Arctic atmosphere, sea ice and ocean during first decade of XXI century are estimated and compared with ones in previous decades in [7].

In paper [8] there is considered the Arctic sea ice distribution over the Northern polar area including temporal variability and sea ice concentration absolute minimum (September 2007). Executed on the base of observations and modeling results obtained with an ensemble of global climate models statistical analysis demonstrated the relationship between the warming signal in the Arctic and the sea ice extent.

These results of data statistical analysis of the relationship between the warming signal in the Arctic and the sea ice extent were obtained from observations and modeling by an ensemble of global climate models.

Papers [9-21] are devoted to the estimation of observed meteorological conditions change input into the decadal ice variability formation in Arctic.

The quantitative analysis of Arctic climate system key parameters and interannual climate changes is executed using the set (ensemble) of general atmospheric circulation models coupled with ocean and sea - ice models, these results are presented in papers [22-45].

In paper [46] the spatial empirical orthogonal functions structure of surface air temperature anomalies in the extratropical latitudes of the Northern Hemisphere during the 20th century is studied from the century dataset (1892–1999). In the Arctic region (60°-90°N) two spatial orthogonal variability components can be used to describe the horizontal temperature structure with a high accuracy. These are the empirical orthogonal functions related to the leading mode of variability of hemispheric atmospheric circulation (North Atlantic Oscillation), they describe the 1920-1930th Arctic warming event. The first leading variability mode describes a positive temperature trend of past decades (warming regime) and the second leading empirical orthogonal function describes a long-term variation. The results of analysis suggest a significant effect of natural climatic variability on surface air temperature anomalies formation in the Northern polar area and some difficulties in separating of an anthropogenic component of current climate changes.

The set of papers [47-55] is devoted to study of possible mechanisms of natural longterm climate variability formation in Arctic and of seasonal anomalies in Eurasia on the base of analysis of numerical results obtained with global climate models.

A lot of papers consider the problems of synoptic climatology of Polar areas. Basic synoptic climatology parameters (cyclone frequency, intensity, size are valuable indicators of current Arctic climate change. In the basic paper [56] the intensive mesoscale vortex sizes and horizontal velocities were estimated based on similarity theory and dimension analysis considerations for rotating fluid convection application. As a result such parameters as sizes, wind speeds, and total kinetic energy were estimated for tropical cyclones, as well as for polar mesocyclones (polar lows). In polar regions, total fluxes roughly twice those in the tropics are needed for the polar low formation which is explained by the much smaller role of latent heat, greater geostrophicity, and stronger static stability of the atmosphere there.

Papers [57, 58] describe the statistical analysis of cyclones and anticyclones parameters in extra-tropical and polar region based on NCEP/NCAR reanalysis data and simulations with the general circulation climate model of the Institute of Numerical Mathematics of the Russian Academy of Sciences (INM RAS GCCM) and other models. The model results have been analyzed for the second half of the 20th century against the NCEP/NCAR reanalysis data and for the 21st century with the SRES-A2 anthropogenic scenario. Overall for the 20th century, no statistically significant changes in the number of cyclones and anticyclones are obtained from either the NCEP/NCAR reanalysis data or from simulations with the INM RAS GCCM. It is found that the total number of cyclones and anticyclones increased in the beginning of the 21st century as compared to the 20th century. It is shown that cumulative distributions of the number of cyclones and anticyclones by their intensities and areas have an exponential form from both the reanalysis data and the model simulations.

In the paper [59] the cyclone activity and cyclonic life cycle are analyzed in the coupled general circulation models ECHAM5/OM and ECHAM4/OPYC3 run results. The present climate (1978-1999) information is compared with ERA-40 and NCEP/NCAR reanalyze datasets. The total number of cyclones, cyclone intensity, propagation velocity and deepening rates are found to be much more realistic in ECHAM5/OM relative to ECHAM4/OPYC3. Changes in extratropical cyclone characteristics are compared between present day climate and future climate under the emission-scenario A1B using ECHAM5/OM. This comparison is performed using the 20-year time slices 1978-1999, 2070-2090 and 2170-2190, which were considered to be representative for the various climate conditions. Regional changes in cyclone numbers and frequencies are evident. Some noticeable changes are also found in cyclone life cycle characteristics (deepening rate and propagation velocity). Cyclones in the future warmer climate scenario tend to move slower and their deepening rate becomes stronger.

In papers [60-62] the connection of synoptic climatology parameters with cloudiness characteristics and extreme meteorological events is found based on reanalysis data and modeling results.

In paper [63] three different methods for extratropical cyclones identification over Northern Hemisphere are compared based on the sea level pressure reanalysis data (1948-2007). Following cyclone parameters are calculated: number, intensity, size, and duration. The characteristics of extratropical cyclones are compared based on reanalysis data (National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research, ERA-40, and ERA-INTERIM) with different spatial resolutions.

In paper [64] the exponential relationship between the extratropical cyclones number and their intensity is found based on six-hourly NCEP/NCAR reanalysis data from 1948 to 2004. The total number of cases being analyzed is 1.5×10^6. Cyclone sizes were obtained with the use of a numerical scheme based on a rotation of the spherical coordinate system such that the pole of the new coordinate system coincided with the cyclone center. Cyclone sizes were determined at each step of the trajectory. The last closed isobar was assumed to be the outer boundary of the cyclone. The interrelation between the number of cyclones and their sizes was estimated for all extratropical cyclones of the Northern Hemisphere regardless of the stage of their development.

Characteristics of polar mesoscale cyclones over the North European Basin are analyzed using cloud cover distribution data for 1981-1995 in [65]. Special features of the annual cycle and interannual variations in characteristics of Arctic mesocyclones with a spiral and comma-shaped cloud structure are obtained. Against the background of large interannual variations, no statistically significant trends were found in the characteristics of Arctic mesocyclones over the North European Basin in the late 20th century. Cumulative frequency distribution of polar low is well approximated by an exponential function in a size range for Arctic mesocyclones from 50 to 400 km. The applicability of the Weibull distribution as an approximation of the polar low size distribution of the number of cyclone days is analyzed. It is shown that the correspondence between the real distribution and the Weibull distribution became worse in the 1990s than in the 1980s, especially the first half of the 1980s. Much of this was due to an increased local maximum in the 1990s in the distribution of polar mesocyclones with diameters about 400 km. This local maximum was found for all types of mesoscale vortices and for all analyzed five-year subperiods during 1981-1995. A large discrepancy between the frequency distribution functions for polar lows depending on their diameters was shown to exist for different types of Arctic mesocyclones.

Regional features of cyclonic and anticyclonic activity over Western Siberia during period 1976-2004, including the frequency and variability trajectories analysis are studied in [66].

The common statistical analysis of multiyear surface air temperature changes, of atmospheric greenhouse gases concentration and of atmospheric action centers dynamics in western part of subpolar area is executed in paper [67]. The decadal stability of statistics obtained with account of possible increasing of atmospheric greenhouse gas concentrations in Northern polar area is estimated. The possible mechanism for teleconnection of baric field low frequency variations in Northern Atlantic with climate variability in northwestern part of Atlantic-Eurasian region is suggested.

The effect of cyclones on the atmospheric electrical field formation in the area of Kamchatka peninsula is studied in [68], cyclonic role in transporting of fine-dispersed particles from troposphere to stratosphere is considered in [69].

The structure features of both seasonal and intraannual variability of polar tropopause parameters (altitude, temperature and humidity, wind speed) are studied in [70] based on aerological data from Barrow station (1990-2007). It is demonstrated, that for indicated period the thermal tropopause became more shaped due to increasing of vertical temperature gradient in the low stratosphere.

Two-dimensional stationary model was applied in [71] for consideration of tropopause displacements over mesoscale mountains (or ice-sheet). The two-layer quasi-static airflow is characterized by a constant velocity and a discontinuity of temperature stratification at tropopause. Partial reflection of wave energy from the tropopause is substantially controlled by nonlinear effects associated with a finite orography shape and height. The tropopause displacement from the equilibrium level has a stabilizing effect on the flow, thus interfering with the development of anomalously strong disturbances. The results obtained in this study are indicative of the importance of a correct consideration of the dynamic interaction between the troposphere and the over-lying layers during both simulation of the process of flow and analysis of real atmospheric situations over mountains or polar ice shield.

Case study of winter polar stratospheric clouds over Yakytsk area (Eastern Siberia) was provided for 2004-2005 in [72] based on local lidar stratospheric station regular data. Air mass trajectory analysis over Yakutsk city demonstrated, that registered polar stratospheric clouds were formed over Norwegian Sea at the altitudes about 18-21 km, where the stratosphere was the coolest, and then they were transported during 4-5 days to the region of observation.

Atmospheric circulation epochs as an indicator for meteorological regime diagnosis and climate change, as well as predictor for climate variability forecast are analyzed in [73]. For this goal one-hundred year series of atmospheric circulation W, E and C forms (by G.Ya.Wangengeim) and Z, M1 and M2 forms (by A.A. Girs) recurrence is used for more than 100-year period, these forms describe climate conditions over the most part of Northern Hemisphere. It is demonstrated, that the frequency of W, C and M1 forms was decreased permanently, while the frequency of E and Z forms was increased, indicating the significant change in atmospheric circulation in Northern hemisphere during last century. The correlation of atmospheric circulation C, (W + E), Z and (M1+M2) forms frequency anomalies cumulative sums with inter-decadal Earth rotation variations is detected. Calendar of basic atmospheric circulation forms for Northern hemisphere can be found in [74].

Mass exchange processes in Arctic atmosphere, affecting the hemispheric meteorological conditions formation, are considered in [75]. Analysis of the wind regime over Arctic boundary during 1997-2004 demonstrated significant changes in the conditions of a meridional air transport between the Arctic and midlatitude regions as compared to the previous years (1960-1990). The wind fluxes of mass and heat (internal) and kinetic energies are estimated without consideration of turbulent and convective processes. The spatial, seasonal, and interannual variations in wind velocity and air temperature in the formation of these fluxes are estimated. During the period 1997-2004, an advective transport of energy from the northern latitudes was occurred in the lower 6-km tropospheric layer at 70° N latitude over almost a whole year. Only in spring (April) the wind fluxes brought heat energy from the south. The total amount of both heat and kinetic energies transported from the Arctic region in this way during a year is comparable to the mean amount of these energies contained in the whole atmosphere over the area bounded by 70° N latitude. The current spatial and temporal distributions of meridional mass and energy fluxes may be used as additional parameters for Arctic routine meteorological data interpretation.

The cycle of investigations [75-96] considers the meteorological conditions of regional transport of atmospheric contaminants in Arctic, including arsenic and heavy metals (Ni,Cu, Pb, Cd, V), the main anthropogenic sources influencing Russian Arctic ecosystems are defined.

Paper [97] presents the analysis of trajectories for sulphur and nitrogen compounds transboundary transfer, and also atmospheric precipitation compound analysis in northwestern part of Russia for the period from the latest 70th to 2007. In this region the sulphur sedimentation intensity is decreased permanently for last decades. The nitrogen sedimentation intensity has the opposite trend. Average annual sedimentations of sulphur as well as of nitrogen are close to accepted critical loads. The most probably sources of contaminants are located in Central Europe.

New possibilities for study of gas exchange processes between Arctic ocean and atmosphere are provided by regular direct observations of greenhouse gases concentration in surface air of Arctic [98-106] greenhouse gases in Arctic [98-106]. Measurements made in Russian drifting stations “North Pole” demonstrated an important role of frozen (melting) processes of sea ice cover during emission (absorption) of carbon dioxide. Since ice formation period lasts longer than summer melting period (carbon dioxide absorption period), the area of water of Arctic ocean and Arctic seas can be considered as the source of carbon dioxide with intensity up to 30 % from global annual anthropogenic carbon dioxide emission into atmosphere according to [104].

Due to renewal of methane concentration increase in surface Arctic air in 2007 the investigations of types and natural sources intensity studies in polar and in subpolar atmosphere become more important. The description of known atmospheric methane sources is completed by new measurements [107-110] and model calculations [111-113] of local ecosystem source intensity. For instance, in

[112] a module of soil thermal physics and the methane cycle is considered for climate model of intermediate complexity, which reproduces well the pre-industrial and observed parameters of both seasonal soil thawing/freezing conditions and the methane transformation. In [113] the regional climate model is applied for estimate of methane emission by wetland ecosystems of Northern Eurasia in XXI century. For scenario of anthropogenic emission SRES A2 the growth of natural methane emission up to 14-17 Mt of CH_4/year to the end of XXI century is obtained due to increasing of warm season duration.

Paper [114] presents the coupled atmosphere–ocean general circulation model with the carbon cycle and with module of methane evolution, in which methane sources in the soil of wetlands and atmospheric methane evolution are considered. A temperature increase to the end of 21st century relative to the 19th century is estimated as 3.5°.

In [114] the methane emission from oligotroph wetland complex is estimated using measurements and estimates made by local model for different types of microlandscapes. In [116] the intensity of methane sources in Northern part of Western Siberia is estimated using direct measurements of methane concentrations in the surface air and regional modeling for the area of Urengoy natural gas deposit. The methane emission was estimated for the part of deposit as well as for the whole area. These results are completed in [117] with multilevel methane concentration measurements with high time resolution. Except of estimation of average flux intensity for wetland landscape the estimates of natural gas leaks during technological procedures at the deposit are obtained.

Paleoreconstructions of dynamics of atmospheric methane during Phanerozoic period, which is useful for present greenhouse gases evolution analysis are presented in [118].

Correct interpretation of satellite pictures, surface meteorological measurement and radiosonde data of high cloud layer parameters is very important for cloudiness climatology estimated on the base of different observations platform. Special method for high cloud layers prediction from temperature and humidity profiles including transparent part of cloud layers was developed in [119].

The possible mechanisms of troposphere–stratosphere interaction and influence of Siberian autumn snow cover anomalies on the surface winter temperature are considered in [120] using the climate system intermediate complexity model.

The changes of albedo and snow cover absorption ability due to snow surface roughness (snow drifts) are estimated in [121] by applying of numerical model, obtained by averaging of radiation transfer equation. Input of 3D rough surface effects in absorption and reflection is estimated depending on optical and geometric characteristics of drifts and irradiance conditions.

Modern correction methods of precipitation in polar areas of Russia, USA and Canada by rain gages of different types are described in [122]. In correction procedure, based on rain gages intercalibration results, the systematic measurement errors of solid precipitation due to snowstorm drift are taken into account.

The possible regional changes of atmospheric precipitations sum and of river water discharge in XXI century are studied in [123, 124] using modeling results.

Paper [125] presents the results of intercalibration of solar shortwave radiation actinometric sensors obtained in Svalbard in April 2007. The possible sources of systematic errors are defined. These results [123-125] develop the presence knowledge about meteorological regime of polar regions.

Different direct links and feedbacks between ozone content (components of ozone cycle) and meteorological regime parameters in Arctic are considered in [126-132]. The results of global chemistry-climate model with cloud microphysics module [126] reconstruct gas and aerosol compositions of stratospheric clouds over both polar areas. The presence of nitrification in the Antarctic stratosphere (see also [127]) in the Arctic region explains the weaker ozone hole in the Arctic.

The observations of ozone total column distribution for winter end over polar region [128] can serve as predictors for early or late spring circulations changes in stratosphere and for following weather character in spring-summer season. The results of the ozone layer parameters measurements over the north-western Arctic in the winter of 2003-2004 [129] based on different satellite observation platform (HALOE, SAGE, and POAM) demonstrated ozone content simultaneously variations. The influence of the 11-year cycle of solar activity on quasi-biennial variations in ozone and temperature in the Canadian Sector of the Arctic is estimated in [130]. An analysis of the high-latitude ozone balloon sounding data derived from Canadian stations shows that, in the maximum of the 11-year cycle of solar activity, the ozone content in the lower stratosphere is higher than in the solar activity minimum. One possible “conductors” of the influence of the 11-year solar activity cycle in the Canadian sector of the Arctic is quasi-biennial oscillation (sea also [131]). This conclusion was suggested in [132] on the base of multiyear (1998-2005) ground-based and satellite measurements of total ozone content. Except of quasi-biennial oscillation phase the ozone distribution is influenced by circumpolar vortex evolution and by winter polar stratosphere temperature.

Significant Arctic ozone layer chemical destruction event was described in [133] for the extremely cold winter conditions (2004-2005) based on SAGE-III satellite data. Chemical ozone loss in the stratosphere over the Kola Peninsula due to polar vortex air masses diabatic descent in the 2002/2003 Winter season was obtained from Microwave Sounding data and long-term ozone observations [134]. The results of international investigations of atmospheric ozone content, atmospheric water vapour and aerosol in Arctic, at Heisa islands (Arkhangelsk area) and Dikson (Krasnoyarsk area), in Salekhard (Yamalo-Nenetskiy autonomous area) and in Yakutsk (Eastern Siberia) are presented in [135].

The peculiarities of atmosphere – underlying surface (ocean, sea ice, permafrost) interaction in polar areas are considered in [136-153], including the description of physical mechanisms being responsible for long-term climate variability and regional meteorological regime parameters anomalies formation in Arctic and sub-Arctic.

The modeling results of basic Earth climate system components in high latitudes of Northern hemisphere are combined in [154-160].

Regional features of meteorological conditions and their changes in Northern Polar area and adjacent regions are considered in [161-194].

For instance, based on routine data of standard meteorological observations at polar station Tiksi (August 1932 - December 2007) the sub-range approach to analysis of climate variability of air temperature, atmospheric surface pressure, absolute humidity, tenth of total cloudiness and wind velocity was applied in [193-194]. The statistical estimates in ranges of interannual variability, annual course, synoptic scale variability and diurnal course are calculated. The assumption about influence of synoptic systems on long-term air temperature trends is stated. The consistency of air temperature and total cloudiness trends during summer and winter seasons is revealed. The model of periodically correlated stochastic processes had been used for detailed analysis of key meteorological characteristics.

2. Investigations in Antarctic Meteorology

Current meteorology, actinometry, ozone and upper air dataset of Russian Antarctic Circumpolar network has been completed based on observation results for field measurement programs [195]. Detailed inter-comparisons of standard synoptic observations were organised between all polar stations located at King George Island (Antarctic Peninsula) [196, 197]. These comparisons indicate the influence of local environment conditions on observed climatic trends and possible causes of inhomogeneity of surface time-series.

In the frames of IPY COMPASS (COmprehensive Meteorological dataset of active IPY Antarctic measurement phase for Scientific and applied Studies) cluster key climatic parameters observed at different Antarctic polar stations were collected also. Inter-comparison between Russian Novolazarevskaya station surface data and Belgian automatic weather station was made. Comparison demonstrates good agreement in annual course of local temperature, pressure and wind speed data and estimates possibility of numerical verification of automatic weather station data. The new Russian automatic weather stations were established at Molodejnaya station (Eastern Antarctica), Russkaya and Leningradskaya station (Western Antarctica) which were opened after conservation.

Local features of unique wind regime formation (due to orographic effects) at Russkaya station are considered in [198-199] based on complete set of current meteorological observations (1980-1990). Estimates of inter-annual variability parameters, parameters of annual rithmics, processes of synoptic scale and diurnal variability with account of low frequency modulation are obtained in terms of mathematics expectance vector and of invariant of dispersion tensor and spectral density in suggestion of stationary and periodic correlation vector stochastic process. For parameterization of synoptic scale variability the model of stochastic impulse process is applied. The most prominent features of wind regime in the area of Russkaya station are the prevailing of winds from eastern sector and high frequency of strong and storm winds. The features of annual course and inter-annual wind speed variability are defined by synoptic scale processes. The reasons of intensive katabatic circulation formation over ice cover are studied in [200].

Katabatic wind structure and wind interaction with the underlying surface were investigated using observational data at Mirny Observatory and Bellingshausen station and modeling. The turbulence structure of wind at various distances along a glacier slope was studied to analyze the influence of the underlying surface structure, its roughness parameter and drag coefficient. Heat and momentum transfer were also measured at different sites along the slope [201]. This work results can be useful to the lower boundary conditions definition for regional models with inhomogeneous topography determination.

In [202-204] the study of temperature regime and albedo of surfaces with different reflective characteristics in Sub-Antarctic is executed (King George Island). Parametric dependencies of albedo as a function of temperature are built. These results are very useful for small and middle resolution satellite pictures interpretation development.

The first summer season after the Interannual Polar Year active observation period in South Polar Area was characterized by natural variability of atmospheric processes [205]. The warmest January (-25.5 °C) for last 30 years period was indicated in the South Pole in 2010, it was the third warmest January for all observation period (1958-2010), and almost the warmest February (-37.9 °C) was observed for last 15 years. The several records of wind speed were registered at the Pole at the end of March 2010, which were generated by intensive cyclonic activity. At continental station Vostok the average surface air temperature was almost 2^0 higher than multiyear climate means. The increasing of air temperature in summer and winter seasons gives statistically significant growth of air temperature annual values, which is estimated as +0.016 ± 0.018 °C/year. The remarkable positive anomaly of surface air temperature was registered at Mirny Observatory in January 2010. The surface observations at Novolazarevskaya station demonstrate small, but stable increasing of air temperature for all seasons, especially remarkable in summer 2010. On the contrary, the lowest surface air temperatures for all period of instrumental measurements (1968-2010) were registered at sub-Antarctic Bellingshausen station, which can indicate the possible inverting of air temperature change tendency in region (see also [206-208]).

All above estimates are obtained on the base of operative data collection system, quality control procedure and statistical analysis of Antarctic stations current data, created in the frames of IPY COMPASS Project, managed by AARI scientists [209].

The reason of above mentioned cooling in the region with strong regional warming signal is unprecedented El-Ninio, sourced in equatorial area of Pacific Ocean in October 2009. Usually during El-Ninio period anticyclonic anomaly of atmospheric pressure is formed over Bellingshausen sea in the front of which the southern air flows in low troposphere are prevailing. Another circulation factor, responsible for features of Antarctic Peninsula meteorological regime is annular Antarctic mode (Antarctic oscillation) [206]. The connection of Antarctic oscillation with other large scale circulation modes and with climate changes in

Southern Hemisphere is identified in [210] using reanalysis data. The possibility of applying of reanalysis data for studying of Antarctic climate and climate changes by comparison of reanalysis data and permanent observation station data is considered. In paper [211] an attempt is made to estimate the connection between inter-annual changes of Antarctic oscillation and wave-eddy activity characteristics in the atmosphere.

Long-range variations of air temperature and humidity in troposphere over Eastern Antarctica based on aerologic sounding data at Russain Novolazarevskaya station (1969-2007) and Mirhy Observatory (1982-2007) are investigated in [212, 213]. Estimations of climatic trends parameters of free atmosphere are obtained using method, taking into account intra-row correlation based on global CARDS archive and Russian Antarctic Expedition dataset (1956-2007).

Trends in low cloud boundary for cloud layers with cloud amount 0-100% of the sky over Antarctic were calculated in [214]. Long-period averages and decadal changes of ceiling in different atmospheric layers are presented. The investigation was made on base of dataset contained time series of cloud boundaries and cloud amount for cloud layers, created on the base of radiosonde sounding data CARDS for cloud amount and boundaries reconstruction for Antarctic stations.

The estimations of cloud layer low boundary variability for cloud with amount 80-100% of the sky over Antarctic region are calculated in [215] for different months and seasons for different atmospheric layers. Seven coastal Antarctic stations: Bellingshausen (1970-1999 years), Halley (1966-2001 years), Novolazarevskaya (1969-2001 years), Mawson (1969-2001 years), Davis (1970-2001 years), Mirny (1969-2001 years), Casey (1969-2001 years) were selected for research.

Climatic trend estimations in time series of temperature anomalies at the standard isobaric levels calculated in [216] by the method based on current radiosonde sounding observations with taking into account the possible time correlations of observations for eight coastal Antarctic stations (Bellingshausen, Halley, Novolazarevskaya, Syova, Mawson, Davis, Mirny, Casey). Troposphere warming for all months (except October), seasons and for year is detected over Bellingshausen station only. The middle and high troposphere layers warming is bigger than it is in low troposphere for all season and year. Warming in troposphere for winter season was detected for all studied stations except Mirny Observatory. Small cooling was detected in some layers of troposphere over Novolazarevskaya and Syova stations. Cooling in the low stratosphere was determined over all stations.

Multy-year results of total contents of carbon monoxide and methane measuring based on the method of solar-absorption spectroscopy are summarized in [217]. The measurements were organized at the Molodezhnaya station (1977-1978), Mirny Observatory (1982-1992) and Novolazarevskaya station from (2003-2006). The methane total content was increasing during the observation period 1977-2006.

Direct measurements of surface concentrations of carbon dioxide and methane over Atlantic Ocean and Antarctic coastal zone results are presented in [218].

First (2003) measurements of surface methane concentrations sampled at King George Island near Russian Antarctic Bellingshausen station over different underlying surfaces are described in [219]. Air samples were made into metal flasks (1.5L) with electropolished internal surface. Probe analysis was provided by A.I.Voeikov Main Geophysical Observatory laboratory based on calibration mixtures with international inter-comparison. Measurement results are compared with current data of other Antarctic stations. Data comparison shows that Bellingshausen data reliable describe the Southern Polar area air gas composition background conditions.

During IPY period the national circumpolar network for Antarctic permafrost and soil studies was created in the frames of ANTPAS (Antarctic permafrost and Soils) Project [220].

Warming meteorological conditions over Shirmacher oazis (Eastern Antarctics) were characterized in [221-223].

In the frames IPY ClicOPEN (Impact of CLImate induced glacial melting on marine and terrestrial COastal communities on a gradient along the Western Antarctic PENinsula) Project at Bellingshausen station organized year-round plankton investigations and regular lichen community study. Lithosols of the King-George Island are described in terms of a humus formation process. The humus state of soils formed under the grass (*Deshampsia antarctica*) and lichen (*Usnea aurantiaco-atra*) are presented in [224]. The affect of overmoistening on the processes of organic matter transformation under the grasses was investigated. The higher plants assist to aggregate soil formation in residues of these plants meanwhile the higher nitrogen percentages in them than in lichens don't result in increasing humus richness by nitrogen. The intensity of humification is higher in soils under grasses than in soils under lichens which is well expressed in accumulation of humic and fulvic acids groups. All lithosols investigated are characterized by a low degree of humification, small portions of humus connected with a mineral part of soils, essential portion water-soluble fractions of organic matter and low stability of organic matter to the oxidation. In the similar conditions of parent materials, relief and climate during the same period of time the soils with different humus content and composition were formed. This is the evidence of the maximal affect of biochemical peculiarities of plant residues on kinetics of accumulation and transformation of organic matter in Antarctica.

General description of strong meteorological conditions of Russian Vostok station (Central Antarctica) is summarized at [225-226].

The first detailed analysis of the absolute low surface air temperature of the globe (- 89.2 ^{0}C, Vostok station, 0245 UT on 21 July 1983) formation was provided in [227] based on full meteorological and upper air observations data, reanalysis and energy balance modeling results. The record low temperature was measured following an approximately linear cooling of over 30 K over a 10 day period from close to mean July temperatures. The key specific meteorological conditions correspond record event are following: the temperature at the core of the midtropospheric vortex was at a near-record low value; the center of the vortex moved close to the station; an almost circular flow regime persisted around the station for a week resulting in very little warm air advection from lower latitudes; surface wind speeds were low for the location; no cloud or diamond dust was reported above the station for a week.

Antarctic applied meteorological works are provided in [228-230].

The role of atmospheric ozone and aerosol dynamics in Antarctic meteorological condition are considered in [231-237].

Solar activity effects on dynamical and temperature tropospheric processes have been studied at Vostok station and Mirny Observatory [238-241]. It is shown that the temperature regime at Vostok is strongly affected by variations of the interplanetary electric field, the warming up to 10-15o C was being observed within 24 hours after the sharp increase of the dawn-dusk interplanetary electric field. It is suggested that influence of the interplanetary electric field on atmosphere is realized through the global electric circuit affected by the interplanetary and magnetospheric electric fields and currents.

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Radiation

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During 2007–2010 the Russian Radiation Commission in cooperation with interested departments and institutions hold the scientific conference "Physics and Education" devoted to 75-jubilee of Atmospheric Physics Department at SPbSU (2007), the International Symposium of Former USSR Countries on Atmospheric Radiation and Dynamics (2009) and 5th International Conference "Atmospheric Physics, Climate and Environment" (2010). At these conferences most actual problems of atmospheric physics (radiation transfer and atmospheric optics, greenhouse gases, clouds and aerosols, climate changes, remote measurement methods, new observation data) were discussed. In this review, 5 directions of studies covering the complete spectrum of investigations in atmospheric radiation are given.

1. Radiative transfer theory

Numerous investigations in this line are devoted to the study of the radiative transfer in different mediums and for different measurement geometries, the development of methods and algorithms for solving the radiation transfer equation for different problem of atmospheric optics.

Theoretical papers in this line are dedicated to the analysis of physical principals of the radiative transfer theory on the basis of the matrix Green's function [Budak and Veklenko, 2010] and studies of continuity properties of the solution to a boundary-value problem for the radiation transfer equation (RTE) with generalized conjugation conditions at the interface of media [Prokhorov, 2009].

Different methods of radiation transfer theory are intensely developed by the MPEI (Moscow Power-Engineering Institute) team. The new approach to the solution of the RTE is formulated on the basis of the solution separation on the anisotropic and regular parts [Budak and Korkin, 2008a]. On its basis the solution of the vectorial RTE (VRTE) is studied for the case of the turbid medium slab [Budak and Korkin, 2008b]. Its comparison with well-known methods was carried out [Sokoletsky et al., 2009; Kokhanovsky et al., 2010]. The matrix-operator approach is proposed for VRTE method for a stratified medium with an arbitrary underlying surface based on eliminating the anisotropic part of the solution [Budak et al., 2010]. The aerosol influence on polarization properties of the scattered radiation is analyzed [Budak and Korkin, 2008c]. The angle distribution of electrons scattered by the slab target is studied [Budak and Korkin, 2008d], that opens up possibilities for the satellite measurement modeling by the precision gage of the modern electron microscopy.

At Institute of Atmospheric Optics (IAO SB RAS) in the frames of the theory of multiple scattering, the system of equations has been formulated that describes correctly the transfer of wideband optical radiation in a disperse media that allows to propose and realize new algorithms of statistical modeling, to solve a number of practical problems of lidar sounding of atmosphere and vegetative cover [Krekov et al., 2008, 2009; Veretennikov, 2007a]. Modeling of the solar radiation transfer under different atmospheric conditions were performed, different methods for calculating the atmospheric transmittance functions and radiation fluxes were proposed [Prigarin et al., 2007; Chesnokova et al., 2007; Bogdanova and Rodimova, 2008; Zhuravleva, 2008; Zhuravleva et al., 2009a; Tvorogov and Rodimova, 2008; Belov and Tarasenkov, 2010; Zhuravleva and Kokhamovsky, 2010; Tvorogov et al., 2008, Gorchakova et al., 2009]. A new method for retrieving the aerosol microphysical characteristics from simultaneous measurements of the spectral transmission and solar aureole brightness is considered [Veretennikov, 2007b].

Influence of spectroscopic data quality on modeling the radiation transfer has been estimated [Chesnokova and Voronina, 2008; Firsov and Chesnokova, 2010; Chesnokova et al., 2009]. Modeling of the radiation transfer using different spectroscopic databases of absorption lines has shown that it is necessary to take into account water vapor lines in a spectral range of 0.5–1 μm, which are absent in the HITRAN database (http://cfa-www.harvard.edu/hitran/). The input of these lines to the transmittance calculated even with the middle spectral resolution (20 cm^{-1}), can achieve 1.5 % and 4 % on vertical and slant paths, respectively, and the input of isotopic HDO modifications can be equal to 1%.

At IAM RAS (Keldysh Institute of Applied Mathematics RAS, Moscow) numerical methods for the radiation transfer modeling in atmosphere have been improved. A simplified method to calculate the brightness coefficient of the solar light reflected by spatial-heterogeneous atmosphere, composed by some large homogeneous zones, is proposed. The grid algorithm to solve the transport equation in 1D, 2D, 3D geometries under discrete definition of phase functions on parallel computers with shared memory is modified (the code RADUGA); in particular, the adaptive algorithm to calculate scattering matrix elements is developed and realized. Comparison of three different discrete ordinate methods in the problem on plane albedo for the semi-infinite sea water slab layer (when the scattering phase function is both forward-peaked and backward-peaked) is carried out under different zenith angles of the sun. The semi-analytic method to solving the transport equation with the small-angle approximation to anisotropic part of a solution, the iterative method to solving the transport equation via grid schemes, the iterative method to the Ambartsumian's nonlinear integral equation are under consideration. All methods yielded relative differences within 1.8 % for modeled natural waters. An analysis of plane albedo behavior resulted in the development of a new extended QSSA approximation to the plane albedo for remote sensing problems [Nikolaeva et al., 2007a, 2007b, 2010a, 2010b; Bass et al., 2009; 2010].

At Saint-Petersburg State University (SPbSU) studies of the non-LTE radiation transfer in middle and upper atmosphere is being continued. The advanced version of the complete model of O_2 and O_3 photodissociation in the mesosphere and thermosphere (in the altitude interval of 50–125 km) with consideration of the kinetics of electronic-vibrationally excited products was developed. This model was used for formulating and solving applied problems (algorithms of ozone and water vapor retrievals, parameterization and error study of solutions of direct and inverse problems etc.) [Yankovsky et al., 2007; Kuleshova and Yankovsky, 2007, Yankovsky and Babaev, 2011]. To found results, the sensitivity of the model was analyzed for direct and inverse problems [Kuleshova and Yankovsky, 2007]. The paper [Feofilov et al., 2009] describes the use of this model for the water vapor retrieval from the broadband 6.3 μm emissions measured by SABER, the limb scanning infrared radiometer on board the TIMED satellite.

During 2007–2010, the fundamental problem of radiation radiative transfer in the ro-vibrational bands of CO_2 molecules (near 4.3, 2.7, 2.0, 1.6, 1.4, 1.25, 1.2 and 1.05 μm) and of CO molecules (near 4.7, 2.3, 1.6 and 1.2 μm) under conditions of local thermodynamic equilibrium breakdown over vibrational states of these molecules (vibrational NLTE) has been solved for the first time taking account for both scattering and absorption of radiation by the Martian aerosols. 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 and a reflection of radiation by a planetary surface has been developed [Ogibalov V.P., 2007, 2008, 2009]. In addition this method allows taking account for the aerosol scattering (with a phase function of general type) and the absorption of radiation at frequencies in spectral ranges of the CO_2 and CO ro-vibrational bands. The spectra of the limb radiation and the radiation outgoing at the Martian atmosphere borders in the near-IR CO_2 and CO bands were modeled taking account for the aerosol extinction of this radiation. The theoretical backgrounds of a new approach for retrieving the optical properties of the Martian aerosols from limb radiation measurements in the near-IR CO_2 and CO bands were proposed.

2. Atmospheric molecular spectroscopy

Main directions of investigations in molecular spectroscopy of atmospheric gases are experimental studies of spectroscopic parameters, the development of methods for calculating the parameters of spectral lines, transmittance functions and the updating of spectroscopic databases (IAO SB RAS, IAP RAS (Institute of Applied Physics, N. Novgorod), Tomsk State University (TSU), SPbSU).

At IAO SB RAS jointly with foreign scientists intensive experimental studies and the modeling of spectroscopic parameters of atmospheric gases in different spectral ranges and under different conditions [Lyulin et al., 2007, 2008, 2010; Mikhailenko et al., 2008a, 2008b; Nikitin et al., 2009a; Lavrentieva et al., 2010; Perevalov et al., 2008a, 2010; Ptashnik and Smith, 2010; Tashkun et al., 2010a, 2010b], molecular spectra and intermolecular interactions [Perevalov et al., 2007a, 2007b, 2008b, 2008c; Tvorogov et al., 2007; Ni et al., 2008a; Wang **et al., 2008;** Nikitin et al., 2009b; Bykov et al., 2010**]** are carried out. The most complete set of ro-vibrational energy states of $HD^{18}O$ and $D_2{}^{18}O$ molecules has been determined [Ni et al., 2008b; Mikhailenko et al., 2009, 2010; Naumenko et al., 2010; Liu **et al., 2009**]. Results of these studies (jointly with scientists of France, England, Belgium and USA) filled up the HITRAN database by new and refined information [Rothman et al., 2009]. In the frames of the Project IUPAC «A database of water transitions from experiment and theory» jointly with scientists of other countries, a critical expertise of all published vibrational-rotational transitions has been performed and high-accuracy ro-vibrational levels of $H_2{}^{17}O$, $H_2{}^{18}O$, $HD^{16}O$, $HD^{17}O$, $HD^{18}O$ molecules that meet the main reliability criteria are determined [Tennyson et al., 2009, 2010; Voronin et al., 2007, 2010; Shirin et al., 2008; Yurchenko et al., 2008].

For the first time in experiment, the continual absorption of water vapor in visible spectral range was registered; experimental results were compared with calculations using two last versions of semiempirical continuum model CKD. The method has been developed for the calculation of water vapor line shape parameters using exact wave functions, this method gives the possibility to calculate broadening and line shift induced by transitions to highly excited states (up to near ultraviolet range). Comprehensive calculations of line shape parameters and their temperature dependence coefficients were performed [Bykov et al., 2008a, 2008b, 2008c; Hodges et al., 2008; Lavrentieva et al., 2008a, 2008b]. The data were brought in the ATMOS information system and GEISA database [Jacquinet-Husson et al., 2008]. The input of our scientists to the updating of other databases and the development of computational information systems is also significant [Perevalov et al., 2008d; Nikitin et al., 2010; Rothman et al., 2010].

High-accuracy measurements of CH_4 and C_2H_4 spectra have been carried out; the influence of peculiarities of the ethylene absorption specter on readings of the laser methane sensor is analyzed [Nikiforova et al., 2008; Kapitanov et al., 2007a, 2007b; Kapitanov and Ponomarev, 2008]. Scientists of IAO SB RAS, Tomsk State University (TSU) and Burgundy University (France) first analyzed ethylene absorption spectra in the 4300–6300 cm^{-1} range (which is practically used for monitoring the methane concentration in atmosphere from satellite measurements) on the basis of high-accuracy measurements by an opto-acoustic laser and Fourier spectrometers. New data on the ethylene absorption specter, absent in the last

HITRAN version, were received [Gonzalez et al., 2010; Ulenikov et al., 2010; Kapitanov et al., 2010].

3. Radiative climatology and aerosol

The research work on this topic has been carried out in several directions: the monitoring of components of radiation budget (RB) and atmospheric constituents effecting the radiation; the study of RB climatic trends near a surface; the analysis of radiative effects caused by atmospheric gases, aerosol and clouds.

Long-term actinometrical observations at Meteorological Observatory of the Lomonosov Moscow State University (MSU) from 1955 gave a possibility to analyze the multiyear regime of radiation budget components, total radiation in wide spectral diapasons (UV, photosynthetically active) and natural irradiance of the Earth surface under conditions of cloudless, broken convective clouds and all-over cloudiness of different levels. Multiyear variability of atmospheric optical characteristics (atmospheric transparency and optical depth at 550 nm) and its trends was estimated. The influence of a megacity, smoke fog and volcanic eruption on the solar incoming radiation and atmospheric transparency characteristics was considered. A number of indirect methods were proposed for calculating the photosynthetically active radiation and natural irradiance [Abakumova et al., 2008]. G.M. Abakumova and E.V. Gorbarenko [2008] have classified and generalized these unique 50-year (1955–2004) data on the aerosol optical depth (AOD), atmospheric transparency and water vapor content. Essential decrease of aerosol turbidity was noted in Moscow against the end of XX century. The estimate of linear trends of temporal series for stations with different anthropogenic loads in Russia verified the global nature of the decrease. The tendency to increasing the atmospheric transparency in Baltic region, Central Europe and Moscow was revealed [Ohvril et al., 2009]. From analyzing the AOD multiyear variability for different geographical regions, it has been shown that there is no a direct significant relation to the cycles of the solar activity in many-year AOT variations [Sakerin et al., 2008a].

The influence of different atmospheric parameters on the UV erythema irradiance were analyzed using long-term measurements for the 1999–2006 period as well as the UV variability data according to a reconstruction model since 1968 [Chubarova, 2008; Bais et al., 2007]. It has been shown that since 1980, the UV erythema irradiance enlarges due to the total ozone (+2.5% per decade), clouds (+2.1% per decade) and the aerosol (+1.1% per decade). The influence of wildland fires (2002) on atmospheric meteorological, radiation and optical characteristics near Moscow was studied [Chubarova et al., 2009]. Seasonal distribution of aerosol properties over Europe and their impact on UV irradiance were estimated from data of satellite MODIS device and ground-based AERONET network [Chubarova, 2009]. Radiation impact of aerosol pollution in Moscow was analyzed using data of three-year observations at AERONET network [Chubarova et al., 2010].

At IAO SB RAS long-term tendencies in changes of RB components [Sklyadneva and Belan, 2007; Belan et al., 2008], the cloudiness [Sklyadneva and Zhuravleva, 2008] and optical and aerosol characteristics of the atmosphere [Panchenko et al., 2007a; Sakerin and Kabanov, 2007a, 2007b; Zuev et al., 2008a; Sakerin et al, 2009a] have been analyzed for Tomsk and some other regions of Russian Asiatic part. Using data of the integrated aerosol experiment in the continent-ocean transition zone (Primorye and the Sea of Japan), it has been shown that the springtime atmosphere in the Far East region exhibits by two times larger the aerosol turbidity in comparison with other (maritime and continental) mid-latitude regions. High AOD values are observed in the spectral range of 0.3–2.14 μm due to continental aerosols of different types (smoke, anthropogenic, and dust) blown from the neighboring regions [Sakerin et al., 2010a; Afonin et al., 2010].

The current status of the Maritime Aerosol Network (MAN), which has been developed as a component of the Aerosol Robotic Network (AERONET) and collected data over the oceans since November 2006, is discussed; results of AOD measurements over the oceans, comparisons with satellite AOD retrievals and model simulations are presented [Smirnov et al., 2009, 2011].

Quantitative estimates of errors resulting in calculations of integral solar fluxes and spectral brightness temperatures of outgoing IR radiation from the neglected peculiarities of light scattering by coarse particles were obtained at the RRC «Kurchatov Institute» on the basis of mathematical modeling. These estimates were performed in the context of the aerosol retrieval algorithm used at AERONET network under conditions of different atmospheric dust turbidity [Rublev et al., 2011].

During 2007–2008 in the Moscow region, scientists of the Obukhov Institute of Atmospheric Physics (IFA RAS) performed a cycle of comprehensive observations of a number of atmospheric gaseous and aerosol constituents; relations between their variations and atmospheric conditions were analyzed [Isakov et al., 2009; Isakov and Tikhonov, 2010]. Statistical analysis of mass concentration variations of the coarse aerosol in Moscow was performed [Gorchakov et al., 2009]. Synchronous measurements by optical methods of soot and submicron aerosol concentrations in regions with different anthropogenic loadings were conducted. The quantity characterizing the relative content of the soot mass in the submicron aerosol mass makes it possible to identify the role of local and regional sources and to trace heterogeneous processes of aerosol transformation [Emilenko and Kopeikin, 2009].

Radiation regime, multiyear variability of total solar radiation and atmospheric transparence characteristics in polar regions have been studied using different measurement means and analyzed (Arctic and Antarctic Research Institute (AARI), IAO SB RAS) [Radionov et al., 2007a, 2009]. Statistical analysis of data of AOD measurements by different devices and scientific teams during 30 years in polar regions made it possible to estimate the AOD trend in Arctic as between – 1.6 % and – 2.0 % per year, depending on location. No significant trend was observed for Antarctica [Tomasi et al., 2007]. Results of measurements of aerosol characteristics on board the research vessel “Akademik Fedorov” during 52d and 53d Russian Antarctic Expeditions are given in papers [Sakerin et al., 2007, 2008b].

A number of investigations are devoted to studying the aerosol radiative effects including those during fires and volcanic eruptions. Investigations of the aerosol radiative forcing and its sensitivity to the change of input parameters in Siberian region have been started at the IAO SB RAS using original algorithms and data of satellite and long-term ground-based measurements [Zhuravleva et al., 2009b, 2010; Zhuravleva and Sakerin, 2009]. Comparison of aerosol radiation characteristics under wildfire and normal conditions was performed on the basis of experimental and theoretical studies. It has been shown that under fire-smoke condition the AOD (0.5 μm) increases by about 2.7 times; the aerosol radiative forcing at the bottom of the atmosphere increases from – 22 (under background conditions) to – 50 W/m^2 in the smoke situations [Sakerin et al., 2010b]. For the first time, it has been experimentally revealed that the increase of the volcanic sulphate aerosol in the lower stratosphere leads to the additional area of the ozone depression in the middle stratosphere at altitudes above 20 km due to the breakdown of photo-chemical balance, and the NO_2 behavior is the indicator of this effect [Zuev et al., 2008b].

At the Voeikov Main Geophysical Observatory (MGO), some results of estimating the radiative forcing in the global scale and its connection with other climate warming indexes are presented [Karol Karol et al., 2009]. Radiative effects of stratospheric aerosol screens (with different dimensions and aerosol sizes) which are projected against the global climate warming are estimated [Frolkis and Karol, 2010; Meleshko et al., 2010].

At the Ural State University (USU), an original model of the thermal balance of Earth surface has been developed. The model takes into account the exponential dependence the thermal radiation in hot CO_2 and H_2O vibrational bands on temperature and predicts the existence of stationary thermal regimes of our planet surface with temperatures higher than the water boiling point. The regime of the greenhouse explosion that leads to the strong overheat of the earth surface (more than 100°) if the CO_2 concentration in the atmosphere exceeds a threshold value, has been studied [Zakharov et al., 2008a, 2009; Zakharov, 2008].

In 2007–2010 scientists of the Central Aerological Observatory (CAO) and the Russian Hydrometeorological Center (RHMC) continued the work in the frames of the sub-project WMO GURME (Global Urban Research Meteorology and Environmental Project). Studies of the vertical structure of the heat island over Moscow were carried out by measuring the temperature profiles of the atmospheric boundary layer (ABL) at three points by Russian microwave temperature profilers MTP-5 [Kadygrov et al., 2007, Kadygrov, 2009; Miller et al., 2009; Gladkikh et al., 2010]. In summer 2010, such data were received under conditions of anomalously high temperatures and strong smokes. Unique data on features of the ABL thermal stratification in the depression and narrow canyon under different synoptic conditions were analyzed [Vorobieva et al., 2010]. In 2007, in the frames of complex expedition for studying the temperature-wind regime in the coastal zone (IFA RAS and CAO), new data on the ABL thermal stratification over the sea surface were received. During the total solar eclipse in Novosibirsk on August 1, 2008, scientists of the CAO, the Radiophysical Research Institute (RRI) and the IFA RAS under the guidance of Prof. G.I. Gorchakov received unique data on the influence of solar eclipse on meteorological regime of the atmosphere [Gorchakov et al., 2007, 2008; 2010].

4. Remote sensing of atmosphere and underlying surface

Passive sounding of the ozonosphere and atmospheric trace gases in visible, IR and microwave spectral ranges, the analysis of their variability, the perfecting of measurement and interpretation methods, the development of the techniques for radiation studying and remote sensing are being carried by a number of institutions (IAO SB RAS, IFA RAS, SPbSU, Lebedev Physical Institute of RAS (LPI RAS), Scientific and Production Association "Typhoon" (SPA "Typhoon"), MGO, CAO, Kotelnikov Institute of Radio Engineering and Electronics of RAS (IRE RAS), AARI, RHMC, etc.).

Long-term monitoring and the analysis of the ozone altitude distribution in the atmosphere over Moscow have been continued using an improved version of the LPI low-noise radio spectrometer operating at frequency of 142.2 GHz. The performance of the instrument is on a level with the world standards. Features of the altitude-temporal ozone distribution demonstrating the ozone layer evolution over middle latitudes in 2007-2010 were analyzed [Solomonov et al., 2009]. Much attention has been given to ozonosphere investigations, the analysis of measurement data and the modeling of the ozone content, the studying of the ozone destroying [Zvyagintsev et al., 2010; Titova et al., 2009; Belan, 2008, 2009, 2010; Belan et al., 2010].

As a result of the long-term observations performed in region of Kola Peninsula by scientists of the IAP RAS, the relation between the character of variations of the ozone content in the stratosphere of Arctic regions and the behavior and structure of a winter polar vortex is established. Data of ground-based microwave measurements were compared with satellite EOS MLS data [Beloglazov et al., 2010]. The increase of the mesospheric ozone concentration by 40 % at the 60 km altitude was registered from microwave measurements during a total solar eclipse (29 March 2006) at the Kislovodsk high-altitude scientific station. This value is close to the value of daily ozone variations [Kulikov et al., 2008]. A new method of the joint analysis of total ozone (TO) data observed from different moving platforms – drift stations and research vessels – was developed [Rusina and Genikhovich, 2010].

Continuous ground-based spectroscopic measurements of CH_4 and CO total content (TC) are in progress at SPbSU. The analysis of CH_4 temporal variability and its long-term trends near St. Petersburg has been shown that in recent years CH_4 trends change essentially – the positive trend decreases, and it turns out to be negative for a number of months [Makarova et al., 2009]. In after years, it seems the information not only on global CH_4 trends but on spatial-temporal trend variations will be need for the reliable climate forecasting. Factors, determining the anomalous variability of the CO TC near St. Petersburg, were studied [Makarova et al., 2007].

At Petergof beginning with 2009, measurements of solar IR radiation spectra by the Fourier-spectrometer Bruker with a high spectral resolution and complex retrievals of total content of many climatically active gases are carried out [Poberovskii, 2010; Poberovskii et al., 2010a; Poberovskii et al., 2010b]. Possibilities for using ground-based measurements of direct solar IR radiation with a high spectral resolution for the retrieval of parameters of vertical profiles of the ozone total column amount were studied [Virolainen and Timofeyev, 2008]. The ground-based synergetic method for the retrieval of ozone vertical profiles from simultaneous measurements of direct solar IR radiation with a high spectral resolution and microwave downward thermal radiation has been developed. The method gives a possibility to determine the ozone vertical profile at the 0–70 km altitudes [Virolainen and Timofeyev, 2010]. Comparisons of ground-based total ozone measurements by different instruments (Bruker, Dobson, M-124) with satellite OMI data have shown that the Fourier-spectrometer Bruker can measure the total ozone with the random error of ~ 3 DU [Virolainen et al., 2011].

Data of long-term ground-based measurements of NO_2 (2004–2010) and CO (1995–2009) total column amounts by the automated spectral complex for spectroscopic measurements of scattered solar radiation near St. Petersburg were analyzed. It has been shown that data of ground-based twilight measurements of the total NO_2 well agree with satellite measurements (SCIAMACHY) – the mean deviation is $0.07 \cdot 10^{15}$ мол/см^2, the relative error is ~ 12 %. The impact of wood-fires on the total CO temporal variability in the atmosphere was studied. The analysis of the CO annual behavior and long-term trend showed the absence of significant long-term variations for the vicinity of St. Petersburg [Poberovskii et al., 2007; Makarova et al., 2011a].

The analysis of spatial-temporal variability of CO, NO_2 and O_3 concentrations and total content fields in troposphere for Russian north-west on the basis of experimental and modeled (CMAS) data gave a possibility to estimate the impact of the emission from St. Petersburg. It has been shown that under some synoptic conditions, the influence of St. Petersburg can be detected at distances more than 300 km and can degrade the quality of atmospheric air in adjacent states [Makarova et al., 2011b].

Long-term airborne monitoring of greenhouse gases over South Siberian, led by scientists of IAO SB RAS, revealed the growth of CO_2 and N_2O concentrations in the atmosphere (the layer of 0–7 km) with the rate of 1.9 mln^{-1}/year and 0.73 $mlrd^{-1}$/year, respectively. Periodical variations without the single-valued trend were found in multiyear behavior of the CH_4 concentration [Arshinov et al., 2009a, 2009b]. For the first time, comprehensive physics-chemical and biological investigations of gas exchange between the atmosphere and water surface of Lake Baikal in the period of open water have been performed jointly with Limnology Institute of RAS. It has been shown that in spring (May-June), the CO_2 flux is directed to the atmosphere and the CO_2 sink to the water surface is observed during August-September [Panchenko et al., 2007b; Sakirko et al., 2008, 2009; Domysheva et al., 2010a, 2010b].

Continuous measurements of atmospheric trace gases are being continued at Antarctic stations. Results of measurements by solar absorption spectroscopy of total CO and CH_4 at the Molodezhnaya Station (1977–1978), the Mirny Observatory (1982–1992) and the Novolazarevskaya Station (2003–2006) are described [Kashin et al., 2007a]. Features of the total ozone content in northern and southern polar areas are discussed in the paper [Radionov et al., 2007b].

Scientists of the SPA "Typhoon" are being continued regular measurements of atmospheric trace gases at Obninsk and Issyk-Kul and the Novolazarevskaya (jointly with AARI, MGO, IAP RAS) Stations. Data of the multiyear monitoring gave a possibility to determine the most significant characteristics of the variability of main radiative-active gases: trends, seasonal and other variations with different periods [Kashin et al., 2007b, 2008, 2010; Aref'ev et al., 2008, 2009].

In the Russian Research Center "Kurchatov Institute" (RRC «Kurchatov Institute»), the algorithm for retrieving the total NO_2 from AERONET data was perfected. Comparison of retrieved NO_2 estimates with collocated measurements by ORIEL spectrometer, performed by the IFA RAS, and SCIAMACHY data over AERONET stations in different earth regions has demonstrated the possibility to apply the algorithm for the validation of satellite measurements. To estimate the aerosol and NO_2 radiation forcing under cloudless conditions, the on-line code CSIF 2009 (Calculator of Solar Integral Fluxes) (http://litms.molnet.ru/csif1/index.php) was developed, and calculations for NO_2 were performed using data of 20 AERONET stations for 2003–2006 [Rublev et al., 2008].

At the USU the recent experimental complex – the Ural Atmospheric Fourier Station (UAFS) – began to operate. The Station lies in a background forest region at 80 km to the north-west of Ekaterinburg (h = 300 м; 57.038°N; 59.545°E). The UAFS is equipped by automated Fourier spectrometer BRUKER IFS 125M linked with the solar tracer A547N and destined for measuring the solar radiation spectra in the 450–25000 cm^{-1} spectral range with the maximal spectral resolution of 0.0035 cm^{-1} in order to monitor greenhouse and contaminative gases and validate satellite data. Measurements at the UAFS were started from July 2009 mainly in the 4000–12000 cm^{-1} spectral range with the 0.02 cm^{-1} resolution during cloudless days according to requirements of TCCON (Total Carbon Observing Network), https://tccon-wiki.caltech.edu/Sites [Zakharov et al., 2008b]. The method for retrieving the HDO/H_2O in atmosphere from IR spectra with a high resolution is developed and approved [Toptygin et al., 2007; Gribanov et al., 2011].

A number of papers of the Shirshov Institute of Optics RAS, SPb branch (IO RAS) are dedicated to the problem of the remote passive and active (lidar) sounding of ocean and its surface [Levin and Kopelevich, 2007; Levin, 2008;

Levin et al., 2009a; Dolina et al., 2010], including the underwater imaging problem for the case of airborne observation through wavy sea surface [Savchenko et al., 2008; Levin et al., 2008; Levin et al., 2009b] and the problem of detecting the oil pollutions on sea and ice surfaces and in the water body [Aleshin et al., 2008].

Techniques for radiation studying and remote sensing are developed and made by a number of institutions. The portable solar photometer SPM for measuring the AOD and atmospheric moisture content was developed at the IAO SB RAS. The instrument precedes the analog Microtops II (USA) in spectral diapason (0.31–2.14 μm) and channel number. A new version of solar photometer SP-9 for the all-year automated monitoring of the spectral AOD and atmospheric moisture content was made [Sakerin et al., 2009b, 2010c]; an informative system for network solar photometers is developed [Kabanov et al., 2009]. A lidar for measurements of ozone distribution in the upper troposphere-lower stratosphere for studying the ozone dynamics in the tropopause region and, in particular the processes of stratospheric-tropospheric exchange, was developed; the ozone monitoring at altitudes of 5–18 km was performed [Zuev et al., 2008c]. At the MGO the testing of samples of UV ozone spectrometer destined for the re-equipment of Russian ozonometric stations is being continued [Solomatnikova, 2009]. A device for direct measurements of radiative heat influxes in atmosphere on the basis of an optics-acoustics receiver was developed and first measurements were performed [Eliseev and Privalov, 2007; Eliseev et al., 2009]. The development and the making of new generation spectrometers for ground-based remote sensing the ozone, chlorine and other trace gases at mm-waves are carried out at LPI RAS [Ignat’ev et al., 2007]. A mobile microwave spectrometer of a new generation for studying the earth ozonosphere was developed at the IAP RAS. The automated instrument receives the thermal radiation of stratospheric ozone at 110836 MHz in the 240 MHz band with the 1 MHz spectral resolution in the O_3 line center. The ozonometer gives a possibility to receive the ozone distribution at altitudes from 20 to 60 km during 15–20 min. [Krasil’nikov et al., 2011].

5. Interpretation of satellite measurements

Investigations dedicated to the perfecting of methods for interpreting the satellite measurements, retrieving atmospheric characteristics from satellite measurements and validating satellite data are the main part of studies in this line.

At SPbSU (jointly with SRC "Planeta") on the basis of numerical experiments, potential accuracies of the satellite sounding of different atmospheric and surface parameters (vertical temperature and humidity profiles, the content of the ozone and a number of greenhouse gases, the surface temperature, the land emissivity, the cloud liquid water content and the near-water wind speed) by new Russian instruments operating in IR and microwave spectral ranges (satellite «Meteor», devices IKFS-2 and MTVZA) were studied [Polyakov et al., 2009, 2010a, 2010b; Virolainen et al., 2010]. New method for retrieving the TOC from measurements by SEVIRI on board geostationary satellites has been improved, that makes it possible to determine additionally the wind speed in stratosphere [Polyakov and Timofeyev, 2007, 2008]. Methodical basis of the satellite limb method for determining the optical and microphysical characteristics of the stratospheric aerosol from measurements of the solar scattered radiation in IR and near-visible spectral ranges has been developed. Potential accuracies and informativeness of this method were estimated [Semakin et al., 2008, 2009; 2010a, 2010b]. Possibilities to take into account the horizontal inhomogeneity and non-stationarity of the atmosphere when sounding its composition by different occultation methods was studied [Rakitin et al., 2008]. Statistical relations between aerosol microphysical and optical characteristics in the near-IR spectral range required for interpreting satellite measurements of CO_2 were studied [Virolainen, 2008].

Variations of total O_3 and NO_2, ozone trends at different altitudes over Russia, optical and microphysical characteristics of the stratospheric aerosol and polar stratospheric clouds were studied using SAGE III data (Russian-USA experiment on board «Meteor» satellite) [Kostsov et al., 2008; Chaika et al., 2007, 2008;

Polyakov et al., 2008a, 2008b; Ionov, 2009]. Regional space monitoring of the tropospheric NO_2 has been performed [Ionov and Timofeev, 2009].

Scientists of the SPbSU took participation in some programs of international comparisons for validating the satellite data. Comparison of different satellite measurements of vertical ozone profiles with ground-based microwave measurements [Hocke et al., 2007] was performed. Quality of total NO_2 measurements by OMI satellite instrument was estimated by the comparison with ground-based spectroscopic measurements using the DOAS technique [Ionov et al., 2008; Celarier et al., 2008]. The importance to taking into account of daily variations of stratospheric NO_2 total column amount in the validation of satellite measurements was demonstrated [Wetzel et al., 2007]. Possibilities for perfecting the standard interpretation algorithm of DOAS-measurements of the total ozone used at the international network NDACC were studied [Hendrick et al., 2010].

A number of investigations led by the IFA RAS are dedicated to the analysis and the interpretation of satellite observations of trace gases at different spatial scales (from global to regional). MOPITT data were used to study global and regional effects of the equatorial quasi-beinnial oscillation manifesting in CO [Sitnov, 2008]. On the basis of OMI observations the tropospheric NO_2 content over Moscow region was studied. Peculiarities of spatial distribution of NO_2 in the troposphere over Moscow urban agglomeration as well as characteristics of its seasonal and weekly cycles and also the interannual and long-term NO_2 changes were presented. The results of a comparative analysis of seasonal and weekly cycles of tropospheric NO_2 content over Moscow and other world's largest agglomerations were also presented [Sitnov, 2009, 2011a]. Using satellite retrievals of CO, NO_2, CH_2O, O_3, water vapor and optical characteristics of aerosols, the spatial temporal evolution of combustion products as well as the interrelationship between changes of various atmospheric parameters in the course of development of regional weather anomaly and massive wild fires and smoke of the European part of Russia in summer 2010 were analyzed [Sitnov, 2011b].

At the RRC «Kurchatov Institute», methods for estimating the CO_2 concentration and fluxes in atmosphere from satellite data are being developed [Rublev et al., 2010].

Development and the perfecting of methods for automated classifications of data of scanning radiometer-imagers on board polar-orbital and geostationary meteo-satellites NOAA, "Meteor-M", Meteosat, "Rlectro-L" (instruments AVHRR, SEVIRI, MSU-MR, MSU-GS) are being continued at the Scientific Research Center for Space Hydrometeorology “Planeta” (SRC “Planeta”) for retrieving the cloudiness and precipitation parameters. Systems of processing the AVHRR/NOAA, SEVIRI/Meteosat-9 data for the estimation of parameters of the cloudiness and the regional precipitation (for Europe and ETR) have been developed, approved and put into operation. The validation of satellite estimates of the cloud cover was performed [Volkova and Uspensky, 2007, 2008, 2009].

A new method for retrieving the land surface temperature and emissivity using data of SEVIRI measurements on board the Meteosat-9 satellite was developed. Radiative temperatures measured by SEVIRI under cloudless conditions in channels 9 (10.8 μm) and 10 (12.0 μm) during three sequential dates are used for determining the land surface temperature and emissivity applying the combination of «split window» and «two temperatures» methods. The method was tested using real SEVIRI measurements. Comparison of satellite estimates with independent estimates of land surface temperature given by the LSA SAF (Land Surface Analysis Satellite Applications Facility) was performed. The RMS deviations are 0.9–2.6 K that proves the method efficiency. Additional validation was carried out by comparing the satellite estimates of the land surface temperature with in-situ observations in night-time in summer 2009 (48 Stations in Russian Central regions) [Solovyev and Uspensky, 2009; Solovyev et al., 2010].

Development and refinement of methods for using the remote sounding data on surface characteristics in the modeling of components of water and heat budgets for river headwaters are being continued at the SRC “Planeta”. Methods and algorithms for processing the information from AVHRR/NOAA, MODIS/Terra and Aqua radiometers to estimate the land temperature and emissivity, air near-surface temperature, normalized vegetation index, the leaf index, and projective vegetation cover were developed and perfected. In addition, a version of the model of vertical heat and moisture transfer in the system «soil-vegetation-atmosphere» (SVAT) using satellite data on underlying surface and a number of meteorological characteristics was developed. Using SVAT, calculations of total evaporation, heat fluxes, moisture and heat contents and other components of heat and water budgets were performed for vegetation periods of 2003–2009 [Muzylev et al., 2008, 2009, 2010].

The cycle of investigations for estimating possibilities of remote sensing by IR sounders with a high spectral resolution was conducted. Prospects of the remote temperature-humidity sounding of atmosphere was estimated [Uspensky, 2010]. A number of papers are dedicated to the remote determination of the tropospheric mean concentration of CO_2 (X_{CO2}) and the CH_4 total column amount (Q_{CH4}) from data of satellite sounders AIRS (EOS/AQUA), IASI (MetOp) with a high spectral resolution. Improved method for retrieving the X_{CO2} from AIRS data (cloudless or cloud-corrected) was developed and approved by the comparison with airborne measurements. Similar methodology was used for retrieving the «instantaneous» X_{CO2} values from IASI data. Comparison of satellite estimates with quasi-simultaneous airborne observations during YAK-AEROSIB experiment gave the error estimate of about 2.2 mln^{-1}. To retrieve Q_{CH4} from IASI data, the iterative algorithm using measurements in 4 CH_4-sensitive channels was developed. Data on the temperature profile and other components of the state vector at sounding points were received from the same IASI data. Validation of satellite Q_{CH4} estimates was performed by comparing with collocated estimates from AIRS data. Standard deviation of these estimates (averaged by 2x2°) is not more than 3 % [Kukharsky and Uspensky, 2009, 2010].

Comprehensive studies for developing the methods using satellite data for the monitoring of underlying surfaces are being continued by scientists of the Nansen Environmental and Remote Sensing Center (Nansen Center) [Melentyev and Chernook, 2009]. Joint processing of passive microwave and scatterometer data has been performed that gives a possibility to determine multi-year ice changes in Arctic. Sea ice types identification in the Arctic Ocean was performed using the SAR (Synthetic Aperture Radar) data [Alekseev et al., 2009]. Atmosphere-ocean interactions is studied: a new innovative approach for the synergetic analysis of SAR and optical images is developed; studies of the near-shore upwelling are performed using satellite SAR signatures [Kudryavtsev and Makin, 2009]; polar vorteces are studied using data of satellite microwave sounding [Mitnik et al., 2009]. Aquatic ecosystems and their response to global change are analyzed [Korosov et al., 2009a, 2009b; Pozdnyakov et al., 2009].

At the SPA "Typhoon" the method for determining the atmospheric dynamic characteristics using data from geostationary meteorological satellites was developed. In distinction from others, the method gives a possibility to retrieve not only the field of wind velocity vector, but also the coefficient of mesoscale turbulence diffusion and the vorticity at the single scale of the air mass motion. Fields of dynamics characteristics in regions of dangerous atmospheric phenomena – jet flow zones and tropical cyclones – were studied using measurements by SEVIRI on board geostationary satellites Meteosat-8 and Meteosat-9 [Nerushev et al., 2007].

At the USU the neural network was used to develop the method for retrieving the methane content in the atmosphere from spectra of AIRS sensor installed aboard AQUA satellite. Seasonal mean methane variations in the atmosphere over wetland of Western Siberia were revealed from AIRS data [Gribanov et al., 2007a]. The model to evaluate the casing-head gas outcome in flares using data of satellite sensing in IR channels by sensors like MODIS was proposed [Gribanov et al., 2007b]. The feasibility of the neural network for the retrieval of CO_2 vertical profiles from spectral data of the TANSO-FTS sensor onboard the GOSAT satellite was demonstrated [Gribanov et al., 2010].

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Abbreviations

AARI – Arctic and Antarctic Research Institute, St. Petersburg;

CAO – Central Aerological Observatory, Moscow.

IAM RAS – Keldysh Institute of Applied Mathematics RAS, Moscow;

IAO SB RAS – Institute of Atmospheric Optics of Siberian Branch of RAS, Tomsk;

IAP RAS – Institute of Applied Physics RAS, N. Novgorod;

IFA RAS – Obukhov Institute of Atmospheric Physics of Russian Academy of Science, Moscow;

IO RAS – Shirshov Institute of Optics RAS (SPb branch), St. Petersburg;

IRE RAS – Kotelnikov Institute of Radio Engineering and Electronics of RAS, Fryazino, Moscow Region;

LPI RAS – Lebedev Physical Institute of Russian Academy of Science, Moscow;

MGO – Voeikov Main Geophysical Observatory, St. Petersburg;

MPEI – Moscow Power-Engineering Institute;

MSU – Lomonosov Moscow State University;

Nansen Center – Nansen Environmental and Remote Sensing Center, St. Petersburg;

RHMC – Russian Hydrometeorological Center of Russia, Moscow;

RRC “Kurchatov Institute” – Russian Research Center “Kurchatov Institute”, Moscow;

RRI – Radiophysical Research Institute, N.-Novgorod;

SPA "Typhoon"– Scientific and Production Association "Typhoon", Obninsk, Moscow Region;

SPbSU – Saint-Petersburg State University;

SRC “Planeta” – Scientific Research Center for Space Hydrometeorology “Planeta”, Moscow;

USU – Uralian State University, Ekaterinburg