ASSESSMENT REPORT ON CLIMATE CHANGE AND ITS CONSEQUENCES IN RUSSIAN FEDERATION

General Summary

FEDERAL SERVICE FOR HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING (ROSHYDROMET)

2008

FEDERAL SERVICE
FOR HYDROMETEOROLOGY
AND ENVIRONMENTAL MONITORING (ROSHYDROMET)

ASSESSMENT REPORT ON CLIMATE CHANGE AND ITS CONSEQUENCES IN RUSSIAN FEDERATION

GENERAL SUMMARY

Moscow — 2008

ASSESSMENT REPORT ON CLIMATE CHANGE AND ITS CONSEQUENCES IN RUSSIAN FEDERATION

General Summary

UBC 551.583 (470+570)

Science Coordinating Committee:

A. I. Bedritsky, Head of Roshydromet (Chair); V. G. Blinov; D. A. Gershinkova (Executive Secretary); G. S. Golitsyn; V. P. Dymnikov; Yu. A. Izrael; V. M. Kattsov; V. M. Kotlyakov; V. P. Meleshko; V. I. Osipov; S. M. Semenov

Leading scientific organizations responsible for preparation of the Report:

Voeikov Main Geophysical Observatory, Roshydromet (MGO)
Institute of Global Climate and Ecology, Roshydromet and Russian Academy of Sciences (IGCE)

General Summary submitted for:

— Heads, advisors, and experts of federal and regional executive authorities of the Russian Federation responsible for planning and implementation of specific tasks relevant to various sectors of economy and programs of sustainable development;

— Heads, advisors, and experts of institutions and organizations of the Russian Federation whose activities depend on climate change and have an influence upon it;

— Nongovernmental organizations and scientific community that are interested in receiving objective information about climate condition, its changes, influence on the environment, the economy and human health in the Russian Federation.

General Summary contains minimum specific details and technical terminology that are considered comprehensively in Technical Summary and the main Report (volumes I and II). References are given in the Report. Comments on possible measures for adaptation to changing climate are emphasized in the form of special boxes.

The summary is drafted by:

V. P. Meleshko, Chair, Working Group I "Climate Change in Russian Federation"
S. M. Semenov, Chair, Working Group II "Consequences of Climate Change in Russian Federation"

and lead authors of the Report:

O. A. Anisimov, Yu. A. Anokhin, L. I. Boltneva, E. A. Vaganov, G. V. Gruza, A. S. Zaitsev, A. N. Zolotokrylin, Yu. A. Izrael, G. E. Insarov, I. L. Karol, V. M. Kattsov, N. V. Kobysheva, A. G. Kostianoy, A. N. Krenke, A. V. Mescherskaya, V. M. Mirvis, V. V. Oganesyan, A. V. Pchelkin, B. A. Revich, A. I. Reshetnikov, V. A. Semenov, O. D. Sirotenko, P. V. Sporyshev, F. S. Terziev, I. E. Frolov, V. Ch. Khon, A. V. Tsyban, B. G. Sherstyukov, I. A. Shiklomanov, V. V. Yasukevich

ISBN 978-5-904-206-96-03

Preface

An assessment of observed and expected climate changes and their impacts is an important component of an information system for the development of climate policy at national and international levels. An overview of such information at the international level is undertaken periodically by the Intergovernmental Panel on Climate Change (IPCC), which was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988. The IPCC assesses available scientific, technical and socio-economic information on climate change and its impact, as well as on options for mitigating climate change and adapting to it.

Outcomes of such studies are published periodically as the IPCC Assessment Reports, and by now four reports have been issued (in 1990, 1996, 2001, and 2007). As the Intergovernmental Panel, the IPCC is responsible for the submission of objective scientific findings to the world community for the elaboration of a global and regional development strategy. Furthermore, it is expected that governments can take into account the IPCC findings and subsequently apply them to both the development of internal policy and the adoption of relevant actions resulting from international agreements.

The IPCC reports, which are aimed mainly at global assessments, cannot provide a complete picture of regional climate changes and its impacts. Further development and implementation of practical measures are required to reduce the anthropogenic influence on the climate system and mitigate its consequence at the national level. Therefore, in addition to IPCC activities, many countries carry out assessments at national levels employing comprehensive data sets collected by national hydrometeorological services, thoroughly use results of national research, and take into account inherent regional features and social conditions.

Assessment Report on Climate Change and Its Consequences in the Russian Federation prepared on the initiative of Roshydromet is the most comprehensive and up-to-date assessment of past, present and future climate change. It synthesizes information on climate conditions in the country and considers the following topics:

— Observed and expected climate change;

— Consequences of climate change for environmental and economic systems, human health, and possible adaptation measures;

— Further research needs.

The assessment Report is a continuation and extension of the former report *Strategic Prediction of Climate Change in Russian Federation for Period 2010–2015 and Its Influences on Different Sectors of Economy* published by Roshydromet in 2005.

The current Report is prepared for use by federal and regional executive authorities and other organizations responsible for planning and implementation of both specific tasks relevant to various sectors of the economy and programs on sustainable development, as well as by research and educational institutions, and public organizations concerned with issues on climate change in the Russian Federation.

A.I. Bedritsky
Head,
Federal Service
for Hydrometeorology and Environmental Monitoring

Introduction

The current *Assessment Report on Climate Change and Its Consequences in the Russian Federation* was submitted by a group of scientists from research institutions of Roshydromet, the Russian Academy of Sciences and educational institutions on the basis of analysis of climatic data obtained from the state hydrometeorological network and outcomes of studies published by Russian and foreign scientists on issues of climate change and its impacts.

The *Assessment Report* consists of two volumes. The first volume is devoted to the physical basis of anthropogenic change of global and regional climates. Its main foci are the observed climate change for the 20th century and projected climate change for the 21st century in the Russian Federation (surface air temperature, precipitation, runoff, snow cover and sea ice cover, permafrost, and sea level).

The second volume presents the assessment of impacts of observed and expected climate changes on the natural terrestrial and marine ecological systems of Russia, various economic sectors (agricultural production, water use, river and sea shipping, buildings and engineering constructions, municipal economy, etc.), and public health. Particular attention is given to large-scale consequences of dangerous hydrometeorological events.

The main findings of both volumes of the Report are summarized in two additional publications:

— General Summary provides a brief overview of the main observed and expected climate change and its consequences, as well as a description of possible adaptation measures.

— Technical Summary provides a more extensive overview of the topics concerned, as compared to General Summary with wide use of scientific terminology (published in Russian only).

General Summary is submitted to:

— Heads and experts of the federal and regional executive authorities of the Russian Federation responsible for planning and implementation of specific tasks relevant to various sectors of the economy and programs of sustainable development;

— Heads and experts of institutions and organizations of the Russian Federation whose activity depends on climate change and have influence upon it;

— Nongovernmental organizations and scientific community that are interested in receiving objective information about climate conditions, its changes, influence on the environment, economy and human health in the Russian Federation.

General Summary contains minimum specific details and technical terminology that are considered comprehensively in Technical Summary and the main Report (volumes I and II). References are given in the Report. Comments on possible measures of adaptation to changing climate are presented in boxes. References are also made to specific chapters and volumes of the Report at the end of paragraphs.

General Summary is based on the material set forth in two volumes of the Assessment Report and the report *Strategic Prediction of Climate Change in Russian Federation for period 2010–2015 and Its Influences on Different Sectors of Economy* published by Roshydromet in 2005.

General Summary was submitted by the group of experts guided by Dr. A. I. Bedritsky, Head, Roshydromet. Among other members of the group were V. P. Meleshko (Voeikov Main Geophysical Observatory), S. M. Semenov (Institute of Global Climate and Ecology), as well as V. G. Blinov, D. A. Gershinkova, P. N. Vargin, and A. O. Sokolov, staff members of the Department of Scientific Programs, International Cooperation and Information Resources, Roshydromet.

Climate observing system

To understand causes of climate change and to develop means for its prediction, it is necessary to conduct permanent and coherent observations all over the world.

The Global Climate Observing System (GCOS) established by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, and the International Council for Science (ICSU) uses observational sites placed at continents, ships, floating buoys, weather balloons, aircraft, and satellites.

Basic observations of climate in the Russian Federation are being carried out by the National Hydrometeorological Service (Roshydromet). In accordance with the WMO Convention, Roshydromet participates in the following observational programs: the World Weather Watch (WWW), Global Atmospheric Watch (GAW), Global Ocean Observing System (GOOS), and Global Terrestrial Observing System (GTOS).

Regular climate observations are conducted by Roshydromet at 1627 stations of the surface meteorological network. Of this number, 458 stations belong to the reference network which by definition includes those stations that provide a full program of observations, cover representative areas with uniform meteorological conditions, have long series of observations and cannot be closed or relocated. In addition, the regional basic climate network includes 238 stations. GCOS comprises 135 reference stations and 12 upper-air stations of the Russian Federation. It also includes two stations (Teriberka and New Port) providing monitoring of greenhouse gases (carbon dioxide and methane), and 27 stations performing measurements of total ozone. Actinometric observations are conducted at 191 sites, hydrological observations on rivers, lakes, and reservoirs are carried out at 3085 sites, and one site located at Obninsk provides regular observations in the atmospheric boundary layer (up to 300 m). There are also 11 avalanche observing sites in the mountain regions of Northern Caucasia.

Some observations relevant to climate study are also conducted by other agencies and institutions (for instance, Ministry of Defence, the Russian Academy of Sciences). However, Roshydromet carries out the total amount of observations significantly exceeding those undertaken by other agencies.

The meteorological network is rather sparse for study of regional climate in some areas of Russia.

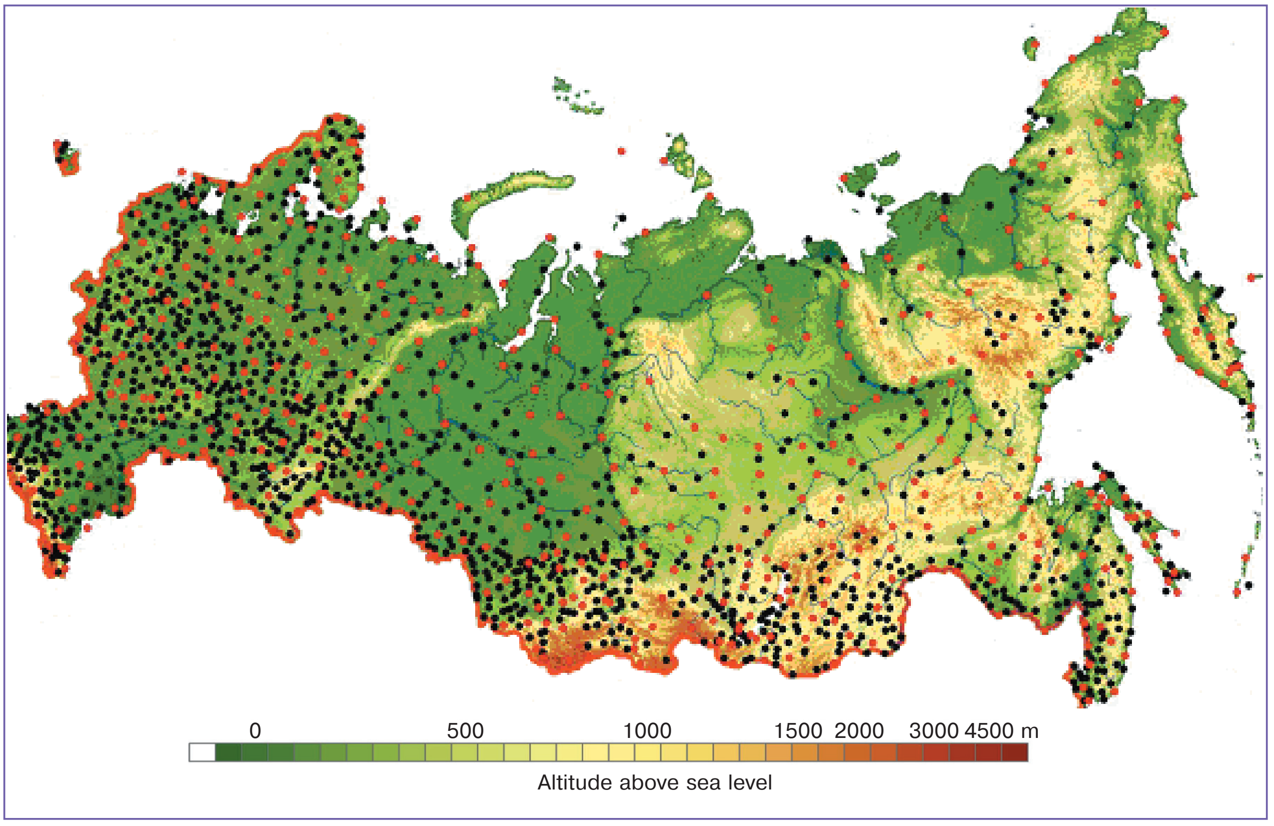

Fig. GS1. Basic surface meteorological network of the Russian Hydrometeorological Service that consists of 1627 stations including 458 reference stations (red circles).

Therefore, along with efforts aimed at the enhancement of the surface network, emphasis is placed on analysis of regional climate using satellite observations.

Roshydromet prepares the annual report that describes climate conditions in different regions of the country during the year, including the occurrence of anomalous conditions and extreme weather phenomena (AR, vol. I, Ch. 2).

Climate change during the period of instrumental records

Surface air temperature. Evidence from observations and model simulations indicate that warming in Russia as a whole is larger than global warming. According to observations provided by the meteorological network of Roshydromet, the warming in Russia was 1.29°C for the last 100 years (1907–2006), whereas global warming for the same period was 0.74°C according to the IPCC Fourth Assessment Report. Furthermore, the mean warming in the country was 1.33°C for the period 1976–2006 (Fig. GS2). The annual maxima and minima of daily surface air temperature increased, and the difference between them decreased (minima grew faster than maxima). The largest increase in minimum and maximum daily temperature occurred in the cold season. The number of frosty days decreased (AR, vol. I, Ch. 3).

Precipitation. Due to both a complicated physical nature of phenomenon and heterogeneity of observations, precipitation changes are evaluated with less confidence than surface air temperature changes. It was found that annual precipitation over Russia increased (7.2 mm/10 years) for the period 1976–2006. However, considerable differences were observed in patterns of region precipitation changes. The most essential changes are the increase in spring precipitation (16.8/10 years) in the western and northeastern regions of Siberia and in the European part of Russia (EPR). However, a decrease in winter precipitation was observed in the north-eastern regions of Siberia including the Magadan district, the northern part of Khabarovsk land and the eastern part of the Chukchi autonomous region. Indicators characterizing extremely large precipitation show a weak increase in the number of cases with heavy precipitation and some decrease in maximum duration of dry periods (AR, vol. I, Ch. 3).

Clouds. During the second half of the 20th century, the amount of convective clouds increased with a simultaneous decrease in stratiform clouds in the greater part of Russia. On the whole, it contributed to the increase in high clouds (AR, vol. I, Ch. 3).

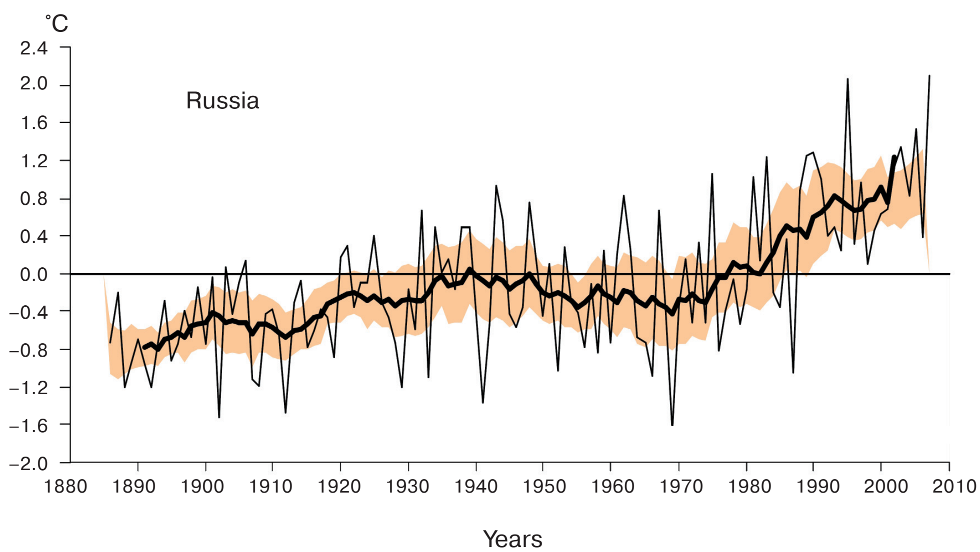

Fig. GS2. Changes in annual surface air temperature (˚C) averaged over Russia relative to its mean value for the period 1961–1990. The thin line shows observed temperature. The thick line implies a smoothed air temperature trend derived from 11-year moving averages. Considerable inter-annual variation of temperature took place against the background of its persistent growth.

River runoff. The annual runoff increased by 15–40% for the period 1978–2005 relative to 1946–1977 at rivers in the western regions of the EPR and tributaries on the left bank of the Volga River. The runoff increased by 10–15% in the upper basin of the Northern Dvina, upper reaches of the Dnieper, and left-bank tributaries of the Don. A runoff increase of 20–40% also took place on the left-bank tributaries of the Tobol and the Irtysh rivers in the Asian part of Russia (APR). Runoff increases were also observed in the Yenisey basin (8%) and in the greater part of the Lena basin, particularly in the last decade of the 20th century. The runoff also increased by 5–15% in the north-eastern river basins of the APR (AR, vol. I, Ch. 3).

Snow cover. Satellite measurements for the last 30 years showed that snow cover considerably decreased in the Northern Hemisphere in spring and summer. In the western regions of the EPR, Transbaikalia, and Chukci region there was a tendency for a decrease in snow depth. The main reason of such a change in recent decades was the surface air temperature rise. On the other hand, the increase in snow depth was also observed in some regions where very low annual mean temperatures persisted and the increase in precipitation was observed in winter (AR, vol. I, Ch. 3).

In most regions of the country the number of days with snow depth of 20 cm has increased. Along the coast of the Arctic seas extending from the Kola Peninsula to Taimyr, the linear trend of this characteristic was 6–8 days/10 years. Similar trends were also documented in the eastern regions of the EPR and in the south of Western Siberia.

Permafrost. In the last quarter of the 20th century, the rise of temperature of the upper ground layer was observed at many sites of the permafrost zone, and the increase in depth of seasonal thawing took place in some regions. The annual ground temperature increased by 1.0°C at many sites of the permafrost zone of Western Siberia and by 0.8–1.0°C in the north-western regions of the EPR (AR, vol. I, Ch. 3).

Sea ice in the Arctic basin. Long-term variation of sea ice extent is a good indicator of climate change in the Arctic. Satellite observations have shown a steady downward trend in sea ice for the last two decades. Since the beginning of satellite observations in 1979 the minimum seasonal sea ice area observed in September every year has been decreasing by 9% per decade, and in September 2007 ice cover had a minimum value ever recorded, 4.3 million km^2 (AR, vol. I, Ch. 3).

Changes of greenhouse gases and aerosols in the atmosphere

Atmospheric greenhouse gases

Human activities have significant influence on the concentration of greenhouse gases of the atmosphere Amongst such gases are (Fig. GS3):

— ***Carbon dioxide (CO$_2$)*** is the most important greenhouse gas in view of its influence on climate. The rate of its growth was unprecedented over the past 250 years, and now its current level makes up 35% of the pre-industrial period. In 2005 the CO_2 concentration reached 379 ppm.

— ***Methane (CH$_4$)*** is the second greenhouse gas by its significance after CO_2; its current concentration is 2.5 times as high as the pre-industrial value and reached 1774 ppb in 2005.

— ***Nitrous oxide (N$_2$O)*** increased by 18% in 2005 relative to the pre-industrial period and its concentration constituted 319 ppb. At present about 40% of N_2O, emitted to the atmosphere is due to human activities (fertilization, cattle breeding, chemical industry) (AR, vol. I, Ch. 4).

The CO_2 concentration series at Teriberka (Fig. GS4) station operated by Roshydromet showed that the annual trend was 1.7 ppm/year over the recent 17 years with a considerable seasonal variation of 15–20 ppm.

The national emission of greenhouse gases to the atmosphere by various sectors of the economy has been evaluated on the basis of statistical analysis of activities leading to gas emissions from different sources and their removal from the atmosphere by appropriate absorbents. In accordance with the commitments of the Russian Federation to the UN Framework Convention on Climate Change and the Kyoto Protocol, national reports on the cadastre of anthropogenic emissions from different sources and sinks of greenhouse gases are regularly submitted and presented to UNFCCC Secretariat. The reports are also placed at Roshydromet web site.

Emissions of greenhouse gases in Russia are due mainly to power generation, industry, agriculture and waste recycling (Fig. GS5) and for the period 2005–2006 they were about 70% of those of 1990.

Radiative forcing of greenhouse gases and aerosols in the atmosphere

Modifying the radiative properties of the atmosphere is the main way of the anthropogenic influence on the global climate system. Contribution of atmospheric greenhouse gases is the main driving mechanism of such forcing.

All greenhouse gases with long lifetimes and ozone have a positive radiative forcing (2.9 ± 0.3 W/m^2). The

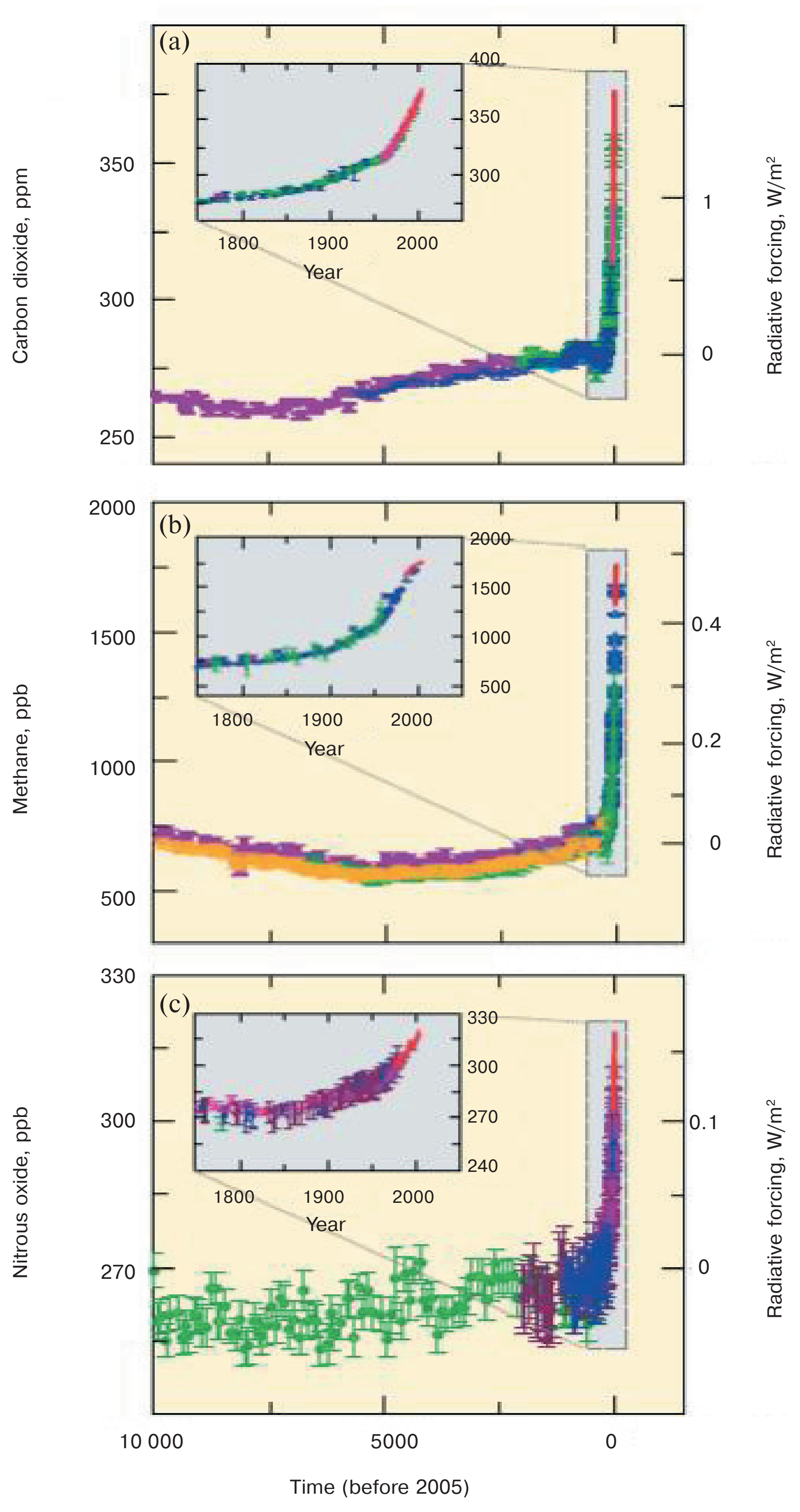

Fig. GS3. Time dependence of the concentration of carbon dioxide (a), methane (b) and nitrous oxide (c) in the atmosphere over the past 10 000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colors from various studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels (AR, vol. I, Fig. 4.1).

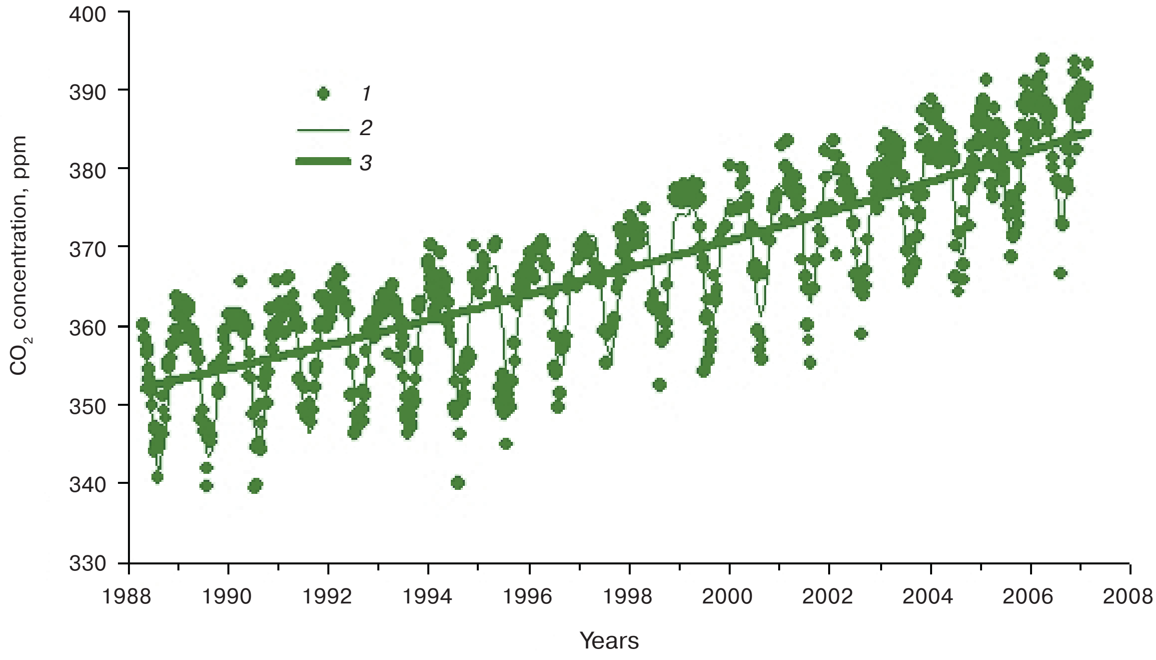

Fig. GS4. Time dependence of CO_2 concentration in the atmosphere at Teriberka station (Kola Peninsula) for the period 1988–2007. Solid circles and lines show individual observations, seasonal cycle and multi-year trend.

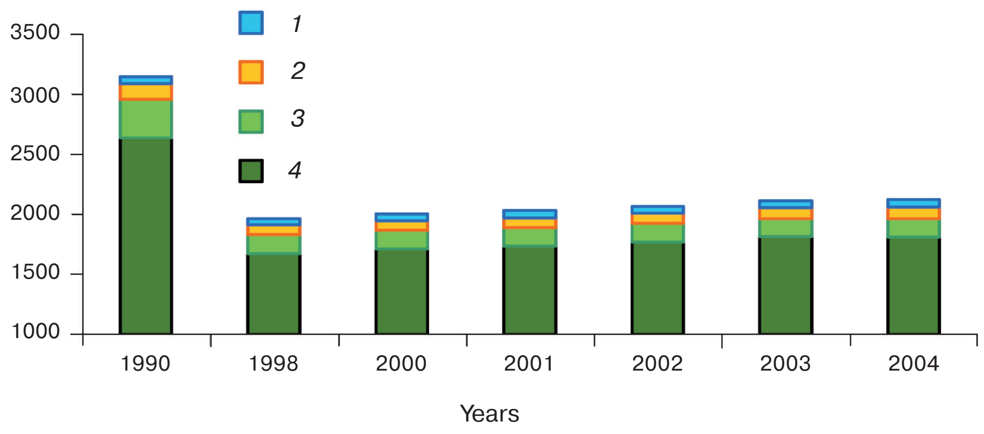

Fig. GS5. Emissions of the main greenhouse gases (CO_2, CH_4, N_2O) from sources associated with industrial and agricultural production and waste recycling (10^6 tons CO_2-equivalent) in Russia for 1990–2004.

net forcing produced by concentration changes of all greenhouse gases and aerosols makes up 1.6 (from 0.6 to 2.4) W/m^2.

All types of aerosols produce direct radiative effect and act indirectly by changing cloud albedo. The net aerosol forcing is negative (–1.3 ± 0.8 W/m^2). However, reliability of this estimate is much less than that for greenhouse gases.

Since the beginning of the industrial era, the processes of land ploughing and forest cutting have significantly accelerated, and by the end of the 20th century agricultural and arable lands occupied 35–

39% of the whole area, while the part occupied by forests was reduced by 20–24%. The radiative forcing associated with land use is evaluated at 0.15–0.20 W/m^2 (AR, vol. I, Ch. 4).

The direct radiative forcing due to solar irradiance change since 1750 until present makes up 0.12 W/m^2. Therefore, according to the IPCC Fourth Assessment Report, there is no reason to believe that changes of solar activity and associated changes of the solar flux coming to the top of the atmosphere are the only cause of observed climate warming (AR, vol. I, Ch. 4).

Current climate models

Atmosphere–Ocean General Circulation Models (AOGCMs) are the main and the most promising tool for prediction of future climate changes due to internal interactions between different components of the climate system and external forcings of natural and anthropogenic origin. The model can also be used for detection and attribution of causes of observed climate changes.

An important property of the models is their ability to respond to external forcings (such as changes in solar irradiance, volcanic activity, and atmospheric composition). This is determined by internal processes of the climate system with feedbacks contributing to enhancement or suppression of the influence of the forcings. The current models show different sensitivity to the same external forcing, and this is one of the sources of uncertainty in estimates of future climate change. The studies also show that the sensitivity of equilibrium climate to a doubling of CO_2 concentration ranges within 2.0–4.5°C and the value of 3°C is considered as the most probable sensitivity. The spread of sensitivities among models is mainly due to differences in the description of cloud-radiative feedbacks. A large contribution to sensitivity is made by other feedbacks resulting from reduction in snow and sea ice extent and related changes of surface albedo (AR, vol. I, Ch. 5).

A set of parallel computations of climate parameters using different initial conditions or results of simulations with different independent models is called a model ensemble. Ensemble simulations are usually most successful in reproduction of observed climate. This is because systematic errors inherent in particular models often turn out to be random with respect to the ensemble, and when averaged in the ensemble, they are reciprocally compensated. It is of importance to develop quantitative indices that could be used to evaluate aggregated quality of the models and subsequently set up an optimal ensemble (AR, vol. I, Ch. 5).

In connection with preparation of the IPCC Fourth Assessment Report, the CMIP3 project unprecedented by its scale and a number of participating institutions has been successfully implemented. Its main purpose was to simulate and to analyse climate of the 20th and 21st centuries using mostly new generation AOGCMs developed by leading research institutions all over the world.

As compared with a previous generation of the models, the new ones have been further improved by increasing space resolution, further improving parameterization of physical processes and including additional, climatically significant processes in several models. It has led to further improvement of simulation of the current climate in many aspects. Climate simulations for Russia with the CMIP3 ensemble showed the following features (AR, vol. I, Ch. 5):

— AOGCMs successfully compute the seasonal variation of surface air temperature in different regions of Russia. However, the annual mean temperature was underestimated (–1.8 ± 1.5)°C for the whole country. This becomes particularly apparent during the cold season in the north-western regions of the country and in Western Siberia.

— AOGCMs successfully compute the distribution of annual maxima and minima of surface air temperature in most parts of Northern Eurasia including the location of the highest temperature in Central Asia. However, models underestimate annual maxima by 2–4°C in Central and Eastern Siberia and overestimate annual minima mostly in Eastern Siberia.

— AOGCMs realistically reproduce the main patterns of precipitation including summer maxima and winter minima. At the same time, the models overestimate annual precipitation (by 8%) in most of Russia. Inter-model standard deviation turns out to be, as a rule, 1.5–2.0 times greater than annual mean errors for all Russia.

— The annual mean runoff in major watersheds was computed by AOGCMs realistically. According to observations, the inter-annual variability of runoff for the major Siberian rivers (Ob, Yenisey, Lena) was 7–15%, and the multi-model spread turned out to be 18–26% relative to its annual mean values.

— Models successfully reproduce the location and intensity of the Icelandic and Aleutian lows and Siberian high in winter. The current models more realistically simulate the location of blocking systems. However, their frequency is lower and they persist for shorter periods.

— The models overestimate snow cover extent in the cold season and show considerable multi-model differences in pattern distributions of snow cover. Many models demonstrate excessive snow cover in spring and delay of spring thawing because of the underestimation of surface air temperature in Northern Eurasia as a whole.

— The computed annual zero isotherm at 3 m depth for loamy soil rather realistically represents the current boundary of permafrost including the zone of intermediate and sporadic permafrost.

— Models satisfactory reproduce the seasonal cycle of sea ice extent in the Arctic Ocean. At the same time, the majority of models overestimate sea ice extent throughout the year.

Anthropogenic contribution to climate warming

A large number of studies have been conducted with AOGCMs aimed at the reproduction of observed climate changes for the period of instrumental records. Comparison of simulated and observed variations of surface air temperature provides convincing evidence supporting the anthropogenic nature of observed climate warming. Furthermore, anthropogenic warming has been revealed not only on a global scale, but on a continental scale as well (AR, vol. I, Ch. 6).

Climate observations indicate that surface air temperature has also been increasing in Russia since the middle of the 1970s. Good agreement was also revealed between observed and simulated trends of surface air temperatures averaged over the whole country when computation was carried out with the AOGCM ensemble describing, in particular, the anthropogenic increase in greenhouse gases and aerosols (Fig. GS6). Further analysis of observations and climate simulations for major continents provided a consistent picture of warming and allowed the following conclusions (AR, vol. I, Ch. 6):

— Climate changes observed for the last 50 years are very unlikely to occur without external forcing.

— With high confidence one can claim that since the middle of the 20th century the observed growth of the concentration of anthropogenic greenhouse gases has stipulated the largest portion of global warming.

At the same time, global warming takes place against the background of the inter-annual natural variability of climate which is particularly significant in middle and high latitudes, and it frequently exceeds the anthropogenic signal on space scales smaller than the scales of a subcontinent (AR, vol. I, Ch. 6).

Expected climate changes

Prediction reliability of future climate change depends upon many factors, each of which yields some degree of uncertainty. The main sources of uncertainty are (AR, vol. I, Ch. 7):

— There is a fundamental problem to forecast future technological development and energy use in the world for a long period. In turn, it causes uncertainty in future emissions of greenhouse gases and aerosols to the atmosphere.

— It is a priori impossible to take into account natural external forcings such as future volcanic eruptions and changes of solar flux at the top of the atmosphere.

— Current models describe climatically significant processes and relevant feedbacks with some inaccuracy, which is caused by inadequate understanding of some physical processes.

Projection of climate change for the 21st century in Russia and contiguous regions was obtained from

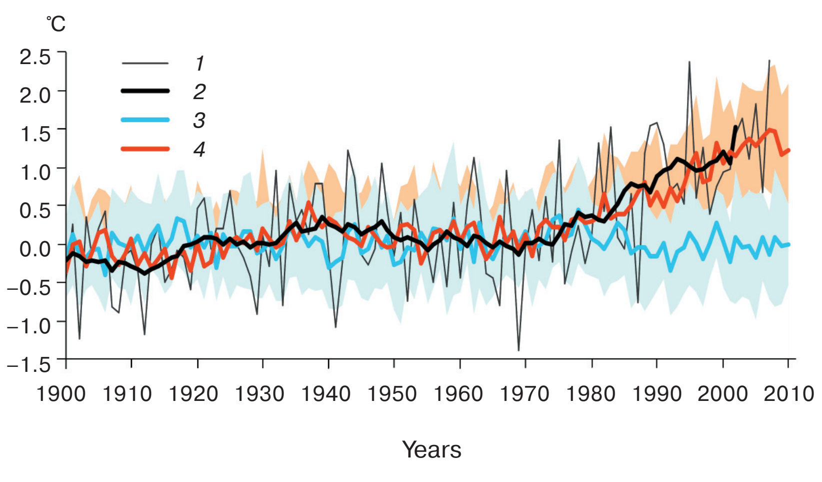

Fig. GS6. Time dependence of the mean annual anomaly of surface air temperature for the whole country obtained from observations (*1*, *2*) and derived from the ensemble of 16 CMIP3 AOGCMs with only natural external forcing (*3*) and anthropogenic and natural forcing (*4*). Anomalies are computed relative to the annual mean for 1901–1950. Curve (*2*) is obtained from (*1*) by applying 11-year moving averages. Slightly coloured zones indicate scatter of the standard deviation (±σ) relative to the ensemble mean (AR, vol. I, Fig. 6.7).

simulations of global climate using the ensemble of CMIP3 AOGCMs (16 members). In analysis, the period 1980–1999 was taken as the reference one.

The IPCC has developed scenarios of emissions of greenhouse gases and aerosols to the atmosphere for the 21st century taking into account demographic, economic, technological, and other factors. According to the "strong" SRES A2, scenario, the concentration of carbon dioxide (CO_2) and methane (CH_4) will increase by 1.51 times and nitrous oxide (N_2O) by 1.21 times by 2050 relative to 1990. However, it has been shown that, at least, by the middle of the century the global warming and warming in Russia will depend only slightly on the selected emission scenario (AR, vol. I, Ch. 7).

Surface air temperature. The increase in annual mean temperature is expected to be much larger in Russia than the global warming. By 2020, its growth will exceed the multi-model spread (standard deviation) which will be 1.1 ± 0.5°C. By the middle of the century, the temperature rise will be even larger (2.6 ± 0.7°C), particularly in winter (3.4 ± 0.8°C) (Fig. GS7a, b). In the southern and north-western regions of the EPR, the rise of the lowest daily temperature minima is expected to be 4–6°C. The rise of daily temperature maxima will not exceed 3°C. Thus, the annual difference between the highest and lowest daily temperatures will decrease for all Russia and particularly in the EPR. In Siberia and the Far East the

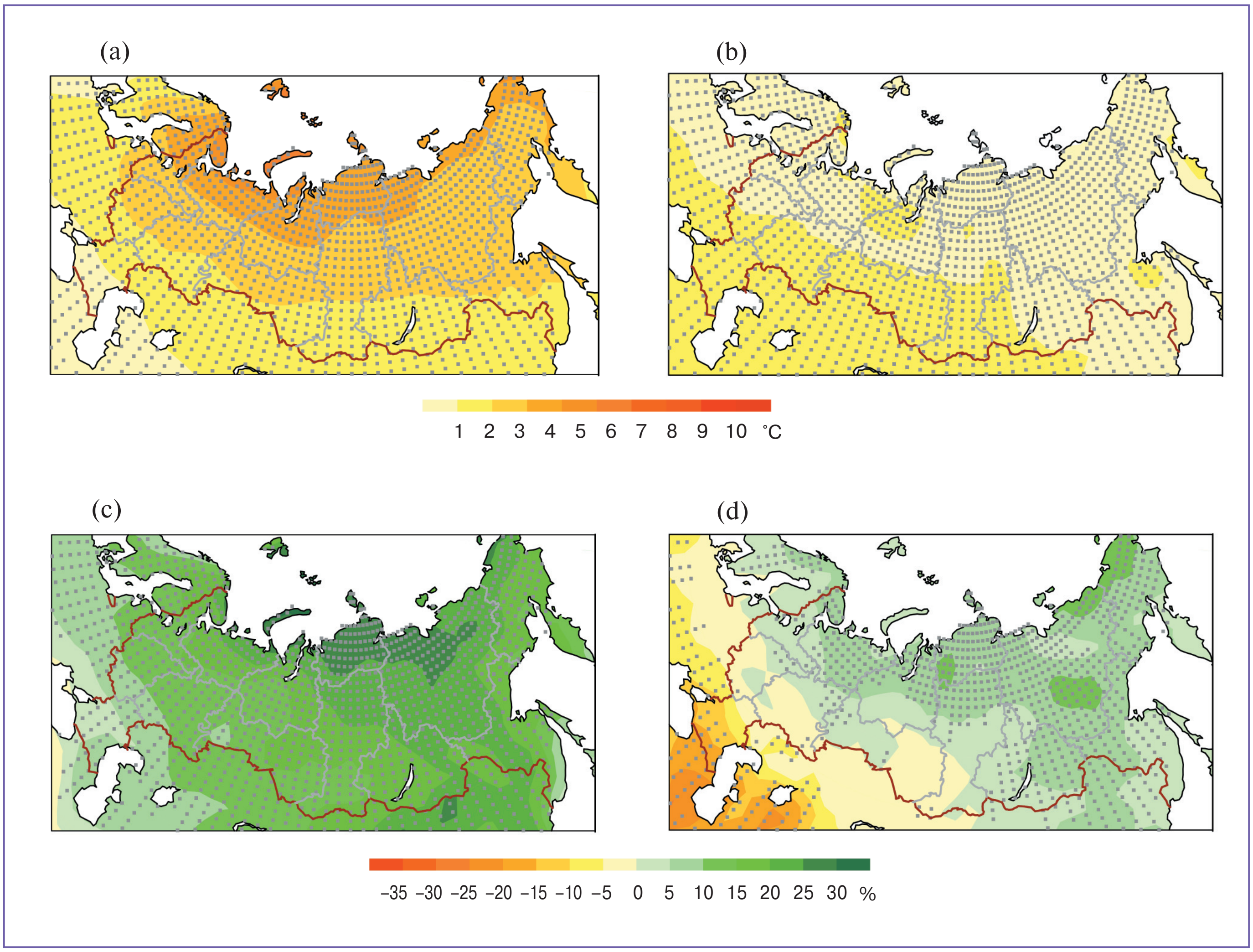

Fig. GS7. Changes in surface air temperature (a, b) and total (solid and liquid) precipitation (c, d) in Russia and adjoining regions for winter (a, c) and for summer (b, d) during the period 2041–2060, as compared to the period 1980–1999. Assessment was obtained from the ensemble of 16 CMIP3 AOGCMs using scenario A2. Temperature is given in degrees Celsius and precipitation in percent relative to its value in the corresponding season for the period 1980–1999. In the upper panels (a, b) dots imply that mean temperature changes exceed the standard deviation of the inter-model scatter (signal is larger than noise), and in the low panels (c, d) they denote the areas where two thirds of the models show changes of the same sign (AR, vol. 1, Figs. 7.7, 7.14).

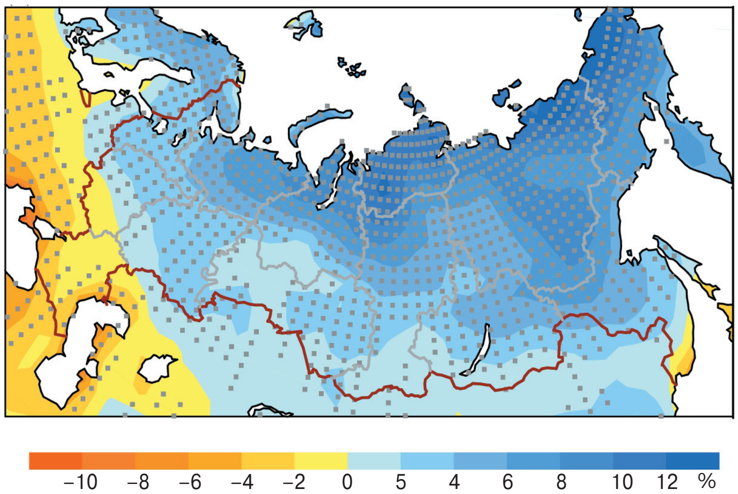

Fig. GS8. Changes in annual runoff for the middle of the 21st century (2041–2060) derived from the ensemble of 16 CMIP3 AOGCMs for the SRES A2 scenario. Values are given in percent relative to the reference period. Dots denote areas in which two thirds of the models show changes of the same sign.

number of frosty days will decrease by 10–15 days and in the EPR by 15–30 days (AR, vol. 1, Ch. 7).

Precipitation. By the middle of the century, winter precipitation is expected to increase all over the country, and in summer the sign of its change will depend upon the region considered (Fig. GS7c, d). The region with precipitation decrease is clearly seen in the southern regions of the EPR and Southern Siberia. In this period the increase in winter precipitation will far exceed the inter-model spread, particularly in the eastern regions of Russia. In summer, the standard deviation will remain large enough and, as a rule, will exceed mean changes in most regions of the country. Convective precipitation is expected to increase in most regions in summer, but it will occur against the background of large inter-model spread. Furthermore, precipitation of high intensity may also occur against the background of the decreased number of cases with precipitation in some southern regions (AR, vol. 1, Ch. 7).

Annual river runoff. During the 21st century further increase in water resources is expected in regions where they are now available or excessive, and further decrease will occur in regions which experience water shortage nowadays. The largest increase in river runoff will occur in watersheds of the northern rivers (Northern Dvina, Pechora, Mezen, and Onega) and the Siberian rivers. On the other hand, runoff will decrease in watersheds of the southern rivers (Don and Dnieper) due to annual precipitation decrease and evaporation increase in spring and in summer. By the middle of the century the annual changes of runoff will exceed inter-model spread in watersheds of the Lena, the Yenisei, and the northern rivers. Only in watersheds of the Volga and the Ural will runoff changes be insignificant until the end of the century (AR, vol. 1, Ch. 7).

Snow cover. Due to climate warming, a substantial reduction in snow cover will be expected in most of the country. The increase in winter precipitation in the EPR will be due mainly to liquid phase, and in Siberia the major portion of additional precipitation will be in solid phase. Thus, in the EPR, the reduction in snow mass and the increase in winter runoff will occur, and in Siberia further accumulation of snow mass in winter and its more rapid melting in spring can be expected. This will result in more frequent and extensive flooding.

Sea ice in the Arctic. Considerable reduction in ice covered area in the Arctic will continue during the 21st century. The maximum sea ice extent, which is normally observed in March, will continue to decrease by 2% per decade, and the minimum ice extent, which normally happens in September, will be reduced by 7% per decade relative to ice extent for the period 1910–1959 with a faster reduction in the area of multiyear ice in comparison with the seasonal ice area (AR, vol. 1, Ch. 7).

Natural terrestrial ecosystems

In the 20th – early 21st century, under changing climate, discernible shifts in phenological dates in plants (including frondescence (Fig. GS9)) and animals (e.g., seasonal migration in birds), in spatial

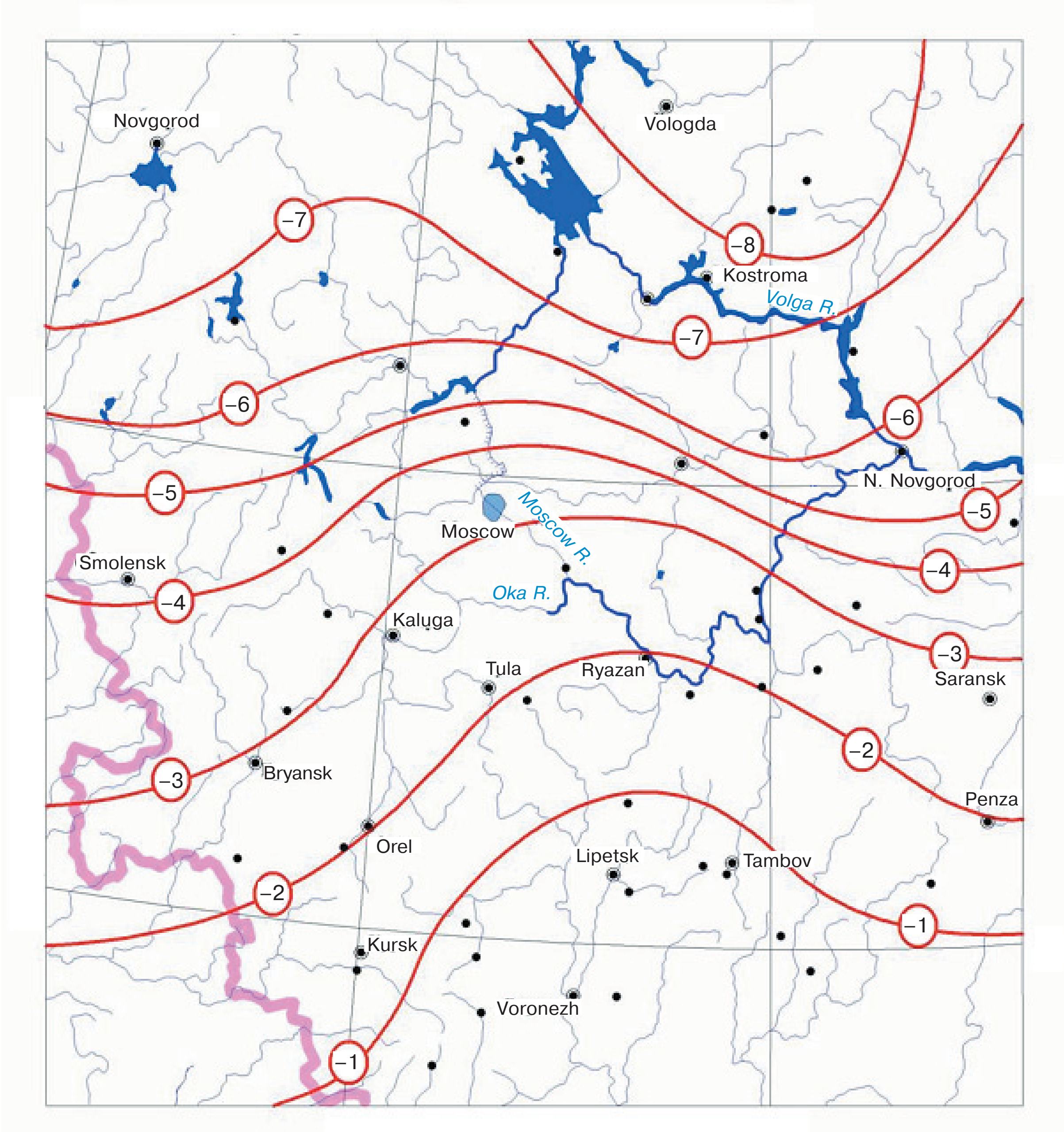

Fig. GS9. Isolines for shifts in a frondescence date (first leaves) in common birch over the European part of Russia in 1970–2000. Dots indicate locations of phenological observation stations (AR, vol. II, Fig. 2.6.2).

limits of vegetation zones and ecosystem structure were observed in some regions (AR, vol. II, Ch. 2.6).

These tendencies will prevail under further warming in the 21st century. Boundaries of vegetation zones will typically shift northward. The forest zone will expand northward in the European part of Russia, but southward expansion is also possible under humid warming (i.e., if warming is accompanied by an increase in moistening). In Siberia, the decrease in forest area may occur along with an increase in floristic biodiversity. Climate change may potentially cause a species interaction mismatch, shifts in vegetation zones in plains and altitudinal belts in mountains, and alterations in ecosystem structure. Nature reserves and other protected areas may partly lose their nature conservation value due to such climate-driven changes (AR, vol. II, Fig. 2.6.2).

It is expedient to supplement the territorial approach to nature protection (i.e., nature protection regime at selected lands, e.g., nature reserves, game preserves) with other measures ensuring protection of species and biological communities over their whole changing spatial range. The development and implementation of the extended concept of nature protection based on the long-term ecosystem monitoring in nature reserves and over the adjacent areas is one of possible ways of adaptation to changing climate.

Climatic changes over most of Russia during the last quarter of the 20th century and the beginning of the 21st century caused an increase in the net primary production of ecosystems (under the assumption that other, nonclimatic conditions remained unchanged). At the same time, in some regions, at different latitudes, observed values of the radial tree increment declined in the second half of the 20th century vs. those measured in the middle of the century.

In the last quarter of the 20th century and at the beginning of the 21st century, the carbon content in soils increased (under the assumption that other, nonclimatic conditions remained unchanged). In the 21st century, under moderate warming and sufficient moistening, carbon accumulation will be possible for most of soils in Russia.

In the 20th century, desertification observed over the Russian arid lands was predominantly anthropogenic. These lands do not belong to the climatic desertification zone. Their aridization (i.e., decline in moisture content) is just sporadically maintained by climatic factors in the years of dangerous droughts.

At the end of the 21st century, if the arid warming (i.e., warming accompanied by a decrease in moistening) occurs over the European part of Russia, the aridity of climate will increase in the forest-steppe, steppe, and semi-desert zones. Steppes of the Krasnodar Territory and the Rostov region will become dryer.

An excessive land-use load on arid lands under changing climate may cause disastrous local desertification.

Rational control of land use in arid areas, with the interactions of anthropogenic and climatic factors of desertification taken into account, may be an efficient adaptation measure.

Terrestrial cryosphere

Discernible climate warming, which was observed in the second half of the 20th century, particularly in its last quarter, has modified the thermal regime of permafrost. That has caused changes in the spatial distribution and bearing capacity of the frozen ground. In the 20th century, there was a 1 to 2 latitudinal shift of the southern permafrost boundary in response to climate cooling of 1960–1970 and subsequent warming (AR, vol. II, Ch. 2.7).

In the 21st century, degradation of permafrost due to climate warming will result primarily in an increase in depth of seasonal thawing and temperature of the frozen ground. In some regions, separation of the seasonally frozen surface layer from the deeper relict permafrost layer may occur (with unfrozen ground between them). The depth of seasonal thawing and freezing is governed largely by the soil type, snow depth and surface temperature (AR, vol. II, Ch. 3.7).

The southern permafrost boundary is expected to move northward in areas of its intense degradation in Western Siberia, by 30–80 km in the next 20–25 years and by 150–200 km by 2050 (Fig. GS10).

Permafrost occupies more than 60% of land in Russia. Changes in the frozen ground have a significant impact on the ecosystems of the permafrost regions. They lead to a decrease in bearing capacity of the ground and enhance methane emissions from soils to the atmosphere. However, in the 21st century the expected increase in emissions of methane from wetlands of Russian permafrost regions will not have any impact on the global climate.

In Russia, in the second half of the 20th century, particularly in the last decades, a tendency towards degradation of glaciers in the Arctic islands and mountain glaciers became evident. Such changes in mountain glaciers were observed in the Caucasus, Urals, Altai, north-eastern Siberia and the Kamchatka Peninsula. Such a tendency will prevail in the 21st century under expected continuous warming.

Seas

Northern seas (Baltic Sea, Arctic seas, Bering Sea). Ice cover of the Arctic seas of the Eurasia shelf directly influences the marine economic activity. In the 20th century the total ice cover decreased due to climate warming. However, the northward shift of the sea ice boundary did not occur everywhere. For example, in the last two decades of the 20th century, in the eastern sector of the Arctic the boundary of multi-year ice shifted southward by 300 km on average relative to the previous two decades (AR, vol. II, Ch. 2.8).

In 2001–2005 under warming, ice conditions for navigation along the Northern Sea Route at the end of

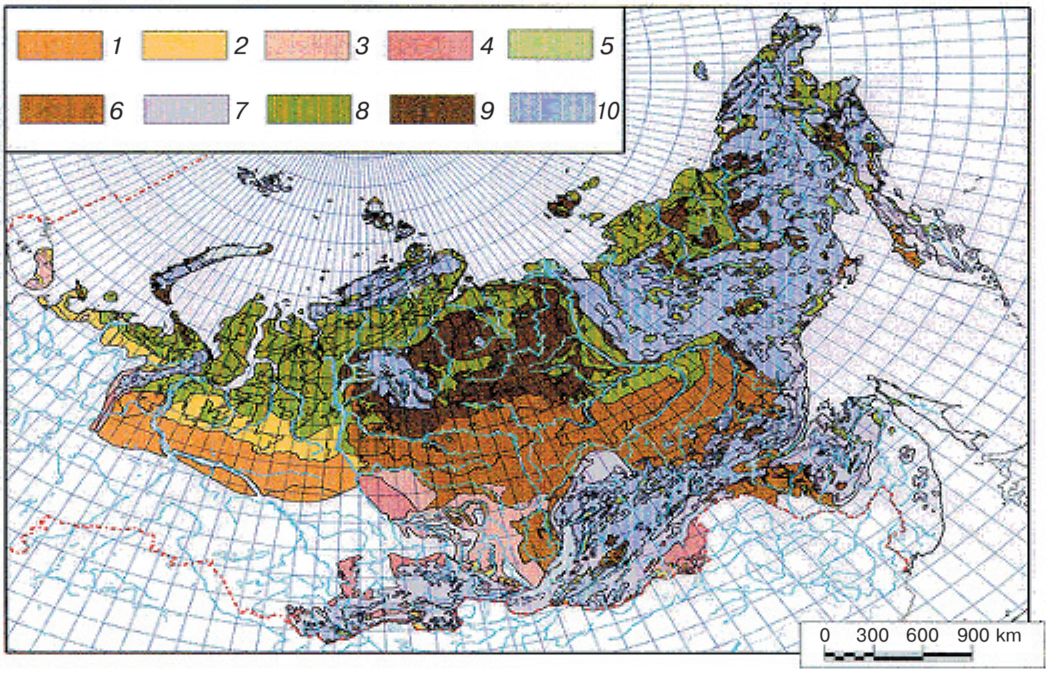

Fig. GS10. Possible changes in permafrost over the territory of Russia by 2020 and 2050 due to climate change. (*1*) Thawing everywhere in plains by 2020; (*2*, *3*, *4*) thawing everywhere by 2050 in plains, plateaus, and mountains, respectively; (*5*, *6*, *7*) partial thawing by 2050 in plains, plateaus, and mountains, respectively; (*8*, *9*, *10*) relatively stable state in plains, plateaus, and mountains, respectively. Black lines within color domains indicate areas with a different character of permafrost changes under climate warming (AR, vol. II, Fig. 3.7.1).

the warm season (August and September) became substantially more favorable in high latitudes, namely, to the north from the Arctic archipelagos Franz-Josef Land, Severnaya Zemlya, and New Siberian Islands. However, the increased occurrence of icebergs enhances the risk for marine transport and fishery. The changes in climate have negatively affected the coasts of the northern seas (intensification of erosion) and coastal infrastructure.

Ecosystems of the northern seas discernibly changed under changing climate in the 20th century. It refers to microbiological parameters, phytoplankton, zooplankton, zoobenthos, fish, and populations of marine birds and mammals. At the end of the 20th century the habitat of polar bear decreased significantly as a result of reduction in sea ice cover.

In the 21st century, under further warming, the overall tendency will be the reduction of ice cover in the northern seas, although some periods of its increase and decrease at the regional scale may occur. An increase in the iceberg occurrence is possible during periods of warming, as well as degradation of the fast ice and erosion of the costline.

Cyclic changes in conditions of navigation along the Northern Sea Route associated with periods of increase and decrease in the ice cover will be observed in some regions. For example, the possibility of formation difficult and very difficult ice conditions will remain in the Dmitry Laptev, Sannikov, and De Long straits. An increase in the ice cover may occur in the Barents and Kara seas in 2020–2030.

In the 21st century, under changing climate, further northward shifts in spatial ranges of many marine species as well as changes in biodiversity and size of populations are expected. Alterations of climate will substantially affect the conditions for fisheries in the northern seas (AR, vol. II, Ch. 3.8).

It is expedient to take into account patterns of future changes in the mid-term and long-term planning of marine economic activity in the Arctic, in particular, in designing ships, planning ice-breaker services, and building the coastal infrastructure. Although marine ice cover will decline on average over the whole 21st century, maintenance of the ice-breaker fleet is an imperative in view of a cyclic character of changes in ice conditions.

Rational planning of fisheries, including designing the fishery fleet and optimal selection of regions for fishery, can serve as possible measures of adaptation to the changing climate of the northern seas for this sector of the economy.

South seas (Black Sea, Azov Sea, Caspian Sea). The major physical and chemical climate dependent parameters of the southern seas (thermal regime, level, salinity), as well as chlorophyll concentration, were substantially changing at the end of the 20th century and the beginning of the 21st century (AR, vol. II, Ch. 2.9).

The rise of the Black Sea level has been observed since the 1920s. It has become much more rapid since the middle of the 1980s (about 2 cm per year). On the whole, the annual mean sea surface temperature increased at the end of the 20th century and the beginning of the 21st century. Over this period, no unidirectional variations in the surface layer salinity and chlorophyll concentration were revealed. Along with temperature variations, the Danube flow variations influenced the chlorophyll concentration significantly. The long-term tendency to increase in the Danube flow was detected for the 20th century.

The Azov Sea level has started to rise rapidly (similarly to that of the Black Sea) since the beginning of the 1990s. From the 1920s to the beginning of the 1980s, the sea surface temperature was increasing slowly; then the rate of increase has multiplied. Some periods of substantial increase in salinity due to control of the water flow and climatic factors were observed. However, since the beginning of the 1990s, the regional climate change has led to a decrease in Azov Sea salinity that dropped down to values typical of the times before the river flow control in the sea basin had been set up. In the basin of the Azov Sea the river flow has had a long-term tendency to increase since the end of the 1970s.

The Caspian Sea surface temperature was increasing slowly over the 20th century up to 1970. Then the rate of increase multiplied by 5 to 10. Significant long-term changes in salinity were observed predominantly in the shallow north part of the sea. They were caused mainly by variations in the Volga flow. Chlorophyll concentration was also changing at the end of the 20th century and the beginning of the 21st century; however, the long-term tendencies have not been detected. The Caspian Sea level varied substantially over the 20th century, roughly from –29 to –25.7 m (in the Baltic System of heights, BS), see Fig. GS11. Its significant decrease by 1977 and subsequent increase by 1995 caused noticeable damage to the regional environment and economy. According to existing mid-term projections, the Caspian Sea level will not exceed –26 m (BS) by 2015.

The long-term (up to the end of the 21st century) projections of the Caspian Sea level are uncertain. According to some studies, an increase is expected, while others project a decrease. The major source of uncertainty is differences in the parameterization of evaporation processes (AR, vol. II, Ch. 3.9). An increase in the Caspian Sea level exceeding –26 m (BS) may negatively affect settlements and economic infrastructure, and the landscape within the coastal area up to 30 km wide.

It would be expedient to account for the risk of flooding in the coastal zone of the Caspian Sea in the long-term planning of the development of the coastal regions, namely, the Astrakhan' region, Republic of Dagestan, and Republic of Kalmykiya. Such plans should include special adaptation measures for settlements and infrastructure, in particular for transport.

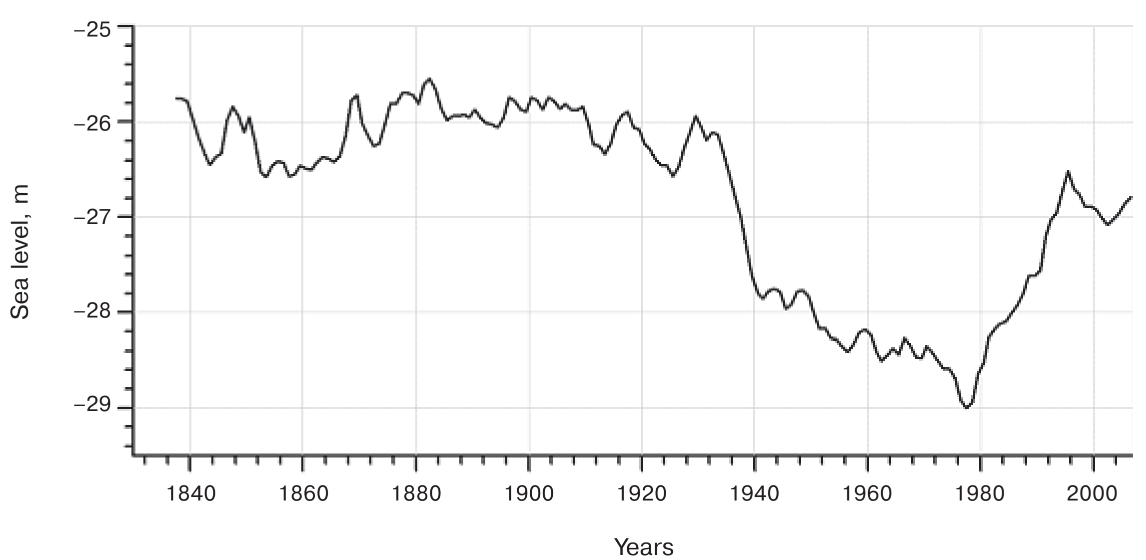

Fig. GS11. The long-term variations of the Caspian Sea level (m BS) in 1837–2006 (AR, vol. II, Fig. 2.9.14).

Engineering systems

Buildings and constructions. A tendency towards an increase in snow loads on buildings and engineering constructions has revealed at the end of the 20th century. Wind and icing-wind loads have declined on average. Negative effects of frosting and thawing on buildings increased in the European part of Russia and in the Far East (Primorye). The strength of basements of buildings and engineering constructions located on permafrost has declined in some Siberian regions. This occurred due to changes in the bearing capacity of ground induced by warming and an increase in the depth of seasonal thawing. The contribution of the enhancement of karst processes also played its role (AR, vol. II, Ch. 2.2).

Winter and summer river flows are projected to increase in the Central and Privolzhskiy federal districts, in the southwestern part of the Northwestern federal district and in some other regions by 2015. These changes along with reduction in depth of seasonal ground freezing and its duration will result in groundwater level rise. This may lead to flooding of the vast areas and to deformation and weakening of basements of various buildings and engineering constructions in the Russian plains, since excessive moistening, high level of ground waters and weak drainage capacity are inherently typical of them.

In particular, monuments and architectural complexes and the valuable historical centers of cities in the Arkhangelsk, Vologda and Leningrad regions, the Golden Ring landmarks located in the Kostroma and Nizhniy Novgorod regions and in other areas of the Northwestern and Central federal districts may be damaged. Such processes have already been detected, and, under changing climate, their intensity is expected to increase in the near future.

An increase in precipitation (in particular, liquid and mixed) and frequency of heavy precipitation over a significant part of Russian territory has led to worsening the maintenance conditions for highways and railways and to a danger of erosion for them in some locations. Car transportation along zimnik[1] roads and frozen rivers have become worse due to warming in the Siberian and Far East federal districts, in particular, in the Republic of Sakha (Yakutia) and in the Magadan region.

Under further warming these tendencies will be kept on throughout the 21st century. The negative effects of climate warming on the bearing capacity of ground in the permafrost regions will be most significant in the Chukchi Peninsula, in the upper parts of the Indigirka and Kolyma basins, in the southeastern part of Yakutia, in a substantial part of the West Siberian Plain, on the Kara sea coast, at Novaya Zemlya island, as well as within the area of isolated permafrost area in the north of the European part of Russia. Under changing climate, intensification of riverbed erosion will increase the risk of emergencies in the underwater parts of pipelines (AR, vol. II, Ch. 3.2).

Changing climatic conditions should be taken into account in designing buildings, engineering constructions, communication and transport means, in the development of rules for their maintenance. This can enhance the adaptive capacity of the economic sphere to the climate change. For prevention of possible emergencies at pipe-lines, the design life for underwater parts of the pipe-lines should be revised and reduced, and respective efficient monitoring system of pipe-lines has to be set up.

It is expedient to launch a program for the investigation of historical heritage landmarks, other important buildings and engineering constructions, aiming at prevention of their flooding, deformation and weakening of basements induced by groundwaters rise level. Special protection measures, including control measures for water regime of flooding areas, should be worked out.

Heating season. Under climate warming observed over most of Russian territory in the last three decades, normative duration of the heating season and fuel demand for the indoor heating have decreased. The heating season in Russia will be shorter by 3 to 5 days on average in 2015 vs. 2000. The most pronounced reductions, up to 5 days, will be observed in the southern parts of Primorye, Sakhalin and Kamchatka.

Calculated duration of the heating season will decrease in the 21st century vs. the 1961–1990 mean values: up to 5% by 2025 and by 5–10% by 2050 (Fig. GS12). These reductions will be most noticeable in the Far East. Energy demand for the indoor heating will drop respectively. At the same time, air condition expenses for the indoor cooling will become greater, in between, for industrial buildings (AR, vol. II, Ch. 3.2).

In spite of the reductions in the average duration of the heating season, natural variability of climate should be taken into consideration when strategic decisions are being worked out. As a result of this variability in some years the actual duration of the heating season in some regions of Russia may exceed the regional mean values known to date. A tendency

[1] "Zimnik" is a road on the frozen ground which is impassable in other seasons except winter.

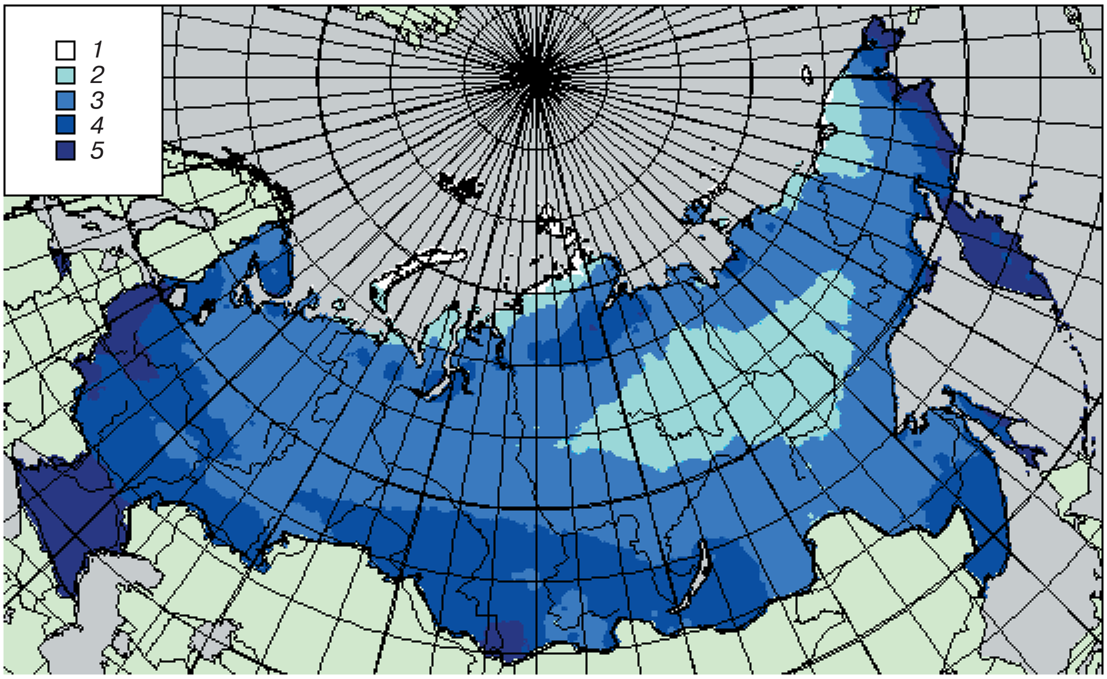

Fig. GS12. Changes in duration of the heating season (%) over Russia by 2025 vs. 1961–1990 mean values: (AR, vol. II, Fig. 3.2.3). *1*) 0…–1,9; *2*) –2…–3,9; *3*) –4…–5,9; *4*) –6…–7,9; *5*) –8…–10.

towards an increase in climate variability may also play a role in the deviation of real demand in heating from its long-term mean values.

Water resources

The annual runoff is a major indicator of water resources. Under natural conditions, it depends predominantly on precipitation in the river basin and evaporation. Augmentation of the annual precipitation (that increased in 1978–2005 vs. 1946–1978) and reduction in potential evaporation over most of Russia led to discernible enhancement in the river flow by the end of the 20th century. The overall annual runoff of the six largest Eurasian rivers running into the Arctic Ocean (namely, Yenisei, Ob, Lena, Kolyma, Northern Dvina, and Pechora) became greater over 1936–2005. Runoff from almost all Russian rivers, except those of the Don basin and of the upper Ob, increased. As a result, water resources of Russia as a whole grew up at the end of the 20th century (AR, vol. II, Ch. 2.4).

On the whole, renewable water resources may increase in Russia by 8–10% in the next 30 years. Their distribution will become more even. However, in some heavily populated regions, which already have limited water resources, a 5 to 15% reduction in their amount is expected along with a 5 to 25% increase in water use load. This is expected in chernozem areas of the Central federal district, in the Southern federal district, and in the southwestern part of the Siberian federal district.

The expected changes in the river runoff will affect the water inflow to the major reservoirs. The annual average inflow to reservoirs of the Volga-Kama cascade reservoir system and of the Northwestern federal district will increase by 5–10%. The inflow to the Angara-Yenisei reservoirs system, and to reservoirs on the rivers Vilyui, Kolyma and Zeya will change by 0–15%. At the same time, the annual average inflow to the Tsimlianskoye, Krasnodaskoye and Novosibirskoye reservoirs will decrease by 5–15%. Seasonal distribution of inflow to reservoirs will also change.

Alterations in the river flow due to expected climate change could be important for the hydropower industry.

In the 21st century, under continuous warming, the glacial runoff will decline both in the Great Caucasus and at its northern slope, although the trends of the overall river runoff in the regions will be positive (AR, vol. II, Ch. 3.4).

In the regions where reduction in water resources is expected, measures aimed at a search and implementation of alternative and additional sources of water for economic needs (in particular, for irrigation and hydropower production) are expedient. Optimization of regional water use is also essential.
Expected changes in the water inflow to reservoirs will require a revision of their operating mode. The interests of major users, primarily of hydro-power industry, and environment protection goals should be taken into account.

Agriculture

In 1975–2004, changes in the heat supply and wintering thermal conditions for agricultural plants, moistening and continentality of climate were positive for crop production in the regions of Russia that produce more than 85% of commodity grain. Despite unfavorable social and economic conditions in the second part of the period, this ensured a positive trend in productivity of cereal and leguminous crops in 70% of constituent territories of the Russian Federation.

Some agricultural pests with the life cycle strongly dependent on climate have become more active in the south of the European part of Russia and Western Siberia in the late 20th century. Locusts and Colorado beetle are amongst them. Their population growth and expansion of ranges have led to considerable yield losses. Further warming over Russia may cause the enhancement of negative impacts of pests on the total crop yield. Particularly, conditions will become favourable for further expansion of locusts in Stavropol Territory, in the Kalmyk Republic, in Volgograd, Astrakhan’, Saratov, and Rostov regions, as well as for the intrusion of locusts into some Siberian regions (AR, vol. II, Ch. 3.5).

The response of agricultural plant productivity to further warming will depend on the character of changes in moistening:

— if moistening reduces in the European part of Russia, productivity will also drop almost everywhere except the north and north-west;

— if moistening rises, the average productivity in Russia will be increasing at least until the middle of the 21st century. Later on, productivity of cereal crops in the Chernozem area will lessen by 10–13% vs. present level, but will exceed the present values by 11–29% in the non-Chernozem area. On condition of present agricultural technologies and geographical distribution of crops, productivity of cereal crops in the Southern Siberia may decrease by 20–25%.

Further warming will allow considerable expansion of the overall agriculture areas in Russia. New opportunities will appear for the geographical expansion of the cultivation of heat-loving agricultural plants. Hence, the limit of cultivation zone for middle-ripening sorts of grain and late-ripening sorts of sunflower will move northward to the Moscow — Vladimir — Yoshkar-Ola — Chelyabinsk line. The limit for sugar beet will be at the Ivanovo — Izhevsk — Kurgan line. New conditions for subtropical agriculture will appear in some southern regions.

The following measures of adaptation of crop production aiming at the use of additional thermal resources are expedient to introduce in areas with sufficient moistening:
— expansion of sowing of more late-ripening and more productive species (varieties) of cereal crops, maize, and sunflower, late-ripening sorts of potato and rape:
— wider use of fertilizers and chemicals which are more efficient in warm and moist climate;
— expansion of beet cultivation and more heat-loving types of green crops, e.g., soybean and alfalfa.

In addition, in the areas of insufficient moistening, adaptation measures should be aimed at the thrifty water use, which means:
— wider application of moisture-saving technologies (snow retention, reduction of inefficient evaporation, etc.);
— expansion of sowing of more drought-resistant cultivars of maize, sunflower, millet, etc.;
— increase in winter crop seeding, namely, wheat in the steppe regions of the Volga and Urals, and barley in the Northern Caucasus;
— expansion of the irrigated agriculture, which is necessary for complete use of additional thermal resources in cultivation of agricultural plants.

Human Health

Climate change can affect human health, including the distribution of some diseases.

Special impact studies of heat waves, i.e., long periods of extremely hot weather, were conducted in several Russian cities, including Moscow and Tver. Negative consequences for morbidity and mortality in some groups of population have been detected. During the last decade, the return time and severity of heat waves have increased (AR, vol. II, Ch. 2.5).

In the 21st century, under increasing frequency of heat waves and elevated maximal temperatures, risks for the vulnerable groups of the population will grow. The combination of heat waves and enhanced air pollution may amplify the negative effects under adverse meteorological conditions. Deterioration of water quality may also occur in some regions, including Kalmyk Republic, Dagestan, and Karachai-Cherkess Republic (AR, vol. 2, Ch. 3.5).

Climate change may alter habitats of certain vectors of infectious and parasitic diseases of humans and animals. Tick-borne encephalitis, Lime disease, hemorrhagic fever with renal syndrome, Crimean haemorrhagic fever, West Nile fever and malaria are amongst them.

During the last three decades of the 20th century, especially at the turn of the century, the incidence of these diseases increased, and their habitat areas extended.

Under further warming these tendencies are expected to continue and even to become more pronounced for some diseases.

Climate change in the Arctic region may affect the health and way of life of indigenous people, particularly due to shifts in the ranges of some species that traditionally serve as resources for local people (AR, vol. II, Ch. 3.5).

The development of means and systems of air-conditioning for residential quarters and industrial facilities, an increase in their availability for people, monitoring of adverse weather conditions, and preventive protection measures in regard to vulnerable groups could serve as means of adaptations to the heat waves.

Continuous monitoring of contagious and parasitic diseases, the habitats and size of populations of vectors will facilitate efficient adaptation to potential expansion of the diseases under climate warming.

Consequences of extreme meteorological events

More than 30 types of dangerous hydrometeorological events are recorded in Russia. On average, the total number of them per year increased at the end of the 20th century and at the beginning of the 21st century. 52% and 48% of them were observed in the European and Asian parts of Russia, respectively. High impact weather events are most frequent in the North-Caucasus and Volga-Vyatka economic regions, in Sakhalin, Kemerovo, Ulyanovsk, Penza, Ivanovo, Lipetsk, Belgorod and Kaliningrad regions, and in the Republic of Tatarstan (AR, vol. II, Ch. 2.10).

According to assessments of the World Meteorological Organization and the International Bank for Reconstruction and Development, a steady tendency towards increase in economic losses and vulnerability of societies associated with increasing impacts of hazardous nature events has been detected. In Russia on average, the annual increase in the number of hazardous weather events in 1991–2005 was 6.3%. This tendency is expected to continue.

Droughts. In the last three decades of the 20th century and at the beginning of the 21st century, the large-scale overall droughts (e.g., the atmospheric and soil draughts simultaneously) were recorded in Russia in 1972, 1975, 1979, 1981, 1995, 1998 and 2002. Droughts of 1975 and 1981 occurred in all crop production regions of the country; they were unprecedented since 1891. The shortage in the total grain harvest in the country was about 23% of the average harvest. However, no certain long-term tendencies in the moistening were detected in the 20th century.

Under some scenarios, regional climate projections show decline in soil moisture in spring and summer, as well as drier conditions over most of European Russia. Assuming a substantial increase in air temperature, precipitation decrease, and the more frequent occurrence of extremely high temperatures and extremely low precipitation, repeatability of soil droughts will increase in southern regions of Russia, in particular, within the Don and Dnieper basins (AR, vol. II, Ch. 3.10.2).

Forest fires. Long periods of dry and hot weather lead to increasing probability of forest fires. They may cause substantial damage. However, the prime source of about 70% of forest fires is violation of fire safety rules by people while in forest. Direct losses from forest fires (i.e., cost of burnt and damaged stands, forest production, etc.) made almost 20 billion rubles in 2004. The number of documented forest fires in Russia increased at the end of the 20th century and at the beginning of the 21st century. The number of days with ‘high or greater’ flammability has noticeably increased, in particular, in the central part of European Russia, in southern parts of Western Siberia and in the Far East.

The number of days with the flammability risk will increase by 5 days per season over most of the country by 2015. The number of days with both high flammability and medium flammability will increase. This is expected to be most pronounced (by 7 days and more) in the southern part of the Khanty-Mansi Autonomous Area, in the Kurgan, Omsk, Novosibirsk, Kemerovo, and Tomsk regions; in the Krasnoyarsk and Altai Territories; and in the Republic of Sakha (Yakutia).

Most of Russia is covered by woods. In this part the number of days per year with potential ‘high or greater’ will increase by 20–60% in the southern parts of European Russia and Western Siberia, at middle latitudes in eastern Siberia and the Far East (Fig.

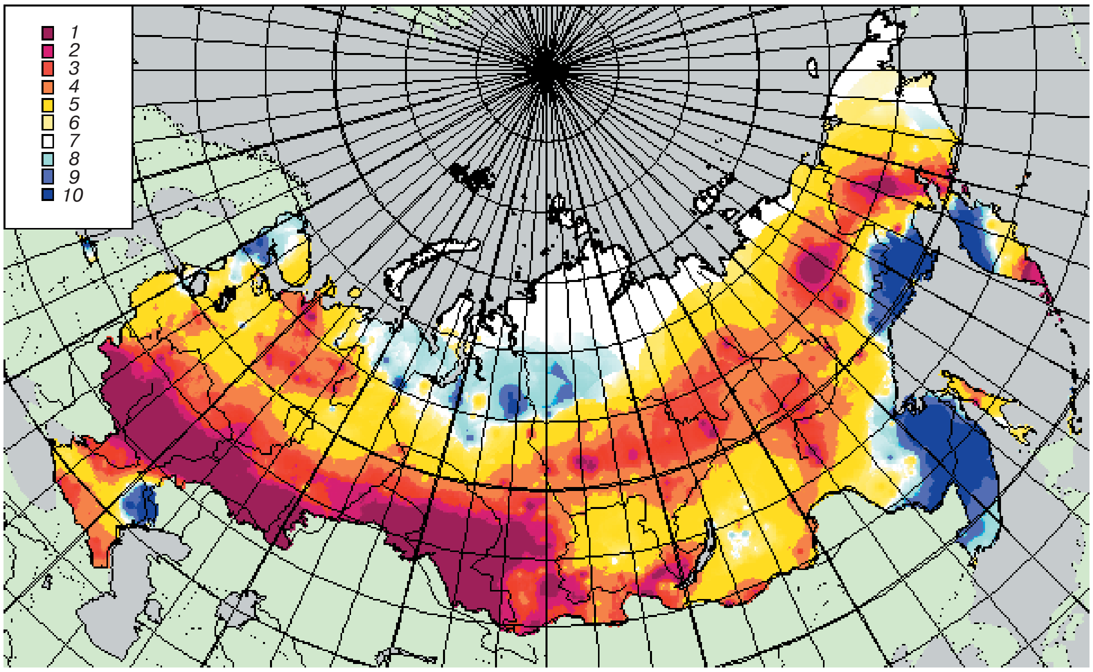

Fig. GS13. Changes (%) in the number of days with 'high and more flammability' by 2025 vs. 1961–1990 mean values: *1*) 60–50; *2*) 50–40; *3*) 40–30; *4*) 30–20; *5*) 20–12; *6*) 12–1; *7*) 0; *8*) –1...–10; *9*) –10...–20; *10*) –20...–30 (AR, vol. II, Fig. 3.10.1).

GS13). At the same time, the number of days with a flammability risk will decrease in Priamurye, in the Magadan region, and in the eastern part of the Kamchatka Peninsula (AR, vol. II, Ch. 3.10.3).

> Remote (plane, satellite) operational monitoring of forests, introduction of more efficient means for suppression of forest fires, and strengthening of respective operative services raise opportunities for effective adaptation to forest fires.
>
> Development and implementation of programs stimulating people to follow the rules of fire-prevention safety while visiting forests, strengthening the nature protection sections in the undergraduate and graduate educational programs are important components of adaptation strategy that may decrease the risks of forest fires.

Floods. At the beginning of the 21st century, in many economic regions of Russia, the frequency of catastrophic flooding caused by high water and spring floods increased by 15% vs. values of the last decade of the 20th century. It was typical, in particular, of the North-Caucasian mountain rivers, of Eastern Siberia and southern part of the Far East. Storm surges in Neva River in St. Petersburg have become more frequent.

Under present tendencies of the climate change continuing in the 21st century, the number of floods should be expected to increase on rivers of a significant part of Russia. As a result of expected precipitation growth, the probability of flooding caused by rainfall at small and medium rivers of the European part of Russia, in particular, of the North Caucasus, and of the Far East will increase. The risk of dangerous floods on rivers in the season of snow melt will grow by 2015 in those regions where ice jams accompany runoff peaks. This is typical of the Arkhangelsk region, Komi Republic, the Ural region, Eastern Siberia, and the north-east of the Asian part of Russia. The probability of storm surges will increase in deltas of big rivers running into the Azov and Baltic seas (AR, vol. II, Ch. 3.10.4).

For reducing damage from inundations and protecting the population, it is necessary to focus efforts on the development of modern automated means for prediction and prevention of flooding. The development of basin-scale flood protection systems is essential. In addition, it is necessary to normalize the land use in zones of risk and to improve the legal base defining the precise responsibility of the state authorities and local administrations for consequences of flooding.

Mudflows and avalanches. Under present tendencies towards climate warming, duration of the period of mudflow danger on the northern slope of the Great Caucasus in the 21st century will increase by 47–50 days on average. The size of mudflows will become greater by 20–30% and amounts of matter forming them will also increase.

The period of avalanche danger will decrease on the northern slope of the Great Caucasus in the 21st century, and the area of avalanche danger will decline at 1500–2000 m altitudes. The frequency of large catastrophic avalanches at heights more than 3000 m will increase (AR, vol. II, Ch. 3.10.5).

Conclusions

Scientific findings of the IPCC Fourth Assessment report, published in 2007, present further evidence that the main cause of observed global warming is associated with increasing human activity. At present it continues to be major concern among public organizations, business community, and governments of most countries of the world.

Studies of Russian scientists, set forth in the first national assessment report, also agree well with IPCC findings. Furthermore, climate change is expected to produce significant influence on the environment and socio-economic activity of different regions of the country.

Most of Russia is located in the area of considerable observed and projected climate change. Due to large size of the country and specific inherent patterns of natural environment, climate changes can manifest regional non-uniformity. In some regions they may be favourable, in others they may produce negative impacts. For example, climate change will favor the displacement of the zone of comfortable habitation northward, reduction of the heating period, and the increase in farming potential in regions with sufficient water resources. Global warming will also provide favourable influence on ice conditions in the Arctic seas, enhancing the potential for sea transportation and development projects on the Arctic shelf.

On the other hand, reduction of water resources is expected in the regions where their deficit is experienced now. Enhancement of seasonal thawing of permafrost, especially nearby its southern boundary, poses a threat to infrastructure installations (houses and engineering constructions, communication lines, including oil and gas pipelines). Climate changes might increase the probability of occurrence of extreme events, such as hurricanes, tornados, floods, avalanches and mudflows in mountain regions, droughts, fire risks in forests. All these will cause significant negative consequences for the population, as well as social and economical activities. Due to climate warming considerable changes are also expected in natural ecosystems, such as enlargement of ranges of some vector-born human diseases.

Further study of future climate change and its consequences and evaluation of adaptation potential are required for the whole country and its individual regions. Special attention should also be given to the development of early warning systems and techniques for prediction of extreme events leading to serious negative socio-economical and ecological consequences.

It is necessary to strengthen studies aimed at the development of technologies contributing to reduction of climate change, increase in energy saving, use of renewable energy sources, and development of carbon dioxide capture and storage technologies.

High-quality performance of the national integrated climate observing system operated under Roshydromet is the basis for successful study of climate change in the country and participation in the international cooperation efforts.

Significant dependence of the natural environment and economy on climate, a large variety of expected impacts on socio economic activity in the country and participation of the Russian Federation in international efforts aimed at mitigation of the anthropogenic influence on global climate require well grounded basis for proper definition of national policy in this problem area. The necessary components of such policy are measures directed at decreasing anthropogenic influence on climate and measures of adaptation to changing climate (i.e., prevention or reduction of harmful consequences of climate change). The most sizeable actions must be regulated by the governmental decisions taking into account that an important part of such actions requires international coordination.

In order to support proper planning and implementation of national climate policy, Roshydromet together with other concerned agencies of the Russian Federation intends to publish, on a regular basis, national assessment reports on climate change, its consequences, and the potential for adaptation to climate change.

ASSESSMENT REPORT ON CLIMATE CHANGE
AND ITS CONSEQUENCES IN RUSSIAN FEDERATION

General Summary

Design and original lay-out are developed by RSC “Planeta”
Editor ***N. V. Leshkevich***
Proof by ***V. V. Borisova***
Designed by ***I. V. Lomakina***
Translated by ***V. P. Meleshko*** and ***S. M. Semenov***

Signed for printing: November 18, 2008.
Offset printing. Format 60 X 84 1/8.
Circulation 400 copies. Order # 36.
Published by RIHMI-WDC
(6, Korolyova str., Obninsk, Kaluga region, Russia)