The Russian Federation National Report on Studies of the Earth Ozone Layer

1. Observations

Routine observations of atmospheric ozone comprise observations of total ozone (TO), its vertical distribution, and surface ozone concentrations.

Routine observations of nitrogen dioxide comprise observations of its content in the vertical atmospheric column.

1.1. Observations of total ozone and other gases / constituents responsible for ozone loss.

In the Russian Federation, responsibility for regular total ozone measurements and interaction with the corresponding WMO bodies lies with the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). Daily TO measurements are being performed on the network of 28 ozone measuring stations (with TO observations resumed on Heiss Island in 2008), located in the Russian Federation, Ukraine and Kazakhstan and equipped with M-124 filter ozonometers. Technical and methodological support of the network is provided by A.I. Voeykov Main Geophysical Observatory (MGO). Observational data are transmitted on-line to the Central Aerological Observatory (CAO) and MGO. CAO performs primary data quality control, archives the data and transmits it on-line to the World Ozone and UV Data Centre (WOUDC) under the Environment Service of Canada. Apart from that, CAO provides operational mapping of TO distribution over the territories of Russia and adjacent countries, revealing anomalies and analyzing the reasons for their occurrence. At MGO, the data undergo more thorough quality control, which enables defining the quality of performance of separate instruments, consecutive data correction, and transmission of final data to WOUDC.

MGO has completed upgrading of M-124 ozonometers that had been in operation on the network for over 25 years, which permitted further TO observations at Roshydromet stations. In the course of modernization, the techniques and programs of processing clear and cloudy sky zenith measurements have been improved, which made zenith TO measurements as accurate as direct solar light ones. The ability to measure in any cloudy conditions (except on precipitation days) in the range of a 5° to 70° sun elevation considerably enlarged the amount of information from the stations and enhanced observations at high-latitude stations.

In 2008-2010, four of the stations tested experimental models of UV ozone spectrometer (UVOS) developed for upgrading the equipment of Roshydromet ozone network. This instrument enables measuring TO, registering total UV and zenith radiation in a 290-400 nm range with resolution less than 1 nm and exposure less than 2 s. The network stations are expected to be reequipped with spectral instruments before 2015.

Besides, TO measurements are made at reference sites by institutions of Roshydromet and the Russian Academy of Sciences (RAS) using M-124 ozonometers, Dobson and Brewer spectrophotometers, and SAOZ instrument. Brewer spectrophotometer measurements of TO are performed in Kislovodsk (Obukhov Institute of Atmospheric Physics, RAS), Tomsk (Zuev Institute of Atmospheric Optics, RAS), Obninsk (SI RPA ‘Typhoon’), and Yakutsk (CAO). Total ozone and NO_2 are measured with

SAOZ instrument at two high-latitude stations, Salekhard (67°N, 67°E) and Zhigansk (66°N, 123°E) (CAO).

Regular measurements of NO_2 content in the vertical atmospheric column have been conducted at Zvenigorod research station of A.M. Obukhov Institute of Atmospheric Physics (IAP), RAS, since 1990. The measurements are made with a spectrophotometer based on a domestic monochromator MDR-23, by an original technique. NO_2 vertical profile is reconstructed from twilight morning and evening measurements, and then, NO_2 content in the vertical atmospheric column and, separately, in the boundary layer is determined. The station is included in the International Network for the Detection of Atmospheric Composition Change (NDACC), its NO_2 measurement data being readily available at the NDACC server, at the address: http://www.ndacc.org/.

1.2. Measurements of the vertical distribution of ozone and other gases / constituents responsible for ozone loss.

Measurements of ozone profiles using ozone sondes in winter and spring seasons are carried out at Salekhard station within the framework of the European International program MATCH (CAO). Ozone profiles in the height range of 20-50 km, using microwave radiometer (142.2 GHz) are measured in Moscow (P.N. Lebedev Physical Institute, RAS). In Tomsk (the Institute of Atmospheric Optics, Siberian Branch of RAS), regular lidar measurements of ozone, NO_2 and aerosol profiles at heights up to 70 km are conducted. Besides, monthly measurements of vertical ozone distribution in the troposphere (0-7 km), using chemiluminescent and UV-photometry (TEI-49) ozone gas analyzers installed on board AN-30 aircraft have been conducted there since 1997. These measurements have made it possible, in particular, to assess the influence of different cloud types on ozone concentration. Also initiated there have been experimental studies of the diurnal variation of vertical ozone distribution in the lower troposphere (up to 2-3 km) from board an aircraft.

1.3. Ground-based ozone concentration measurements

Ozone concentration measurements of many years, conducted at remote high-mountain stations in Russia, aim at detecting its long-term changes in the free troposphere. Routine measurements of ozone concentration have been carried out at Kislovodsk High-Mountain Science Station, 44° N, 43° E, 2070 m a.s.l. (the RAS Institute of Atmospheric Physics), since1989, Terskol station, 43° N, 43° E, 3100 m a.s.l. (the Ukraine Main Astronomical Observatory and CAO), since 2002, Mondy station, 51° N, 101° E, 1304 m a.s.l. (the RAS Limnology Institute), using UV gas-analyzers. The UV gas-analyzers are regularly calibrated at D.I. Mendeleyev All-Russia Research Institute of Metrology or compared with the National Standard of Japan. Measurements of surface ozone concentration and concentrations of other minor atmospheric constituents are also fulfilled at a number of flat-country science stations (Moscow, the RAS Institute of Atmospheric Physics; Dolgoprudny, CAO; Obninsk, SI RPA ‘Typhoon’; Tomsk, the Institute of Atmospheric Optics, Siberian Branch of RAS, etc.). In order to study the space and time variability of surface ozone and other minor gaseous atmospheric species, the experiment TROICA (Transcontinental Observations into the Chemistry of the Atmosphere) is being continued, wherein concentrations of the gases are measured annually along the railways, generally, along ‘Moscow-Khabarovsk’ railway. Specialists from Germany, USA, Finland, and Austria are involved in the experiment.

1.4. UV-irradiation measurements

1.4.1. Wide-band measurements

Pilot measurements of UVB-radiation have been carried out at 14 ozone measuring station of Roshydromet since 2006. The UV radiation (UVR) measurements follow the technique developed by MGO and use M-124 ozonometers with correction attachments (Larche sphere). Observational results will be available after calibration of the ozonometers with attachments against an UVR reference sample.

1.4.2. Narrow-band filter measurements

Long-term regular measurements of UV-irradiation in an UV-B spectral range, using an UVB-1YES pyranometer, have been conducted at Lomonosov Moscow State University (MSU) since 1999 and in a 300-380 nm range since 1968.

1.4.3. Spectral measurements

UV-B radiation monitoring using Brewer instruments have been carried out in Kislovodsk since 1989, in Obninsk since 1991, and in Tomsk since 2006.

Besides, at 4 stations of Roshydromet, pilot measurements of the spectral composition of total (global) UV radiation within a 290-400 nm range have been conducted since 2008.

1.5. Calibration procedure

1.5.1 Calibration of ozonometers M-124

MGO fulfils calibration of ozonometers M-124. TO reference is provided by Dobson spectrophotometer No.108, which, in turn, once in 4 years undergoes intercalibration procedure at the WMO European Calibration Center. For the period 1988-2009, Dobson No.108 TO departure from WMO reference values was not more than 1%.

1.5.2 Regular quality control of TO measurements

TO measurement scale stability is maintained through regular calibration of ozonometers M-124 at MGO and monthly ozonometer intercomparisons at the stations. Each station has got 3 instruments – operational, back-up, and reserve. After repair (upgrading) and calibration at MGO, reserve ozonometer is set up at the station and becomes operational. The cycle covers 2 years.

MGO provides continuous control of measurement quality and performance rate of ozonometers

to reveal measurement scale changes and, if required, correct measurement results. Ozonometers showing considerable changes in measurement scale are replaced ahead of the schedule time and undergo calibration.

1.5.3 UV calibration

In 2010, an operational, Category 1 reference sample of irradiation spectral density in a 250-800 nm range, based on a quartz-halogen bulb, certified by the Russian Federation State Agency for Standardization, Gosstandard, was introduced to practice. Absolute scale calibration of UV radiation measurements will be performed at MGO beginning from 2011.

1.5.4 Brewer spectrophotometer calibration

All the Brewer spectrophotometers in Russia, operated in Obninsk, Kislovodsk, Yakutsk, and Tomsk, were last calibrated in 2008.

2. Measurement data analysis results

A number of studies conducted are devoted to analyzing long-term ozone layer changes and revealing quantitative relations between TO variability and various geo- and heliophysical factors. It is shown that in mid and high latitudes of the northern hemisphere and, in particular, over the territory of the Russian Federation, following TO However, with the observed rate of recovery, TO level characteristic of the 1970’s would only be reached in several decades (Zvyagintsev and Ananiev, 2010; Titova and Karol’, 2010). Analysis of the global TO time series for 1964–2006, constructed from the data of the world ground-based ozone measuring network, shows that its drastic decrease in the period between the mid 1070’s and mid 1990’s cannot be only assigned to anthropogenic influence (Bekoriukov et al., 2009). Using the methods of natural orthogonal functions (Kramarova, 2008), regression analysis (Zvyagintsev and Ananiev, 2010), spectral and discrimination analysis (Titova et al., 2009; Titova and Karol’, 2010), quantitative effects of the polar stratospheric temperatures, the arctic oscillation, quasi-biennial oscillation, and El-Nino – southern oscillation on TO changes in different regions of the world have been estimated.

Analysis of stratospheric ozone concentration measurements from satellite-borne instrument SAGE II, obtained during 1984-2005, has yielded estimates of the linear ozone trend for three 10-km layers (15–45 km) over the south of the European territory of Russia. It is shown that the rate of ozone concentration decrease is maximal in the upper stratosphere (a 35–45 km layer), amounting to about 3 % per decade (Ionov, 2009).

Lidar sounding data on ozone, aerosol, and temperature in the stratosphere over Tomsk have promoted clarifying the influence of the world centers of action on the vertical distribution of these parameters through constructing regression models (Kruchenitsky and Marichev, 2008).

From the results of long-term measurements of total NO_2, quantitative estimates of the diurnal and annual variations in NO_2 content, of the role of Pinatubo eruption in NO_2 decrease, NO_2 changes during an 11-year cycle of solar activity, and linear trends of NO_2 content, depending on latitude, were obtained (Gruzdev, 2009). Analysis of the long-term TO data from the World Ozonometer Network and computations using 2D model SOCRATES demonstrated that changes in short-wavelength solar radiation during an 11-year solar activity cycle affects the intensity of the meridional transport of stratospheric ozone during autumn and winter seasons (Gruzdev, 2008).

The influence of an 11-year cycle of solar activity on quasi-biennial variations of ozone and temperature observed in the Canadian Arctic sector is discussed in (Sitnov, 2009). The variability of phase correlation between long-term TO variations at Arosa station and the number of sun-spots during the period 1932-2009 was investigated (Visheratin et al., 2008; Visheratin, 2011). The correlation between inter-diurnal TO variations from TOMS data and the most intense solar flares during the period 1979-2005, with spatial resolution of about 100 km, was explored (Visheratin and Shilkin, 2009). A study to explore the perturbation action of 20 tropical North Atlantic cyclones upon TO field, based on TOMS data, for all cyclone evolution phases from depression to hurricane was fulfilled (Nerushev, 2008).

The parameters of short- and long-term variability of aerosol over Siberian lidar station were determined (Zuev et al., 2008a). Quantitative effects of aerosol, including that of volcanic origin, on the ozone layer parameters were revealed (Zuev et al., 2008d, 2010). Lidar soundings of ozone detected quite a rare process of the stratosphere-troposphere transport across the tropopause (Zuev et al., 2008b).

Based on the results of a synoptic analysis of mean monthly and mean diurnal TO fields, differences were found in the directions of the zonal transport of air masses containing different ozone amounts, depending on temperatures in the polar winter stratosphere, and phase of quasi-biennial oscillations (Syrovatkina et al., 2008).

Processes of air-mass exchange through the tropopause in extra-tropical latitudes were studied by analyzing balloon sounding data on ozone and water vapor, obtained during the field campaign LAUTLOS, as well as by using a trajectory model to clarify the origin of air masses and estimate fluxes through the tropopause (Luk’yanov et al., 2009).

Measurement time series of biologically active, erythema-weighted UV irradiation in Moscow for the period 1999-2006 were analyzed and its time variation was retrieved for the period 1968-2006 (Chubarova, 2008). The reconstructed model was used to show a marked growth of the rate of erythema-weighted UV irradiation in 1980-2006 due to changes in TO, effective cloud transparency, and aerosol loading. However, no statistically reliable changes in erythema-weighted UV irradiation were observed during a longer period, from 1968 to 2006, which is primarily due to considerable reduction of effective cloud transparency during that period.

A review comprising the most recent information about the chemical composition of the stratosphere and mesosphere has been compiled. The information had been obtained in different seasons and in both hemispheres, using instruments such as MIPAS (IR limb sounder), SCIAMACHY (UV-visible and near- IR nadir and limb viewer) and GOMOS (Global Ozone Mapping Spectrometer) aboard ENVISAT launched in 2002, as well as high-resolution instruments to measure important gaseous species in the stratosphere and upper troposphere on board the recently launched satellite Aura, i.e., HIRDLS – High Resolution Dynamics Limb Sounder, TES – Tropospheric Emission Spectrometer, OMI – Ozone Monitoring Instrument, and upgraded MLS - Microwave Limb Sounder (Repnev and Krivolutsky, 2010).

The results of ground-based spectrometer measurements of atmospheric column NO_2 content from IAP Zvenigirod Research station were used to validate NO_2 data from OMI (Ozone Monitoring Instrument) on board the US satellite EOS-Aura (Gruzdev and Elokhov, 2009; Gruzdev and Elokhov, 2010).

3. Theoretical, modeling, and other studies

Using a three-dimensional chemical-climatic model HAMMONIA, the influence of 27-day rotational variations of solar radiation on the chemical composition and temperature of the stratosphere, mesosphere, and lower troposphere were studied (Gruzdev et al., 2009). The model results were compared with observational data on tropical ozone and temperature response to a 27-year solar cycle.

The reasons for the enhancement in the XXI century of Brewer-Dobson meridional circulation, which in turn leads to TO increase in extra-tropical latitudes and its reduction and lower stratosphere cooling in the tropics, were revealed through the use of a tree-dimensional chemical-climatic model SOCOL (Schraner et al., 2008), developed at MGO in cooperation with the Physical and Meteorological Observatory (Davos, Switzerland) and the Higher Polytechnic School (Zurich, Switzerland). It was inferred that the enhancement Brewer-Dobson model circulation in SOCOL resulted from increased wave activity of planetary and gravitational waves in the troposphere (Zubov et al., 2011). Using a 2D model of atmospheric photochemistry, radiation, and dynamics (SOCRATES), it was shown that ozone inflow to mid latitudes is enhanced when solar activity is high compared with its minimal activity period (Груздев, 2008). According to modeling data, this mechanism accounts for up to 30% of the winter increase of ozone content in the layer of ozone maximum (at about около 22 km) in mid latitudes of the southern hemisphere at the peak of an 11-year solar activity cycle, while in mid latitudes of the northern hemisphere, its major input to the 11-year variations of ozone content in this layer is made in the second half of winter. A thermodynamic-microphysical model of the formation and evolution of polar stratospheric clouds was constructed and integrated into the chemical-climatic model of the lower and middle atmosphere. Model experiments were staged to study the evolution of gaseous and aerosol composition of the stratosphere in Antarctica and the Arctic. The results of studying differences in the changes occurring in the amount of gaseous minor species and aerosol in polar regions show that the formation of a full-scale ozone hole in Antarctica and only casual “mini-holes” in the Arctic is mainly due to de-nitrification observed in Antarctica and its absence in the Arctic (Smyshlyaev et al., 2010).

Using an analytical and a 1D numerical photochemical models, stratospheric ozone sensitivity to the linear trends of the amount of NO_2 and HCl vapor, leading to changes in ozone destruction rate in nitrogen and chlorine photochemical cycles, was estimated. (Gruzdev, 2009). It was shown that to correctly estimate ozone loss due to halocarbons, whose release to the atmosphere is governed by the Montreal Protocol provisions, long-term trends in NO_2 content have to be allowed for.

A lidar to measure ozone concentration distribution in the upper troposphere–lower stratosphere was developed (Zuev et al., 2008c; Burlakov et al., 2010).

A technique to determine TO with high space (3×3 km^2) and time (15 min.) resolution through measurements of the Earth’s outgoing thermal radiation from geo-stationary METEOSAT platforms was suggested (Polyakov and Timofeev, 2008). The technique employs measurements of SEVIRI instrument (8 IR channels) and supplementary information about a three-dimensional atmospheric temperature field and surface temperature from polar satellites (AIRS instrument). Yuri M. Timofeev and his colleagues suggested several improved algorithms to determine TO and vertical distribution of ozone, using satellite-borne UV and IR instrumentation (Virolainen and Timofeev, 2008, 2010; Polyakov et al., 2008, 2010; Polyakov and Timofeev, 2010).

For the first time ever, the mechanism of halogen activation in the lower stratosphere was completed with a new reaction cycle including a family of peroxide compounds, H_2O_2, $H_3O_2^+$, and HSO_5^-. It was shown that reactions of these substances with chloride and bromide anions present in sulphate aerosol particles (Junge layer) can, depending on the conditions, either increase or weaken the influence of halogen activation on the ozone layer in mid latitudes (Larin and Yermakov, 2010). The ozone depleting and greenhouse potentials of C_3F_7I and $C_2F_4I_2$, which could be used to extinguish fires, were estimated (Larin et al., 2010a). By using a method of resonance fluorescence, the constants of the rates of reactions of oxygen atoms with molecular chlorine and iodo-methane were measured (Larin et al., 2010b); also, the formation of atomic iodine through a heterogenic reaction of atomic chlorine with iodo-methane was studied (Larin et al., 2010). Model data on the impact of galactic cosmic rays (GSRs) on minor atmospheric species, including OH, HO_2, O_3, $O(^1D)$, $O(^3P)$, NO, NO_2, NO_3, N_2O_5, HNO_2, HNO_3, HNO_4, ClO, $ClONO_2$, HCl, HOCl, Br, BrO, and HOBr, were obtained. It is shown that relative changes in some of the constituents at a 15-20 km level in mid latitudes due to GSRs can reach or exceed 20%. Also shown is that TO decrease in mid latitudes during the 11-year cycle of solar activity, which determines changes in GSRs flux intensity, can account for one third of the atmospheric ozone loss in the late XX century due to anthropogenic release of chlorofluorocarbons (Larin, 2010).

4. Dissemination of results

4.1. Archiving, storage, and transfer of observational results to national and international data archives

The results of TO observations on the M-124 ozonometer network are transmitted to the Hydrometeorological Center of Russia, CAO, and MGO on a daily basis. CAO performs primary data quality control, archives the data and transmits it on-line to the World Ozone and UV Data Centre (WOUDC). MGO receives initial measurement data from the stations, checks its quality, and prepares it for transmission to WOUDC. The ozonometers M-124 having been in operation for over 25 years, despite the upgrading of the instruments, quite a lot of troubles with the measurement scale occur. Therefore, measurement results require thorough verification, and, occasionally, special ozonometer calibration is needed, which precludes timely transfer of verified data to WOUDC.

TO and UV radiation data obtained at Kislovodsk and Obninsk stations using Brewer spectrophotometer are also transmitted to WOUDC.

SAOZ measurement data from the Russian stations are transmitted on-line to the World Data Center in France (http://gosic.org/gcos/SAOZ-data-access.htm).

IAP Zvenigorod research station measurement data on NO_2 content in a stratospheric column and in the atmospheric boundary layer are regularly transmitted to NDACC (http://www.ndacc.org/).

4.2. Forecasting and public information

Analyses of the current ozone layer state are presented by CAO in the quarterly reviews of the journal “Meteorologia i Gidrologia” (with its English version disseminated by Springer Publishing House). Annually, the reviews include data on long-term changes of the ozone layer over Russia, which are compared with those observed in other regions of the globe. Information about the ozone layer state over Russia is also published in the annual reports on the climate of the Russian Federation and reviews of the state and pollution of the environment in the Russian Federation, presented by Roshydromet.

The technology of TO and UV index forecasting for the Russian territory has been recently developed by CAO in cooperation with the Hydrometeorological Center of Russia. TO forecasting uses current TO observations and predicted weather parameters. To determine the current state and forecast UV-B irradiation fields, observational data and forecasts of TO, cloudiness, and underlying surface albedo are employed. At the present stage, this technology is just a pilot one.

The following 3 monographs have been published:

Zuev, V.V. and V.D. Burlakov. Siberian lidar station: 20 years of stratospheric optical monitoring. - Tomsk: IAO SB RAS, 2008. 226 c.

Belan B.D. Ozone in troposphere. - Tomsk: IAO SB RAS, 2010. 525 p.

Krivolutsky A.A., Repnev A.I. Cosmic influences on the ozonosphere of the Earth. - Moscow: GEOS, 2009. 384 p.

4.3. Scientific publications

Below, some basic 2008-2010 scientific publications are listed:

Bekoryukov V.I., Glazkov V.N., and Kokin G. A.. Long-Term Variations in Global Ozone, Izvestiya, Atmospheric and Oceanic Physics, 45 (5), 566-574, 2009.

Burlakov V.D., Dolgii S.I., Makeev A.P., Nevzorov A.V., Kharchenko O.V., Romanovsky O.A., Differential absorption lidar for Ozone sounding in the upper troposphere – lower stratosphere. Pribory i Tekhnika Experimenta, 5, 121-124, 2010 (in Russian).

Chubarova N.Ye. UV variability in Moscow according to long-term UV measurements and reconstruction model, Atmos. Chem. Phys., 8, 3025–3031, 2008.

Elansky N.F. Russian Studies of the Atmospheric Ozone in 2003-2006, Izvestiya, Atmospheric and Oceanic Physics, 45 (2), 207-220, 2009 .

Gruzdev, A.N. Latitudinal dependence of the variations of stratospheric NO_2 *content. Izvestiya, Atmospheric and Oceanic Physics, 44 (3), c. 345-359, 2008 .*

Gruzdev, A.N. Stratospheric ozone sensitivity to long-term changes in the amount of nitrogen dioxide and hydrochloric acid. Reports, RAS, 427 (3), 384-387, 2009 (in Russian). .

Gruzdev A.N. and A.S. Elokhov. Validation of OMI measurements of NO_2 *content in a vertical atmospheric column on board EOS-Aura, using ground-based measurements at Zvenigorod research station. Izvestiya, Atmospheric and Oceanic Physics, 45 (4), 477-488, 2009.*

Gruzdev A.N., Latitudinal structure of variations and trends in stratospheric NO_2*. International Journal of Remote Sensing, 30 (15), 4227-4246 2009.*

Gruzdev A.N., Schmidt H., and Brasseur G.P. The effect of the solar rotational irradiance variation on the middle and upper atmosphere calculated by a three-dimensional chemistry-climate model, Atmos. Chem. Phys., 9, 595–614, 2009.

Gruzdev A.N., Elokhov A.S. Validation of Ozone Monitoring Instrument NO_2 *measurements using ground based* NO_2 *measurements at Zvenigorod, Russia. International Journal of Remote Sensing, 31 (2), 497-511, 2010.*

Ionov D.V. Vertical structure of long-tern stratospheric ozone trend from the satellite-borne measurements over southern Russia. Issledovanie Zemli iz Kosmosa, 4, 3-11, 2009 (in Russian).

Kramarova N.A., Effect of Certain Geo- and Heliophysical Factors on the Variability of Ozone and UV Irradiance Fields in the Tropics, Izvestiya, Atmospheric and Oceanic Physics, 44 (1), 107-116, 2008 .

Kruchenitskii G.M., Marichev V.N., Influence of global geophysical processes on variability of ozone, temperature, and aerosol vertical distribution over West Siberia, Atmospheric and Oceanic Optics Journal (Tomsk), 21 (4), 257-261, 2008 .

Larin I.K., Yermakov A.N., Whether the hydrogen peroxide can participate in halogenactivationin the low stratosphere? Int. J. Remote Sensing, 31 (2), 531-542, 2010.

Larin I.K., S.N. Kopylov, E.V. Nikonova. Estimation of ozone depleting and greenhouse potentials and atmospheric lifetimes of C_3F_7I and $C_2F_4I_2$. Ekologicheskaya Himia, 18 (2), 65-69, 2009a (in Russian).

Larin I.K., A.I. Spassky, E.M. Trofimova, L.E. Turkin. Measurements of constants of the rate of atomic oxygen reactions with chlorine and iodo-methane using a method of resonance fluorescence of iodine and chlorine atoms. Kinetika i Kataliz, 50 (4), 496-502, 2009b (in Russian).

Larin I.K., A.I. Spassky, E.M. Trofimova, L.E. Turkin. Atomic iodine formation in a heterogeneous reaction between chlorine and iodo-methane. Kinetika i Kataliz, 51 (3), 1–6, 2010 (in Russian).

Larin I.K. On the influence of galactic cosmic rays on atmospheric composition, greenhouse effect, and the Earth's ozone layer. Ekologicheskaya Himia, 19 (3), 133-140, 2010 (in Russian).

Luk'yanov A. N., Karpechko A. Yu., Yushkov V.A., Korshunov L.I., Khaikin S.M., Gan'shin A.V., Kyro E., Kivi R., Maturilli M., and Voemel H., Estimation of Water-Vapor and Ozone Transport in the Upper TroposphereLower Stratosphere and Fluxes through the Tropopause during the Field Campaign at the Sodankyla Station (Finland) , Izvestiya, Atmospheric and Oceanic Physics, 45 (3), 294-301, 2009.

Nerushev A.F. Perturbations of the ozone layer induced by intense atmospheric vortices, International Journal of Remote Sensing, 29 (9), 2705-2732, 2008.

Polyakov A.V. and Timofeev Yu.M. Determining Total Ozone from Geostationary Earth Satellites, Izvestiya, Atmospheric and Oceanic Physics, 44 (6), 745-752, 2008.

Polyakov A.V., Rendall K., Kharvei L., Khoke K. A new upgraded algorithm of interpreting SAGE III eclipse measurements. Issledovanie Zemli iz kosmosa, 1, 31-36, 2008 (in Russian).

Polyakov A.V., Timofeev Yu.M. An upgraded technique to determine total ozone content with SEVIRI instrumentation aboard geostationary satellites METEOSAT. Issledovanie Zemli iz Kosmosa, 5, 42-45, 2010 (in Russian).

Polyakov A.V., Yu.M.Timofeev, A.B. Uspenskii. Potentials of determining the amount of ozone and minor gaseous species from the data of satellite-borne, high-resoluton IR- sounders (IKFS-2). Issledovanie Zemli iz Kosmosa, 3, 3-11, 2010 (in Russian).

Repnev A.I. and Krivolutsky A.A. Variations in the chemical composition of the amosphere from satellite measurements and their relation to fluxes of energetic particles of cosmic origin (review), Izvestiya, Atmospheric and Oceanic Physics 46 (5), 535-562 .

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Sitnov S.A., On 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, Izvestiya, Atmospheric and Oceanic Physics, 45 (3), 324-331, 2009.

Smyshlyaev S.P., Galin V.Ya., Shaariibuu G., and Motsakov M.A., Modeling the Variability of Gas and Aerosol Components in the Stratosphere of Polar Regions, Izvestiya, Atmospheric and Oceanic Physics, 46 (3), 265-280, 2010 .

Syrovatkina O.A., I.L. Karol, A.M. Shalamyanskii and L.P. Klyagina. Interannual variations in total ozone fields at high latitudes of the Northern Hemisphere, November to March 1998–2005, Russian Meteorology and Hydrology, 33 (2), 91-97, 2008.

Titova E.A. and Karol' I.L., Analysis of the Influence that Climatic Variability Has on the Formation of the Total-Ozone-Content Field at Extratropical Latitudes of the Northern Hemisphere, Izvestiya, Atmospheric and Oceanic Physics, 46 (5), 635-642, 2010 .

Titova E.A., I.L. Karol, A.M. Shalamyanskii, L.P. Klyagina and A.A. Solomatnikova. Statistical analysis and comparison of external factor effects on the total ozone field over the Russian territory in 1973–2007, Russian Meteorology and Hydrology, 34 (7), 442-453, 2009.

Virolainen Ya.A., Timofeev Yu.M. Kompleksnyi metod opredeleniya vertikal'nykh profilei soderzhaniya ozona dlya validatsii sputnikovykh izmerenii, Issledovanie Zemli iz kosmosa, 4, 61-66, 2010 (in Russian).

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5. Participation in research projects

Scientists from Russia are involved in the following international projects:

HEPPA - High Energetic Particle Precipitations in the Atmosphere;

ISST (International Space Science Institute) - Study of cosmic ray influence upon atmospheric processes;

MATCH - Determination of Stratospheric Polar Ozone Losses);

POLARCAT - Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport;

RECONCILE - Reconciliation of Essential Parameters for an Enhanced Predictability of Arctic Stratospheric Ozone Loss and its Climate Interactions;

SCOUT-O3 - Stratospheric Climate Links with Emphasis on the UTLS;

YAK-AEROSIB - Airborne Extensive Regular Observations over Siberia – (Russia-France experiment).

6. Future activities

It is planned to resume TO observations at the station on Dickson Island (73,5°N, 80,5°E) and thereby completely restore the Russian Federation ozonometer network of 29 stations that were in operation prior to 1991.

In 2011, the tests of the UV ozone spectrometer are to be completed. Within the period of 2012-2015, these instruments are to be installed at all the ozonometer stations of Roshydromet, which will permit automating TO measurements and provide regular measurements of the spectral composition of the global UV radiation in a 290-400 nm range.

As concerns measurements using Brewer spectrophotometer, it is planned to adopt night-time measurements by the moon and measurements of the vertical profile of ozone concentration by an inversion method, as well as to improve the accuracy of measuring total SO_2 and aerosol optical thickness through upgrading data processing procedure

It is expected, using three-dimensional models, to estimate the input of solar activity to the global changes in atmospheric chemical composition, the temperature and circulation of the middle atmosphere and troposphere (CAO, MGO).

A model version of the numerical forecast of spatial (3-D) ozone distribution for a month’s and a season’s periods in advance (CAO, HMC).