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AND ENVIRONMENTAL MONITORING (ROSHYDROMET)

SECOND ROSHYDROMET ASSESSMENT REPORT ON CLIMATE CHANGE AND ITS CONSEQUENCES IN RUSSIAN FEDERATION

GENERAL SUMMARY

Moscow — 2014

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General Summary

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The Second Roshydromet Assessment Report on Climate Change and its Consequences in the Russian Federation consists of **the main Report, Technical Summary and General Summary**

This brochure is an English version of the General Summary. The Russian original is an official publication of the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) prepared under the general editorship of Dr. A.V. Frolov, Head of Roshydromet.

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Preface

Since the mid-1970s mean surface air temperature in the Russian Federation has been increasing at an average rate of 0.43°C per decade, which is 2.5 times faster than the global warming. Changes in the climate of the Arctic region and subarctic zone of permafrost have become particularly significant.

The ongoing climate change is a matter of a serious concern since its impact on natural and economic systems as well as on humans is becoming more and more evident. Internationally, the need for urgent and effective measures aimed at mitigation of impacts of economic activities on the Earth's climate system and adaption to climate change is now widely recognized. These measures are within the scope of international agreements, primarily the United Nations Framework Convention on Climate Change (UNFCCC).

The development and practical implementation of these measures, which are often cost intensive and even painful for national economies, should be based on objective scientific findings, rigorous and balanced information and careful analysis of observations taken primarily from the state-owned climate monitoring networks. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 for the regular preparation of comprehensive scientific reports assessing the status of climate research and targeted to the general public and policymakers.

The IPCC has issued four Assessment Reports. The Fifth Assessment Report is currently being finalized by the IPCC. Usually "on the shoulders" of the recent IPCC Reports, regional and national assessment reports are prepared providing details on the IPCC findings for respective territories and countries. The Russian Federation also takes part in this process. In 2008, the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) along with the Russian Academy of Sciences and educational institutions issued the first "Assessment Report on Climate Change and its Consequences in Russian Federation"*. De facto the Report was used as a basis for the Climate Doctrine of the Russian Federation approved by the President of the Russian Federation on December 17, 2009. The document is a political declaration determining the main direction for the development of legal, economic and other tools which would protect the state, economy and society against unfavourable consequences of climate change and open the door for benefiting from potentially favourable climate change consequences. As a direct and immediate result the Climate Doctrine Implementation Plan was prepared (2011). More detailed federal, regional and sector-specific programmes and action plans are expected to be developed on its basis.

Six years have passed since the publication of the Roshydromet's first Assessment Report. During this time climate databases were considerably updated, comprehensive models of the Earth's climate system continued to be improved, a lot of climate change-related scientific publications were issued. Manifestations of climate change (e.g., a steady decrease of sea ice extent) became gradually more intense. In addition, large weather and climate anomalies were experienced in Russia in this period, such as a heat wave over the European part of Russia in summer 2010 and flood on the Amur River in 2013. Extreme events of such magnitude need to be understood from the climate perspective, since they give evidence of increasing climate threats, which can

* Assessment Report on Climate Change and its Consequences in Russian Federation. In two volumes, Moscow, Roshydromet, 2008, 230+291 pp.

lead in the nearest future to a substantial increase in economic and human losses, unless measures for adapting sectors of economy and territories to climate change are taken.

Climate issues remain in the focus of the international agenda. In 2012 the first commitment period of the Kyoto Protocol ended. Nowadays, countries seek to come to a new global legally binding, improved and more fair agreement. Furthermore, under the auspices of the World Meteorological Organization a new initiative has evolved: the Global Framework for Climate Services (GFCS). The initiative is intended to provide information services to facilitate adaptation to the current and expected climate change.

Against this background, Roshydromet has undertaken the preparation of the "Second Roshydromet Assessment Report on Climate Change and its Consequences in Russian Federation". The team of contributors included lead experts from research institutions of Roshydromet, Russian Academy of Sciences and educational institutions. Taking the opportunity I would like to express my sincere gratitude to all the participants of this team for the long-lasting, fruitful and harmonious cross-disciplinary work conducted in the atmosphere of mutual understanding and creativity.

Similarly to the first Assessment Report the new Report of Roshydromet is based on materials from peer-reviewed periodical and continued editions, scientific monographs, proceedings of scientific conferences and special scientific reports published upon the decision of scientific editorial councils and boards. Observational data from the federal observing network of Roshydromet as well as from scientific projects implemented under various international and national research programmes were widely used in the Report.

Being an official publication of Roshydromet, the General Summary of the "Second Roshydromet Assessment Report on Climate Change and its Consequences in Russian Federation" is prepared primarily for the federal and regional authorities that develop and implement the national climate policy in compliance with the Climate Doctrine of the Russian Federation, including planning specific tasks relevant to various sectors of economy and programs on sustainable development of territories and regions of the country. The Report can be used by both scientific and educational institutions. It is also intended for professional analysts and practitioners specializing in the field of climate and related problems, including those from business community and field-specific non-governmental organizations, as well as for the general scientific community and for all who are interested in the climate change issues.

A.V. Frolov
Head,
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Section 1. OBSERVED CLIMATE CHANGE

Greenhouse gases, aerosols and climate

Since the publication of the first "Assessment Report on Climate Change and its Consequences in Russian Federation" (AR_RF-1, 2008) no fundamental changes in trends of the atmospheric composition, sources of emission and the effect of major long-lived greenhouse gases have been observed. At the same time, the knowledge regarding atmospheric cycles of short-lived factors affecting radiation regime of the atmosphere and climate characteristics has grown substantially. This relates primarily to aerosols in the form of the so-called black carbon, whose influence on climate was practically not covered in AR_RF-1.

After 2007 the global greenhouse gas monitoring network continued to grow and improve. The number of stations and observation analytical systems has increased.

Carbon dioxide (CO_2) *in 2007—2012.* According to the data from six US monitoring stations, the global mean annual concentration of CO_2 increased from 382.7 to 392.5 ppm; a significant rise in emissions in China and India took place simultaneously. The global mean annual concentration of CO_2 in the atmosphere was 395.3 ppm in 2013. These estimates are in agreement with the data from Russian stations (eg. Fig. GS1.1). The global anthropogenic industrial emission of CO_2 increased from 8.3 ± 0.7 to 9.4 ± 0.8 Gt C/year over 2002—2011, while land use contributed another 0.9 ± 0.8 Gt C/year.

Methane (CH_4). In 2011, the mean global surface concentration of CH_4 was 1813 ppb; it increases by 100 ppb along with latitude (from southern polar latitudes to northern polar latitudes). It is due to emissions of CH_4 from northern swamps and frozen ground and possible emission from gas-hydrates in the shelf area. The global atmospheric emission of methane from natural sources is estimated at 220—470 Mt CH_4; methane leakage from coal and gas mining (which is not properly reported) must be added to this,.

In recent years, aerosols claim to play a significant role in climate change. This primarily relates to black carbon capable of absorbing solar radiation. In terms of contribution to radiative forcing it ranks second after CO_2, but such estimates have a high degree of uncertainty and inaccuracy. Comparison of model outputs with measured concentrations of black carbon in the air (in high northern latitudes as well as in the middle and tropical latitudes) showed that in some cases estimates produced by models exceeded observed values considerably (several times).

Surface air temperature

One of the key outcomes of the recent global climate measurements is global warming observed

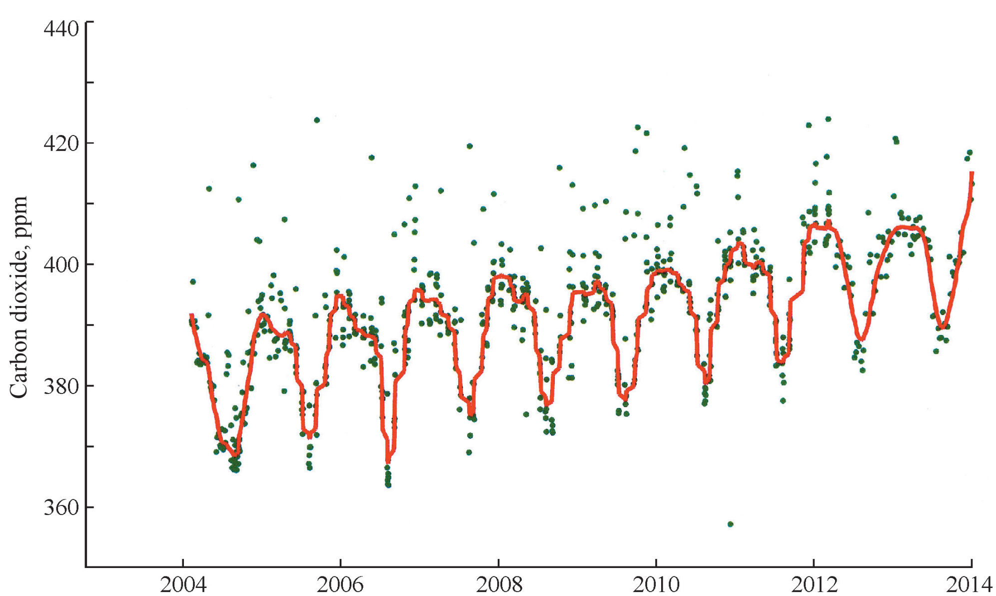

Fig. GS1.1. Daily measurements data of CO_2 concentration at Novy Port station in 2004—2013. Red curve shows the calculated seasonal course of CO_2 concentration .

from the late 20th to early 21st century (beginning from the late 1970s); a key indicator is the global (i.e. averaged over the whole globe) surface air temperature. According to observations, the average rate of global warming is 0.166°C/10 years in 1976—2012 and 0.075 °C/10 years in 1901—2012. In the last decade, a certain slowdown of global warming is exhibited: the global temperature fluctuates around high values that have been reached. However, the first 12 years of the 21st century is globally the warmest 12-year period on record.

In the time series of annual mean anomalies of the surface air temperature averaged over the territory of Russia (Fig. GS1.2), as well as in the global time series, the period after 1976 shows the most intensive warming (Table GS1.1, Fig. GS1.3).

Compared to the estimates presented in AR_RF-1 the average rate of warming for Russia as a whole has not changed (0.43° C/10 years), but inter-seasonal differences between trends have become more pronounced. In all seasons except winter, local estimates of trends are positive almost on the entire

Table GS1.1. *Comparative estimates of the average rates of surface climate warming in Russia in 1976—2006 and in 1976—2012*

Season	1976—2006		1976—2012	
	b	α_0, %	b	α_0, %
Year	0.43	0.2	0.43	0.0
Winter	0.35	28.1	0.18	40.4
Spring	0.52	1.4	0.56	0.0
Summer	0.41	0.0	0.44	0.0
Autumn	0.43	5.6	0.54	0.1

Notes: b — linear trend coefficient (°C/10 years); α_0 — critical significance level. The trend estimate is usually assumed statistically significant if $\alpha_0 \leq 5\%$.

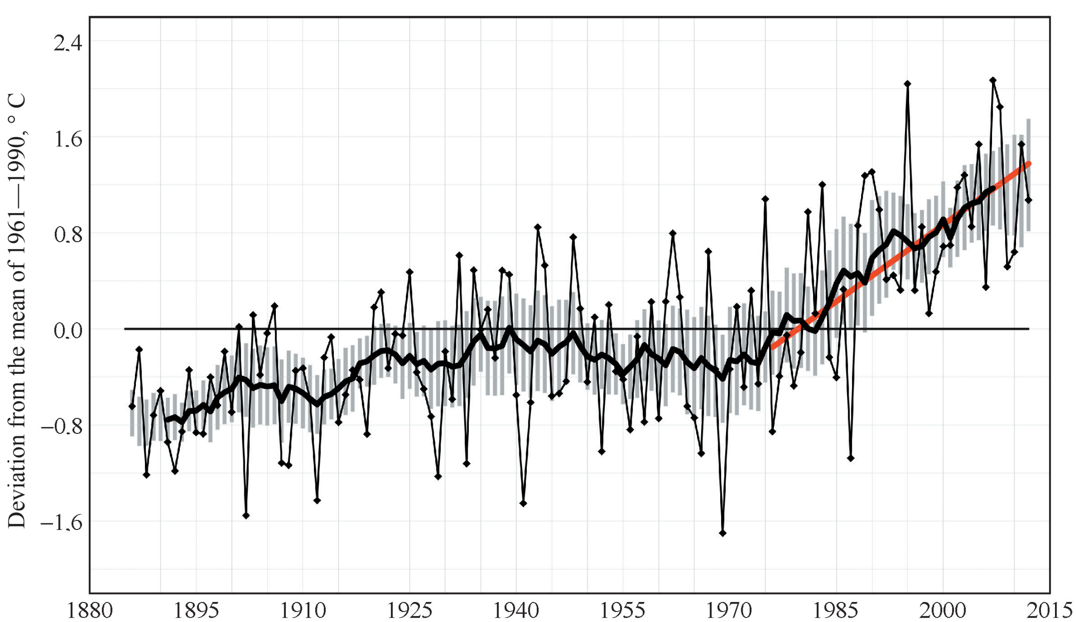

Fig. GS1.2. Changes in the anomalies of the mean annual surface air temperature averaged over the territory of Russia in 1886—2012. Anomalies are calculated as deviations from the 1961—1990 means. The thick line implies a smoothed air temperature course (11-year moving averages). Vertical lines show the 95% confidence interval for 11-year averages (errors of spatial averaging and violation of homogeneity are not taken into account). Red line shows trend for 1976—2012.

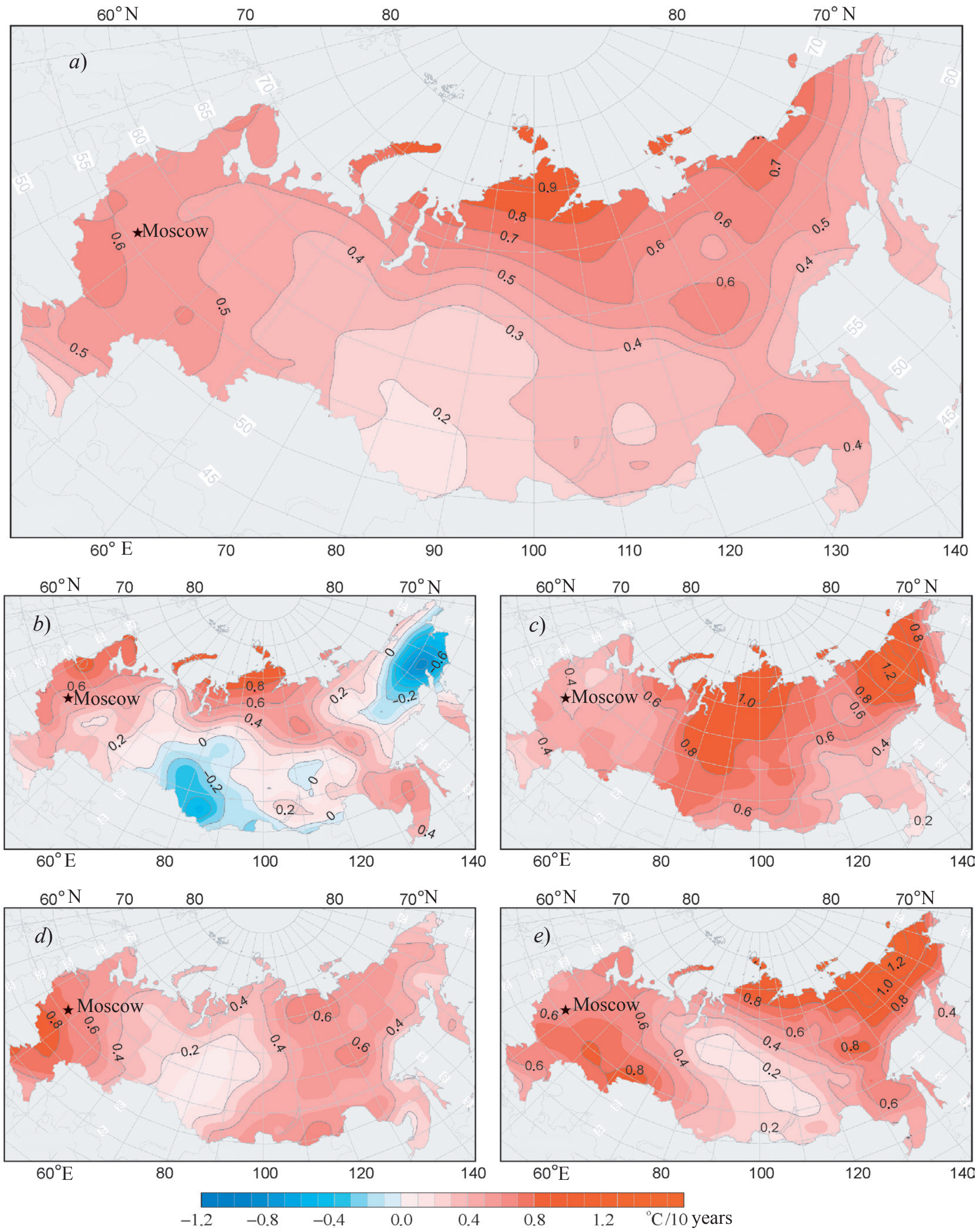

Fig. GS1.3. Geographical distribution of linear trend coefficients for mean annual (*a*) and mean seasonal temperatures (*b — e*) on the territory of Russia in 1976—2012: *b*) winter; *c*) summer; *d*) spring; *e*) autumn. The estimates are based on the observations provided by the Roshydromet's network (data are accumulated for the period since 1886; the database is maintained by the IGCE).

territory of the country. They indicate with confidence that for Russia as a whole warming is continuing (a hypothesis on the absence of warming is rejected at significance level of 0.01%). On the other hand, for several years, winter temperature in the south of Western Siberia has been showing a tendency for cooling (down to –0.6 °C/10 years). This tendency gradually extends to the whole territory of the Asian part of Russia (APR). Therefore, in contrast to the global situation the current climate change in Russia in general (on average per year and averaged over the whole territory) should be characterized as continued warming and according to observations the slowing tendency so far is not discernible (at least during all seasons except winter).

Precipitation

Trend of annual precipitation over 1976—2012 is positive on the most of Russian territory. It is 0.8 mm/month per 10 years for Russia on average (Fig. GS1.4). Estimates of changes in precipitation for Russian territory are obtained on the basis of two different data sets maintained by the Institute of Global Climate and Ecology (IGCE) and the Voeikov Main Geophysical Observatory (MGO). Estimates calculated on the basis of IGCE data set are consistent with the estimates provided in AR_RF-1. The MGO data set is compiled on the basis of hourly precipitation data adjusted accounting all precipitation measurement distortion factors including the main factor, namely, the aerodynamic one. Difference in estimates derived from both data sets and related difference in uncertainty of observed changes in precipitation is still a topic for discussion. Changes in regionally averaged annual bulk precipitation in all regions except Central Siberia are observed against the background of intensive inter-annual fluctuations.

Estimates of changes in precipitation are sensitive to additional adjustments (primarily aerodynamic) in the initial data. An estimate of the annual precipitation trend for 1976—2010 accounting the aforementioned adjustments is positive (0.3 mm/month per 10 years).

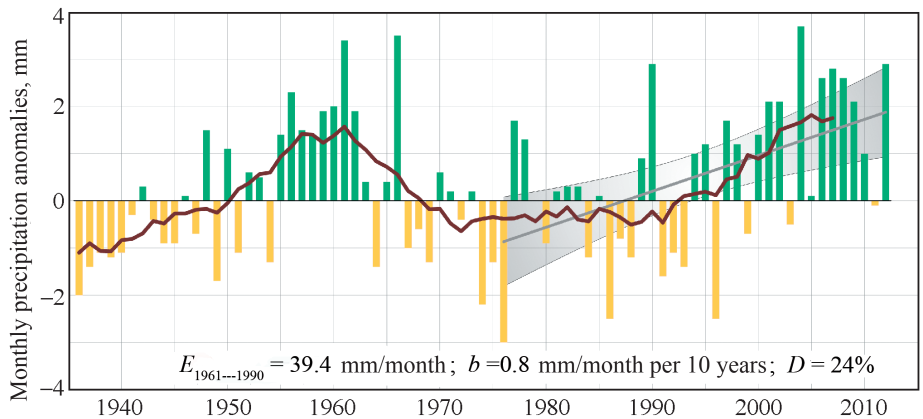

Fig. GS1.4. Mean annual anomalies of monthly precipitation (mm/month) averaged over territory of the Russian Federation, 1936—2012. Estimates are obtained on the basis of the IGCE data set. Anomalies are calculated as deviations from the 1961—1990 means ($E_{1961-1990}$). The smoothed curve shows 11-year moving averages. Linear trend and its 95%-confidence interval are estimated on the basis of data for 1976—2012; *b* — regression coefficient, *D* — contribution to the total variance.

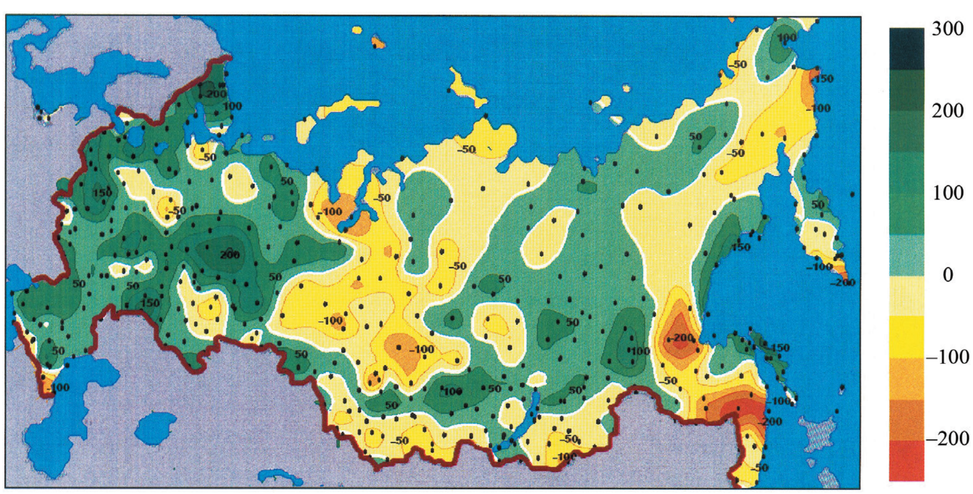

Fig. GS1.5. Temporal changes in the annual precipitation (mm per 75 years) on the territory of Russia in 1936—2010. Estimates are obtained on the basis of the MGO data set. Dots show the stations which provided the data used to construct the map.

Both estimates (with and without data adjustments) show that the maximal increase in seasonal precipitation falls on spring (1.6 mm/month per 10 years). In 1936—2010, annual precipitation increases virtually on the whole territory of the European part of Russia (EPR) and in the Central Siberia (Fig. GS1.5). In Western Siberia, Eastern Siberia, the Baikal and Transbaikal regions, the Amur River region and Primorye territories negative trends prevail. Further to the east the annual precipitation rise is observed occasionally in the narrow coastland area of the Sea of Okhotsk and Sakhalin. Solid precipitation decreases on most of the Russian territory. Liquid and mixed precipitation grows everywhere, particularly in the EPR. Duration of heavy precipitation in 1976—2010 increased on the territory of Russia as a whole.

Snow cover

The highest number of days with snow cover on the territory of Russia is recorded at the coast of northern seas (more than 250 days), the lowest is observed at the cost of the Caspian Sea (about 20 days). On most Russian territory the duration of the snow cover period is more than 100 days. The mean annual maximal accumulation of snow in winter is observed in the north-east of the EPR, Western Siberia and Kamchatka (more than 80 cm).

For considerable part of Western Siberia, Eastern Siberia, coast of the Sea of Okhotsk, in the south of the Far East and in the central and northeastern areas of the EPR the maximal depth of winter snow cover has shown a tendency to increase in 1966—2012 (Fig. GS1.6). At the same time, in Transbaikalia the

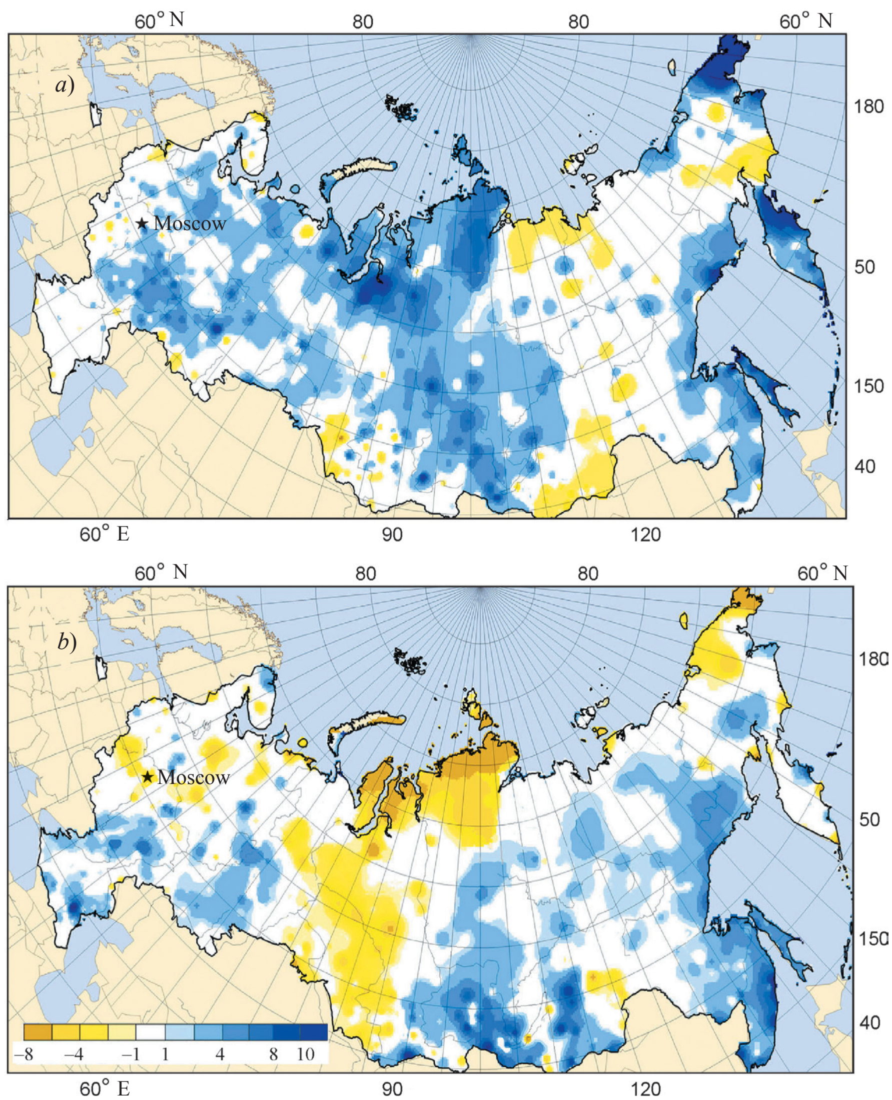

Fig. GS1.6. Changes in the maximal value of the winter snow cover depth (*a*; cm/10 years) and number of days with snow covering more the 50% of the area around station (*b*; days/10 years) for 1966—2012.

maximal depth of winter snow cover decreases due to the lower solid precipitation and considerable rise in spring temperature. The maximal water equivalent of winter snow grows (according to the data of field route surveys) in the north of the East European Plain, in the southern part of the Eastern Siberia forest area and in the Far East. In Western Siberia the maximal water equivalent of winter snow decreases (according to the data of route surveys in the forest). The snow cover period becomes shorter in Western Siberia, Taymyr and Yakutia. In the recent years, later dates of snow cover formation and earlier dates of snow cover loss are found in the north-east of Siberia against the background of sharp interannual fluctuations. Across most of Russia, except for steppe zones of North Caucasus and Western Siberia as well as southern monsoon part of the Far East, the time period of ice crust presence under snow cover becomes shorter and its maximal thickness becomes less.

According to satellite data, the extent of snow cover in Russia in transitional seasons decreases in the last four decades.

Cloudiness and radiation regime

The analysis of the ground-based cloud observations showed that the main tendencies revealed in the late 20th century proved to be valid in subsequent years. There sustains the well-established tendency towards increasing frequency of convective and high clouds. Shares of rain clouds of various types continue to be redistributed. This redistribution is manifested predominantly in the increase of a share of cumulonimbus clouds. Only in the Urals and coastal areas of the Far East a share of nimbostratus clouds has increased in 2001—2010 vs. previous decade. An increase in the total cloud cover and decrease in clear sky weather frequency is observed mainly in spring and autumn.

Since the mid 1990s, in the absence of heavy volcanic eruptions a negative trend in the integral atmospheric turbidity has been clearly revealed in the centre and in the south of the EPR. On the rest of the territory changes in this parameter are poorly expressed and ambiguous (Fig. GS1.7). Moreover, at a time when the total moisture content in the atmosphere grows due to air temperature rise on most Russian territory, there is a negative trend in the aerosol component of the atmospheric turbidity.

An increase in incoming solar radiation observed by the ground-based systems in many regions of the globe in the last decade of the 20th century is also noted virtually across the entire Russia with different confidence.

Changes occurring in the early 21th century are not so large-scale and unambiguous (Fig. GS1.8). In the EPR, particularly in the central and southern regions, a positive tendency continues. This tendency is also typical for the rest of Europe. At some stations the values stabilized at a certain level, though they did not reach their maximum observed in the 1960s. In some regions of the APR a tendency for a decrease in direct and total radiation is restored. This tendency is most pronounced in Central Siberia.

Atmospheric circulation

The following *large-scale circulation systems* are of the greatest interest in relation to the climate of Russia: the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO) and the East Atlantic

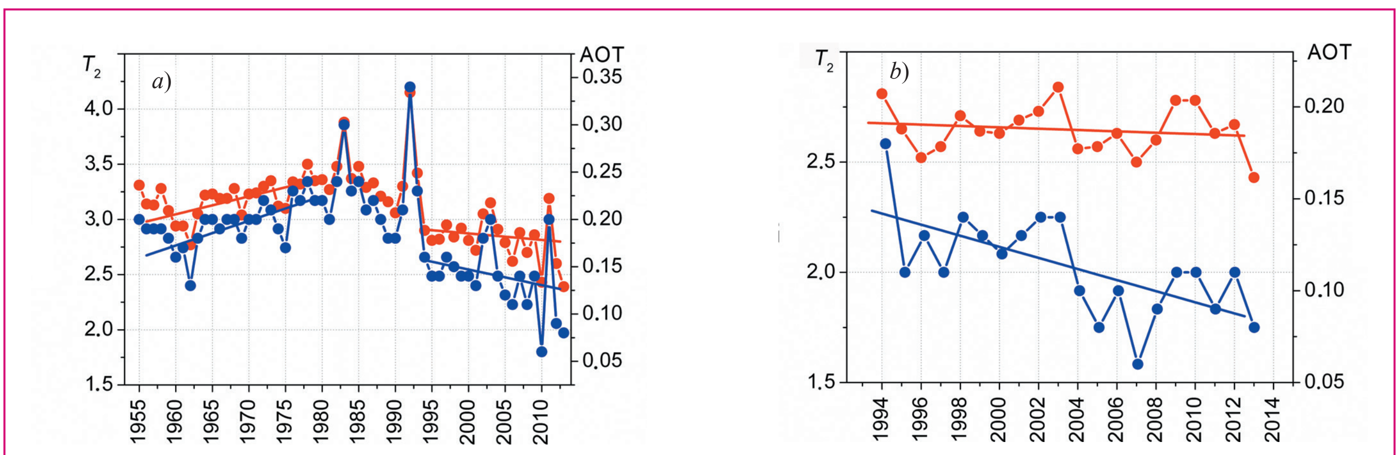

Fig. GS1.7. Mean annual values of the integral atmospheric turbidity T_2 (red lines) and aerosol optical thickness AOT (blue lines) averaged over territory of the EPR (*a*) and Western Siberia (*b*). Straight lines depict linear trends.

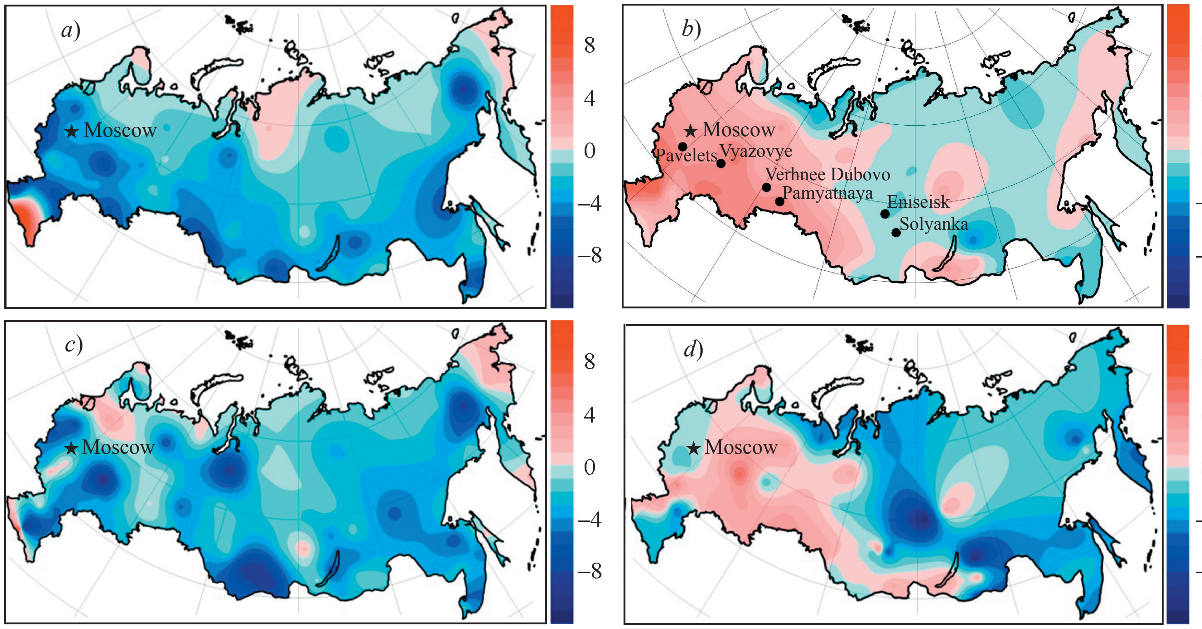

Fig. GS1.8. A change in the annual mean flow (W/m^2/10 years) of direct and total radiation coming to the land surface at different time intervals: *a*) direct radiation, 1961—1985; *b*) direct radiation, 1986—2010; *c*) total radiation, 1961—1985; *d*) total radiation, 1986—2010.

Oscillation (EAO). Amongst them the AO Index is most closely associated with the air temperature anomalies on the territory of Russia.

Cyclones of the Northern Hemisphere are born near the eastern coasts of Asia and North America. In their life cycle they move to the north-east and starts to fill near the Alaska Bay. A close correlation between frequency of Atlantic cyclones and the NAO Index has been found. The lifetime of a cyclone does not exceed three days on average. The mean effective cyclone radius ranges from 200—300 km over continents to more than 900 over oceans. In the second half of the 20th century, winters in North America, North Atlantic and Western Europe show a decrease in cyclone activity and, on the contrary, an increase in anticyclonicity. A decrease in cyclone frequency over the Black Sea and its increase in the Arctic region has also been found.

In 1936—2006, *a surface wind speed* exhibited the following main tendencies: a decrease almost across the whole of Russia (particularly in the EPR, where the decrease reached 0.3—0.6 m/s per 10 years on average); an increase in frequency of low speed wind (up to 3 m/s) and decrease in frequency of higher speed wind (6—7 m/s). The analysis of wind speed time series based on data from 1457 meteorological stations of Russia for 1977—2011 showed that on most of the Russian territory (particularly in the EPR and Western Siberia) wind speed continues to decrease, particularly in winter and spring (Fig. GS1.9). This tendency is consistent with the decrease of surface wind speed on all continents of the globe, except for high latitudes of both hemispheres (higher than 75°), where, on the contrary, the surface wind speed increases. Wind speed also increases over oceans. Reanalysis data indicate that the number of storm winds grows in Central, Northern and Western Europe as well as over the North and Baltic Seas.

Considerable climate anomalies, namely, extreme frosts in winter and droughts in summer are associated with *blocking atmospheric anticyclones (blockings)*. Blockings develop mainly over the Atlantic Ocean and Eurasia, where 73% of their total number occur. Duration of blockings is up to 50—60 days. As for the mean annual number of blocking events, winter blockings play the key role (42%) in the Euro-Atlantic area, while summer blockings prevail in the Euro-Asian (Russia) area. It is also shown that blocking events are more frequent and more intensive during the La Niña period.

Blocking events are associated with meridional forms of circulation, whose frequency has been increasing in recent years, so has the frequency of blocking processes. The conclusion on increased frequency of meridional forms of circulation is also based on the *visual typifications of atmospheric processes* in the Northern Hemisphere.

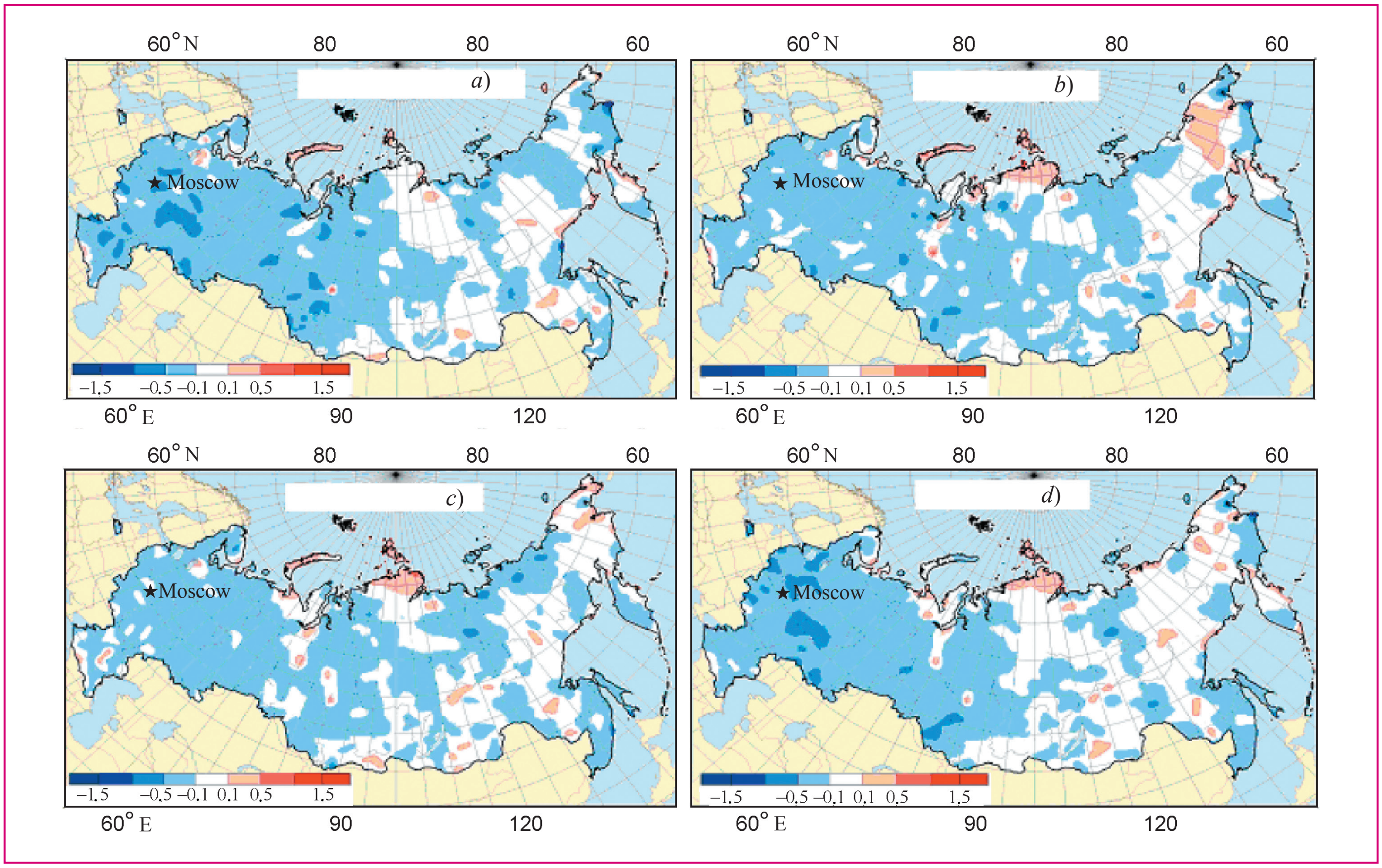

Fig. GS1.9. Distribution of local coefficients of linear trend for surface wind speed (m/s per 10 years) over Russian territory in 1977—2011 in winter (*a*), spring (*b*), summer (*c*) and autumn (*d*).

Extremeness of climate

Extreme weather events (floods, hurricanes, droughts, etc.) are a matter of serious interest due to their negative and often catastrophic impact on natural and man-made systems. The observed global warming may alter frequency and intensity of some extreme events. It is notable that relatively small changes in mean values may lead to considerable changes in statistics of extremes. In terms of geographical distribution these changes may be rather heterogenous, since both natural changes in the atmospheric circulation or those caused by anthropogenic climate change may be non-uniform. Therefore it is important to point out the main geographical features of temporal changes in various characteristics of climate extremeness. A brief summary of changes in the statistics of extreme weather events occurred on the territory of Russia in recent decades is given below.

Air temperature (Fig. GS1.10). Annual air temperature minima and maxima have been increasing on the most of the territory of Russia. The highest increase is observed in the east of the EPR. In the North Caucasian Federal District, in the south of Western Siberia and in Transbaikalia cold temperatures rise; in the South Urals, Siberia and Far East annual maxima decrease. Seasonal extremum values change similarly (5th percentile of winter values and 95th percentile of summer values). In all the seasons the number of days with anomalously high temperature tends to grow (which is most noticeable in summer in the APR) and the number of days with extremely low nighttime air temperature decreases. The total number of days with frost declines almost everywhere over the whole year and in transitional seasons, particularly in autumn. The number of heat waves and their duration and intensity in the western part of Russia show a positive trend in all seasons; the trend of these characteristics for the cold waves is negative.

Precipitation. In winter, over most of the EPR there is an increase in the number of days with anomalously high amount of precipitation (≥ 10 mm). On the contrary, in summer, this number declines notably in the western half of the EPR, the Urals and on most of the North Caucasian Destrict and Southern

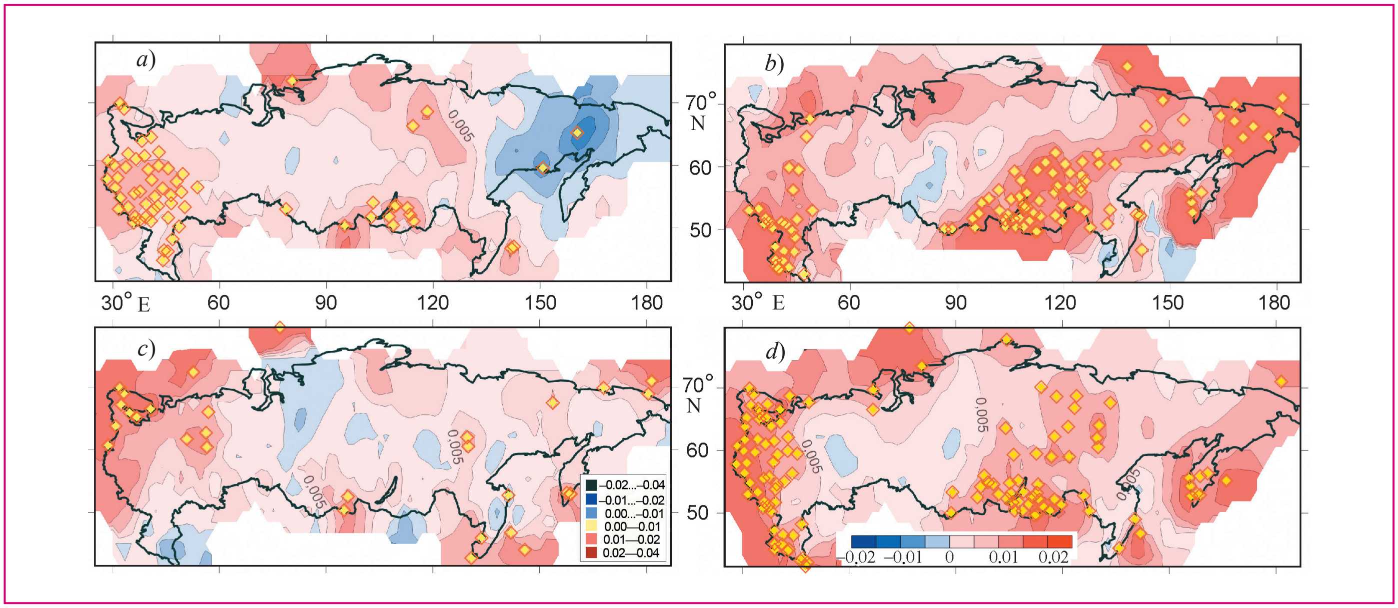

Fig. GS1.10. Changes in P_{95} (*a, b*) and P_5 (*c, d*) percentiles for the standardized temperature anomaly in winter (*a, c*) and summer (*b, d*) (linear trend for 1976—2009.) Anomalies are calculated against the yearly course for 1976—2009. Isoline step: 0.005 year^{-1}. Yellow dots show stations, where trend is significant at the level of 5%.

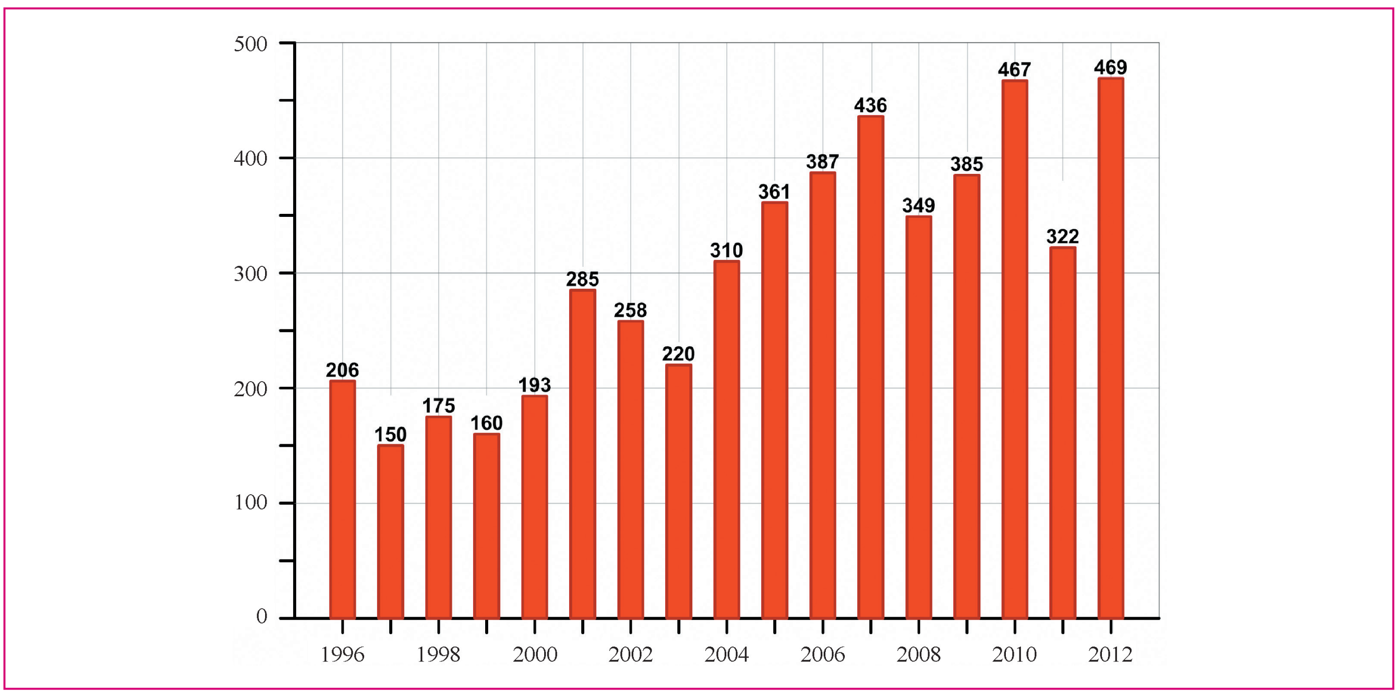

Fig. GS1.11. The total annual number of hazardous hydrometeorological events on the territory of Russia that caused a considerable damage to the economy and population, 1996—2012.

Federal District. A number of dry days in winter grows over most of the country; in summer it increases over most of the EPR, in Kamchatka peninsula and Chukchi peninsula.

Arid conditions. Indices of aridity grow over most of agricultural zone of Russia. In most regions there is a decline in the number of days with extremely low moisture content in the topsoil.

Hazardous hydrometeorological events. In 1996—2012, in Russia the number of hazardous events increased, including those that caused considerable damage to the economy and humans. (Fig. GS1.11).

Climate of the Arctic

Ocean and sea ice in the centre of the Arctic influence the formation of the Arctic climate and affect the global climate. Therefore a special emphasis is always placed on the marine Arctic. In this report Marine Arctic implies a marine part of the Arctic zone of Russia and other water areas of the Arctic Ocean covered in winter with ice.

Changes in the air temperature over marine Arctic are characterized by rapid warming since the late 1990s with an absolute record in summer of 2012 (Fig. GS1.12). On the other hand, sea ice extent data (historical data since 1924 and current satellite data since 1979) provide the evidence for a decrease in sea ice extent in Siberian Arctic seas (Kara Sea, Laptev Sea, East Siberia Sea and part of Chukchi Sea down to Bering Strait) and in the Arctic region as a whole. The reduction has become faster since the late 1990s and is consistent with the air temperature rise in the marine Arctic (Fig. GS1.13).

Sea ice depth in the Arctic basin has also declined since the 1980s by more than 40% on average mainly due to reduction in the amount of multiyear ice. If the consistent tendencies for an increase in air temperature and decrease in sea ice extent continue at the current rate of warming, the 2030s can be considered as a period after which sea ice in September may disappear.

The revealed tendencies are consistent with changes in the atmospheric circulation. For the Arctic the prevailing of anticyclones over the Arctic basin is typical. The circulation system was transformed in mid 1990s. This transformation led to the establishment of cyclonic circulation over the Kara Sea and Laptev Sea and the high pressure area over Canadian Arctic Islands and Greenland. Such circulation is accompanied by air temperature rise, more intensive snow melt in summer and its removal outside of the Arctic basin.

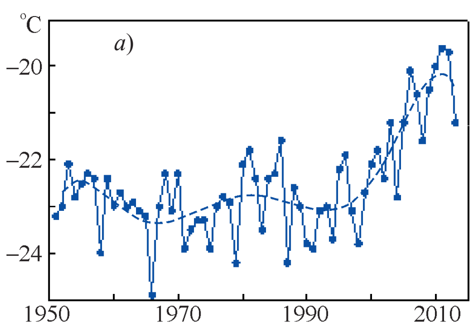

Fig. GS1.12. Changes in the mean air temperature in the marine Arctic for 1951—2013: *a*) winter (December – February); *b*) summer (June – August). Dashed line depicts an approximation with orthogonal polynomials of sixth degree.

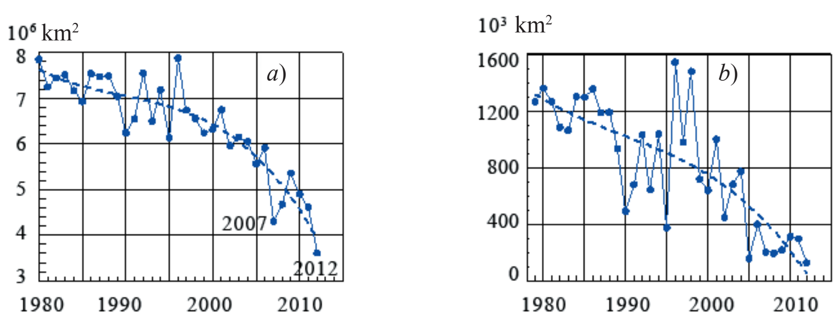

Fig. GS1.13. Average September ice extent in 1980—2012: *a*) in the Arctic (based on the data from the National Snow and Ice Data Centre (NSIDC), USA) and *b*) in Siberian Arctic seas (based on the data from the Arctic and Antarctic Research Institute (AARI), St.Peterburg, Russia). Dashed line depicts an approximation by a cubic polynomial.

Section 2. CAUSES OF OBSERVED CLIMATE CHANGE

Evolution of scientific understanding of causes of climate change

As noted in the AR_RF-1, the Earth's climate system usually defined as a combination of five major components, namely, the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, is never in equilibrium. The climate system is permanently changing even in the absence of changes in external forcings. The latter ones are natural and anthropogenic factors which influence the climate system from the outside and cause the climate change. Climate is defined according to the purposes of the analysis. Therefore, definitions of climate are multiple and they evolve with time. For example, the definition of climate given by A.S. Monin as *"a statistical ensemble of states that the atmosphere-ocean-land system passes over time periods several decades long"* may be extended nowadays by including two other components of the climate system, namely, the cryoshere and the biosphere. In mathematical theory of climate it is sometimes convenient to consider this ensemble over the infinite time interval. In this case climate does not undergo any changes (by definition). For the goals of Roshydromet the definition of G.V. Gruza and E.Ya. Rankova is suitable: *"In a narrow but widely used sense, the climate is a generalization of weather changes. It is represented by a set of weather conditions in a given part of space over a given time interval. A statistical description in terms of means, extremes, variability indices for certain parameters, and frequencies of events over the time period is used for the climate characterization. All of these descriptive statistics are called climatic variables"*. The definition was used in the AR_RF-1. Variations of the Earth's orbital parameters, volcanic eruptions and solar activity are among *external* forcings of natural origin. *Anthropogeni*c forcings are changes in gas and aerosol content of the atmosphere resulted from human economic activities including land use changes.

Internally induced (i.e. not forced by external drivers) variability of the climate system is caused by non-linear interactions between the climate system's components responding to external forcings on different time scales. Positive and negative feedbacks and non-linearity of internal interactions within the Earth's climate system make its response to external forcings extremely complex, which seriously complicates detection and attribution of climate change and, to much greater extent, its prediction.

High priority given today to the problem of anthropogenic climate change and intensive discussions on this topic may mislead one into thinking that this problem is new. However, the theory of anthropogenic global climate change seems to have nearly two hundred-year history, if one counts the very first hypotheses on the role of the greenhouse effect in the formation of the Earth's climate. An idea of the greenhouse effect first outlined by Jean-Baptiste-Joseph Fourier (1827) was further developed by John Tyndall and Svante August Arrhenius. In particular, Arhenius's estimate of the effect of CO_2 atmospheric concentration doubling on the mean global temperature (1896) appears to be the first in historical series of similar estimates that have been provided up to the present.

An assumption that anthropogenic factor could be potentially important for the Earth's climate was put forward more than a hundred years ago. Since that time this theory, having gone through a long period of low interest, has seriously progressed. Nowadays, not only the estimation of future changes in the climate system is possible, but also the verification of predictions made some time ago.

By the middle of the 1970s, the theory has covered a long distance from hypotheses and theoretical works to the first model estimates of future climate changes made with yet rather simple numerical models. But even those simple models did predict a global warming in the nearest decades and the predictions proved true later on. In addition estimates of possible climate changes were obtained using empirical models based on the data on past states of the climate system. It should be noted that scientists of the USSR made a considerable contribution to the studies*. M.I. Budyko was a generally acknowledged leader in this field.

In the early 21st century, the leading climate modelling centres made considerable efforts on the calculation of the climate system evolution throughout the 20th century. These efforts have laid

* During the First World Climate Conference convened by the World Meteorological Organization in 1979 in Geneva, E.K. Fedorov, who was a keynote speaker, noted *inter alia*: "Future climate changes are inevitable. They will become noticeable and maybe irreversible in the next few decades... Therefore, there is a clear need for a strategy, i.e. a system of actions planned in advance which would enable humankind to avoid negative consequences of possible climate changes...".

the basis for a rapidly growing branch of the climate science entitled as detection and attribution of observed climate change.

Causes of observed global climate change

Attribution of climate change is based upon a comparison of observed changes and expected response to probable external forcing obtained with carefully validated climate models. For the comparison, statistical procedures are employed to objectively judge whether quantitative changes observed in the climate system are consistent with expected changes yielded by model simulations. In addition it is verified whether the changes could be induced by other physically possible processes and, in particular, whether they could be just a manifestation of natural inherent variability of the climate system.

Since the appearance of the AR_RF-1, the evidence of human influence on climate has become more substantial. Nowadays more complete and more long-term observational data as well as simulations from a new generation of climate model make it possible to detect anthropogenic influence on changes in more components of the Earth's climate system. The IPCC Fifth Assessment Report (2013—2014) states with 95 percent confidence that human influence is the dominant cause of warming observed since the middle of the 20th century.

The agreement between observed and computed changes in the climate system, including global and regional temperatures, temperature of the troposphere and stratosphere, global hydrological cycle, global energy budget, changes in the cryosphere and global ocean, indicates that the observed climate change is attributable primarily to the increase in greenhouse gas concentrations caused by human economic activities. The magnitude and spatial distribution of warming observed in various components are in good agreement with simulated response of the climate system to anthropogenic and natural external forcings (Fig. GS2.1, GS2.2).

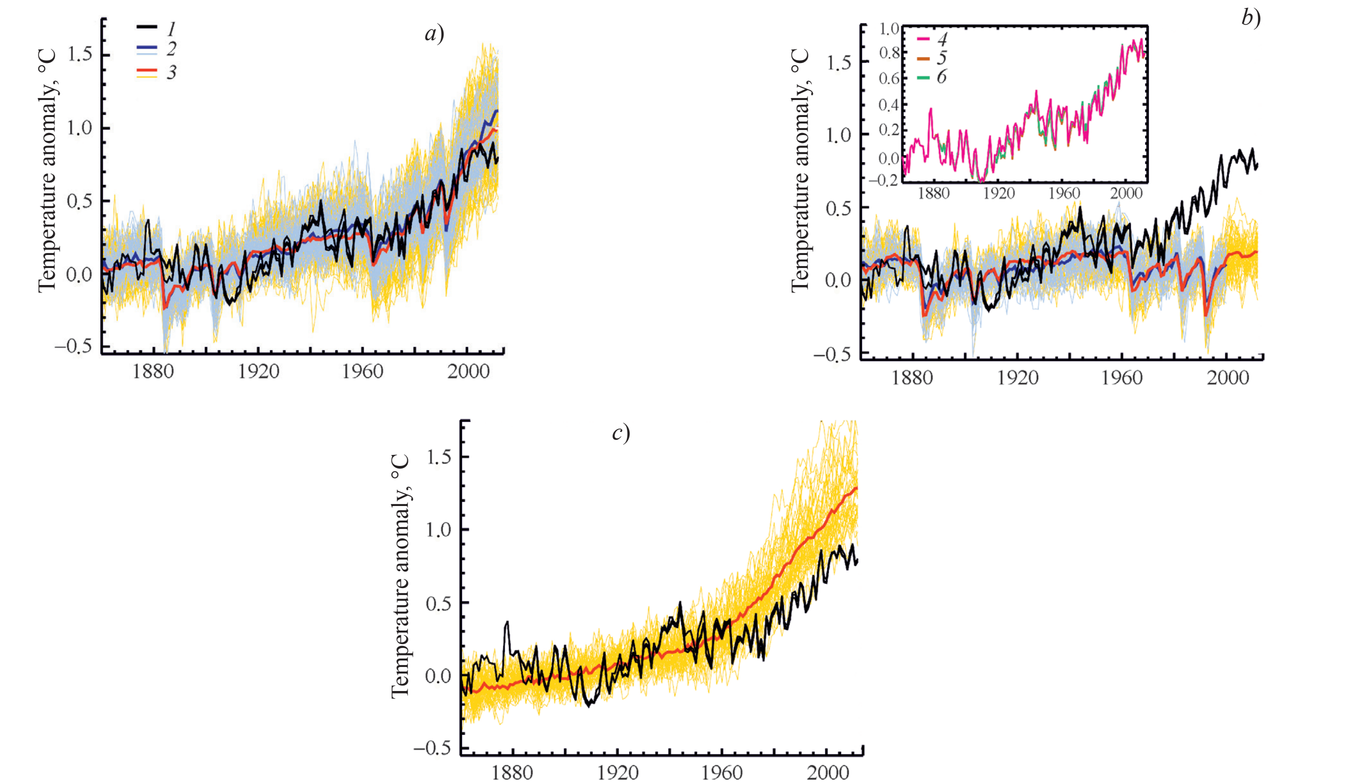

Fig. GS2.1. Estimates of the global mean surface temperature obtained from observational data sets (*1*) and model simulations from CMIP3 ensemble (2) and CMIP5 ensemble (3) with anthropogenic and natural forcings (*a*), natural forcings only (*b*) and greenhouse gas (GHG) forcing only (*c*). Thick lines are the averages across all available CMIP5 and CMIP3 simulations. CMIP3 simulations for GHG forcing only are not shown (*c*). All simulated and observed data were spatially averaged according to the HadCRUT4 archive data, since this archive has the most restricted spatial coverage. They are shown as anomalies against the 1880—1919 level, although initially temperature data in each grid box were calculated as anomalies against the 1961—1990 levels. Inset to (*b*) shows estimates from different observational data sets: HadCRUT4 (*4*), GISTEMP (*5*), MLOST (*6*). The figure is adopted from the IPCC Fifth Assessment report.

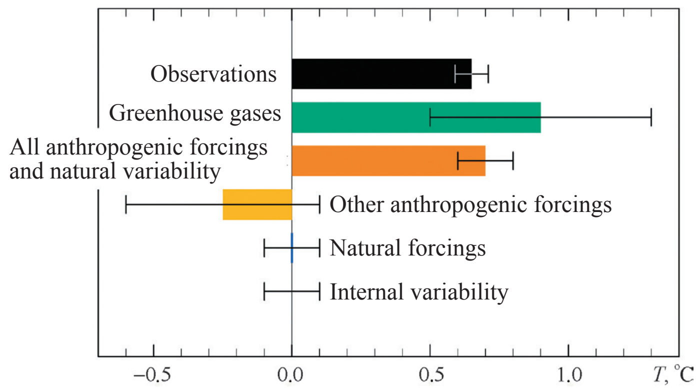

Fig. GS2.2. Statistical ranges (whiskers) and mean values (color bars) for estimates of the contributions from different factors to the linear trend of warming observed in 1951—2010. The trend values based on the HadCRUT4 data set are shown in black with the 5 to 95% uncertainty range (due to uncertainty in this data set). The figure is adopted from the IPCC Fifth Assessment report.

Anthropogenic component of climate change in Russia

From the middle of the 20th century to the early 21st century, changes in concentrations of the greenhouse gases have made the main contribution to the observed temperature increase on the territory of Russia. However, *natural external* forcings are also significantly manifested in the interannual temperature variations. These forcings are particularly detectable in summer, when the influence of aerosols on the flow of incoming solar radiation reaches the annual maximum, while *internally induced* (not forced by external factors) inter-annual temperature variability is relatively low.

Changes in temperature obtained from simulations with the ensemble of modern climate models (CMIP5) using anthropogenic and natural external forcings are in reasonably good agreement (including spatial distributions) with observational data, if natural internal variability of the Earth's climate system is taken into consideration in the verification (Fig. GS2.3). With only natural external forcings taken

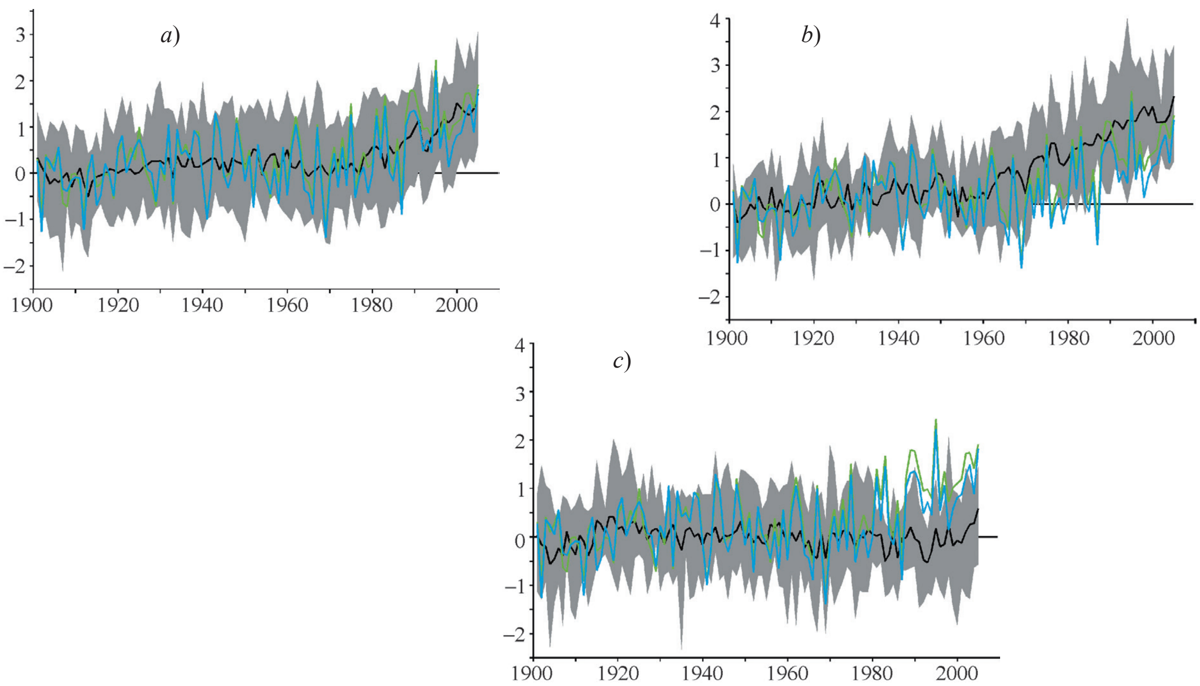

Fig. GS2.3. Anomalies of mean annual surface air temperature in Russia from observational data (green and blue curves) and CMIP5 ensemble means (black curve) with natural and anthropogenic forcings (*a*); major greenhouse gas (GHG) forcing only (*b*); natural forcings only (*c*). Anomalies are calculated relative to the 1901—1930 baseline period. Inter-ensemble spread is shown in grey.

into consideration a substantial discrepancy between observational data and simulations has been found.

Many regions of the globe experience changes in regional temperature extremes, particularly, the number of frost days reduces, warm extremes become warmer and cold extremes become less cold; there is an increase in the frequency of unusually warm seasons, such as occurring once per decade. Using methodologies of the optimal detection, for the North Asia, which includes a considerable part of Russia, an anthropogenic contribution to changes in extreme seasonal and daily temperatures was detected, which is broadly consistent with observed global warming.

The analysis of extreme weather events, the hot summer of 2010 in the EPR in particular, showed that while such extreme conditions are generated mainly by inherent variability of the climate system, the general warming induced by anthropogenic forcings considerably augments the likelihood of their emergence.

Influence of non-anthropogenic factors on the current climate

Climate change is caused by internally induced variability of the climate system and external forcings of natural and anthropogenic origin. Changes in solar radiation flow and volcanic eruptions are considered to be most important amongst external forcings of natural origin (up to centennial time scales).

Solar radiation forcing on climate has changed by 0.05 W/m^2 from the middle of the 18th century to present time and made up to 2% of anthropogenic radiative forcing (2.29 W/m^2).

The most significant decrease in incoming solar radiation in the past occurred in the Mounder Minimum period (second half of the 17th century). A decrease in solar activity caused the cooling which is associated with the Little Ice Age. A study has been conducted to estimate the way such decrease in solar activity may influence anthropogenic warming. The study was based on a model experiment, namely, on reducing solar radiation flow by 0.25% compared with the current baseline value. A decrease of such range most likely took place during the Mounder Minimum period. Model simulations showed that if a similar solar radiation minimum emerges in the middle of the 21st century, it will slow down the global anthropogenic warming and reduce the global surface air temperature by 0.24—0.26 °C. However, if solar radiation increases and reaches the initial value, the warming will renew and be the same as under the baseline scenario.

Major volcanic eruptions emit a great amount of sulphate aerosol, which may influence climate on time scales from year to several years. In the 20th century, eruptions of Agung, El Chichon and Pinatubo had the most considerable impact on variations in global temperature. Moreover, the Asian and African summer monsoons became weaker for some period after the Mt Pinatubo eruption in 1991. The response of the atmosphere hydrological cycle to major volcanic eruptions is very quick and respective negative consequences may manifest themselves for about a year.

Ocean has a substantial impact on the atmosphere and its changes. In recent decades the ocean total heat content was constantly increasing. The ocean impact is most pronounced in high and middle latitudes of the Northern Hemisphere on seasonal to decadal time scales. It is difficult to predict natural ocean temperature variations, since ocean processes are not yet clearly understood. We are still far from resolving the problem of adequate description of processes in the equatorial and tropical ocean areas, where El Niño, 60—70-year oscillation in the North Atlantic and the Pacific Decadal Oscillation are generated.

Nowadays, a “the hiatus” of the global warming observed in the recent fifteen years is a subject of intensive discussion in scientific literature: the observed trend of the mean global temperature appeared to be lower than the average trend obtained from CMIP3 models’ outcomes used in the IPCC Fourth Assessment Report. Research findings give the evidence that short-term (decadal) trends in observational data may occur to a greater extent due to internal variability of the climate system, which largely depends on natural variations in the oceans, rather than due to external forcings. This is also correct for model simulations.

According to the IPCC Fifth Assessment Report, the reduction in the mean surface temperature trend over 1998—2012 as compared to the trend over 1951—2012, is roughly equally attributable to a reduced radiative forcing and cooling of the atmosphere due to internal variability, including possible redistribution of the ocean heat.

Section 3. EXPECTED CLIMATE CHANGE IN THE 21ST CENTURY

New generation of climate models

During the preparation of the IPCC Fifth Assessment Report (2008—2014) the international scientific community initiated another project to analyze climate simulations using global climate models, namely, CMIP5 (Coupled Model Intercomparison Project, Phase 5). The main purpose of the project was to perform climate simulations for the 20th century with prescribed greenhouse gas and aerosol concentrations based on the observational data, and climate simulations for the 21st century under new scenarios of anthropogenic impact on the Earth's climate system denoted as RCPs (Representative Concentration Pathways). In total, more than fifty models developed in different research centers all over the world took part in the project.

The ensemble means of computed climate characteristics more neatly fit to respective observational data than individual model outputs. The reason is that 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.

For the purposes of the present Assessment Report an ensemble of 31 CMIP5 models (EN_31) was adopted. The ensemble is about 1.5 times bigger than the CMIP3 (CMIP, Phase 3) ensemble used for the AR_RF-1. Despite a considerable spread in EN_31 simulation results, a reasonable agreement between basic characteristics of surface climate in Russia derived from the ensemble outputs and the observational data makes it possible to consider this ensemble to be valid for the estimation of future climate changes in Russia (Fig. GS3.1–GS3.3). Comparison of different generations of climate models (CMIP5 and CMIP3) show that the ability of models to simulate successfully certain characteristics of surface climate in Russia is gradually improving.

Expected climate change in Russia in the 21st century

In the new system of scenarios of anthropogenic climate forcing an RCP scenario index denotes the anthropogenic radiative forcing to be reached in 2100, namely, 2.6, 4.5, 6.0 and 8.5 W/m^2 under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 respectively.

According to the IPCC Fifth Assessment Report in the 21st century the global mean temperature will increase under all radiative forcing scenarios. For different scenarios an increase in the global mean temperature in 2081—2100 relative to 1986—2005 is projected to be within the following ranges: 0.2°C to 1.8°C (RCP2.6), 1.0°C to 2.6°C (RCP4.5), 1.3°C to 3.2°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5), assuming confidence interval 5—95%. Differences in precipitation in humid and arid regions as well as during wet and dry seasons will increase, though there may be exceptions in some regions. It is very likely that during the 21st century the meridional circulation over Atlantic will weaken, however, its sharp change or full collapse are extremely unlikely. The global sea level in 2081—2100 is likely to rise compared to that of the late 20th century, ranging from 0.26—0.55 m (RCP2.6) to 0.45—0.82 (RCP8.5); the ocean acidification will continue.

Changes in the mean seasonal temperatures in Russia projected for the 21st century (Fig. GS3.4) are consistent with those presented in the AR_RF-1. In winter in all Federal Districts of the Russian Federation, except the North Caucasian Federal District and Southern Federal District, temperature increase will be more considerable than in summer (Fig. GS3.5). Russia continues to be a region, where climate warming throughout the 21st century will be considerably higher than the average global warming. Absolute annual temperature maximum (the indicator of summer air temperature extremeness) may increase significantly, primarily in the south of the EPR. At the same time, much milder temperature is expected in cold season mainly due to increase in the minimal air temperature, first in the north of the EPR and, in the late 20th century, in the south of the EPR, where winters will become snowless.

In winter, throughout the 21st century under all scenarios, precipitation shows a steady positive trend all over the country (Fig. GS3.6). In summer, an increase in the mean seasonal precipitation is expected over most of Russia with the exception of southern regions, where by the late 21st century precipitation is projected to decrease by up to 25% as compared with the late 20th century. Changes in precipitation will differ considerably in different Federal Districts, in winter it will differ in amount, while in summer both in amount and in sign (Fig. GS3.7).

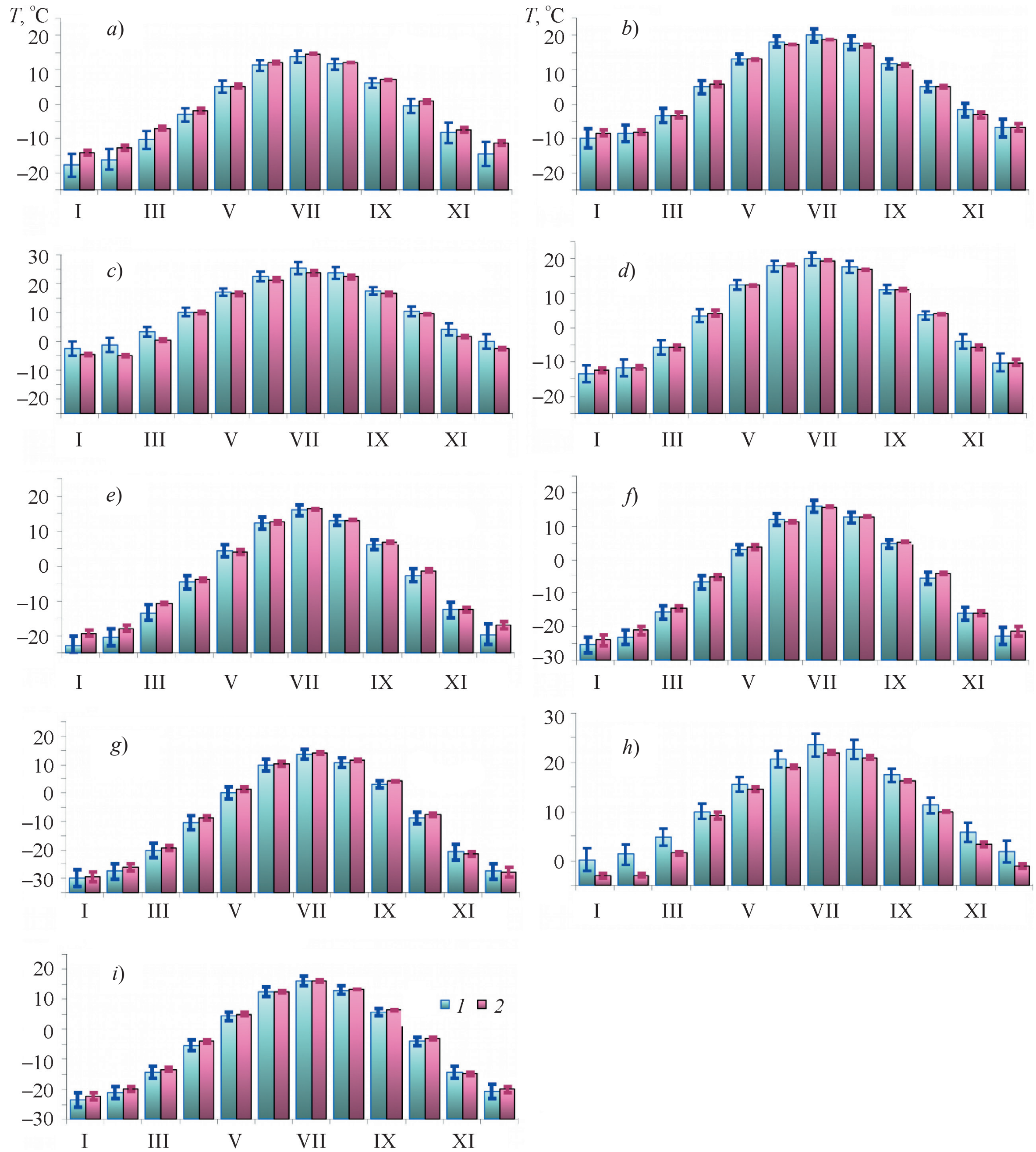

Fig. GS3.1. The annual course of surface air temperature for 1981—2000 derived from the ensemble of 31 CMIP5 models (*1*) and obtained through averaging the observational data (*2*) for the Northwestern Federal District (*a*), Central Federal District (*b*), Southern Federal District (*c*), Volga Federal District (*d*), Urals Federal District (*e*), Siberian Federal District (*f*), Far Eastern Federal District (*g*), North Caucasian Federal District (*h*) and for the entire Russia (*i*). In addition to mean values the figure shows standard deviations characterizing the spread ± σ between models and between observational data (reanalysis data). Most of models simulate successfully the annual cycle of surface air temperature averaged over territories of Federal Districts. In most cases mean monthly values of temperature from observational data (and often spread between observational data (reanalysis data)) appear to be within one standard deviation from the ensemble mean. The inter-model spread exceeds the ensemble mean error considerably.

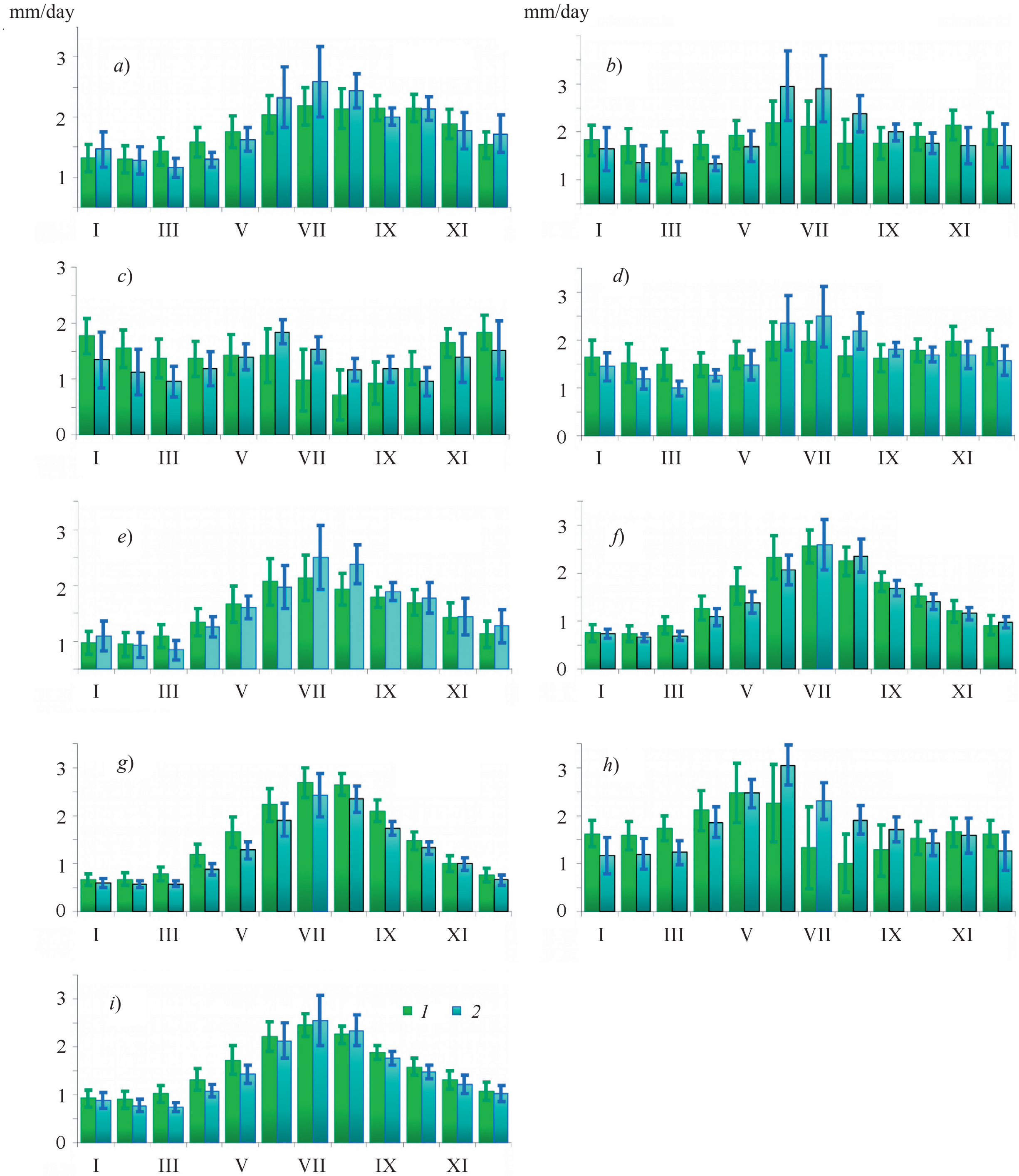

Fig. GS3.2. The annual course of precipitation for 1981—2000 derived from the ensemble of 31 CMIP5 models (*1*) and obtained through averaging the observational data (*2*) for the Northwestern Federal District (*a*), Central Federal District (*b*), Southern Federal District (*c*), Volga Federal District (*d*), Urals Federal District (*e*), Siberian Federal District (*f*), Far Eastern Federal District (*g*), North Caucasian Federal District (*h*) and for the entire Russia (*i*). In addition to mean values the figure shows standard deviations characterizing the spread ± σ between models and between observational data (reanalysis data). The yearly course of precipitation derived from CMIP5 model in general shows satisfactory consistency with observational data (reanalysis data) from various sources.

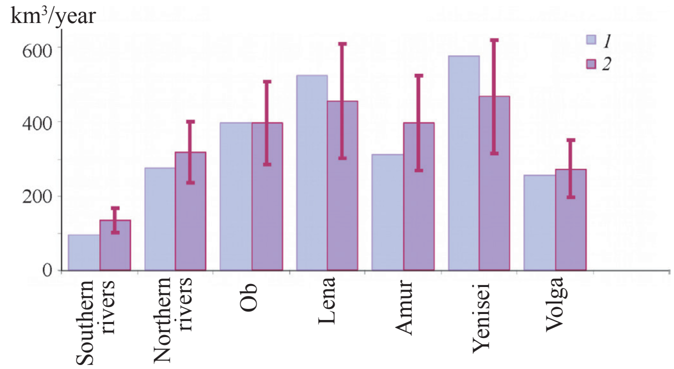

Fig. GS3.3. The mean annual river runoff in large watersheds obtained from observational data (*1*) and derived from the ensemble of 26 CMIP5 models for 1981—2000. For model data in addition to mean values standard deviations characterizing the spread between models are given.

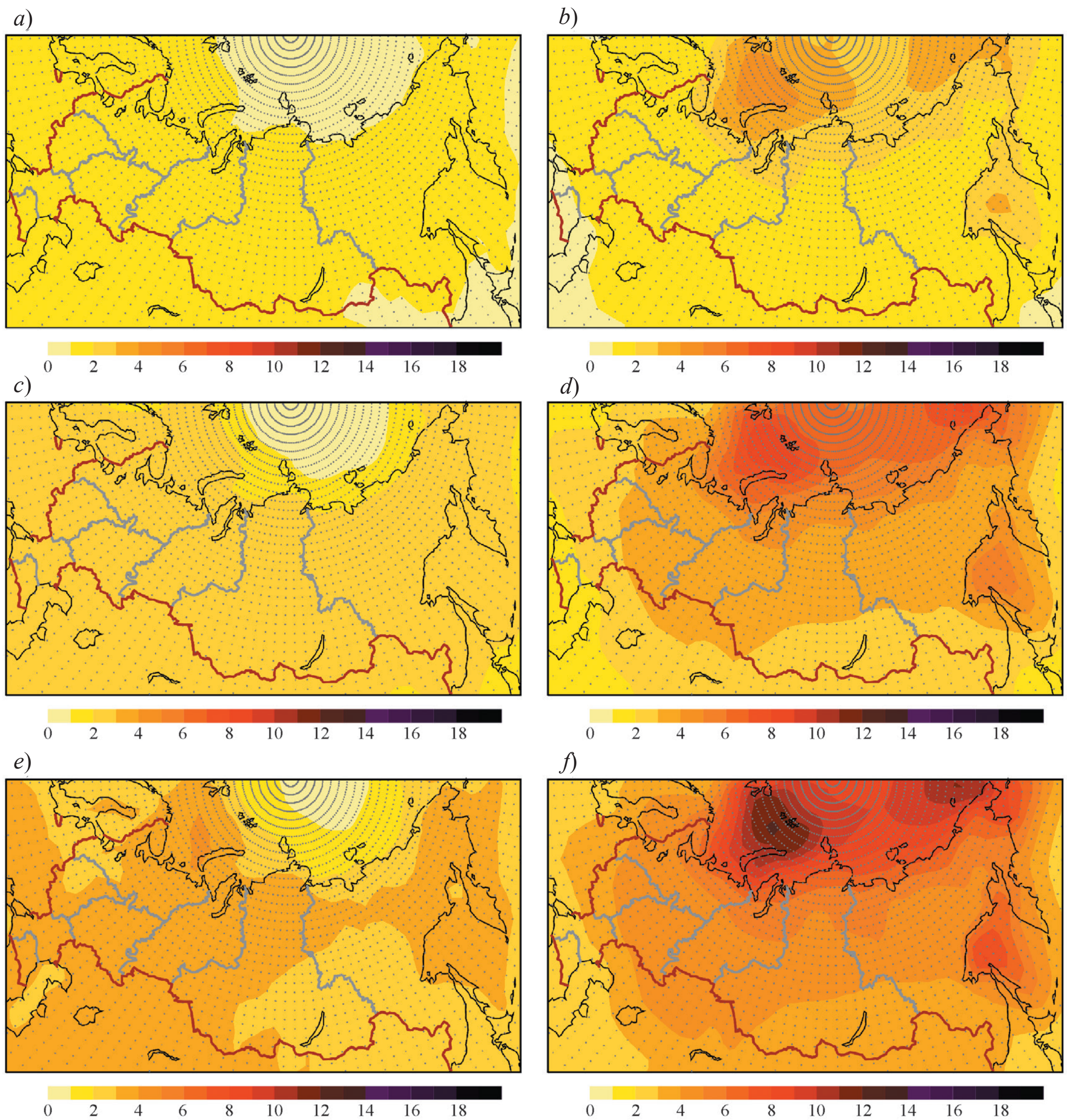

Fig. GS3.4. Changes of mean seasonal surface air temperature (°C) in 2011—2030 (*a*, *b*), 2041—2060 (*c*, *d*) and 2080—2099 (*e*, *f*) relative to the late 20th century in summer (*a*, *c*, *e*) and winter (*b*, *d*, *f*) derived from the ensemble of 31 CMIP models for the RCP4.5 scenario. Dots show the regions, where the ensemble mean to inter-model spread ratio exceeds 1.

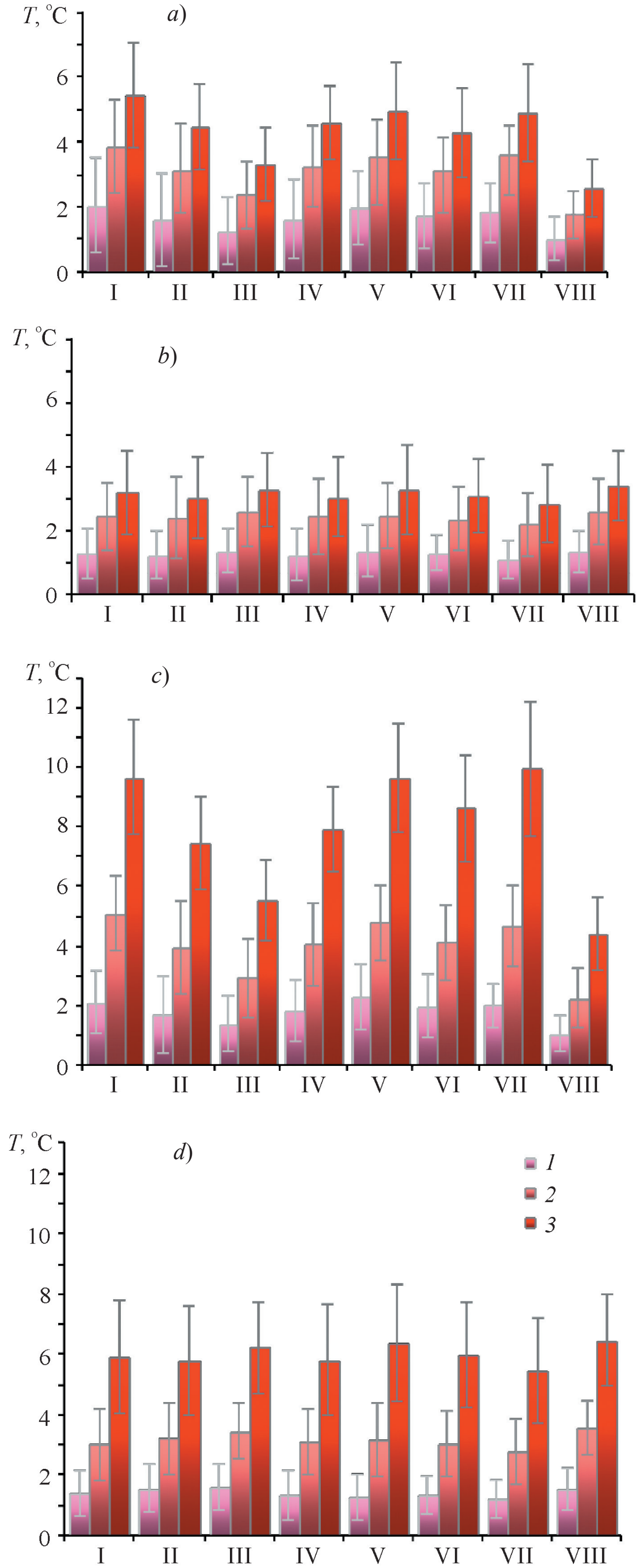

Fig. GS3.5. Changes of mean surface air temperature (°C) in January (*a*, *c*) and July (*b*, *d*) in 2011—2030 (*1*), 2041—2060 (*2*) and 2080—2099 (*3*) relative to the late 20th century for the Northwestern Federal District (I), Central Federal District (II), Southern Federal District (III), Volga Federal District (IV), Urals Federal District (V), Siberian Federal District (VI), Far Eastern Federal District (VII) and North Caucasian Federal District (VIII) derived from the ensemble of 31 CMIP5 models for the RCP4.5 (*a*, *b*) and RCP8.5 (*c*, *d*) scenarios. Grey vertical whiskers show an uncertainty range to which 90% of model estimates belong.

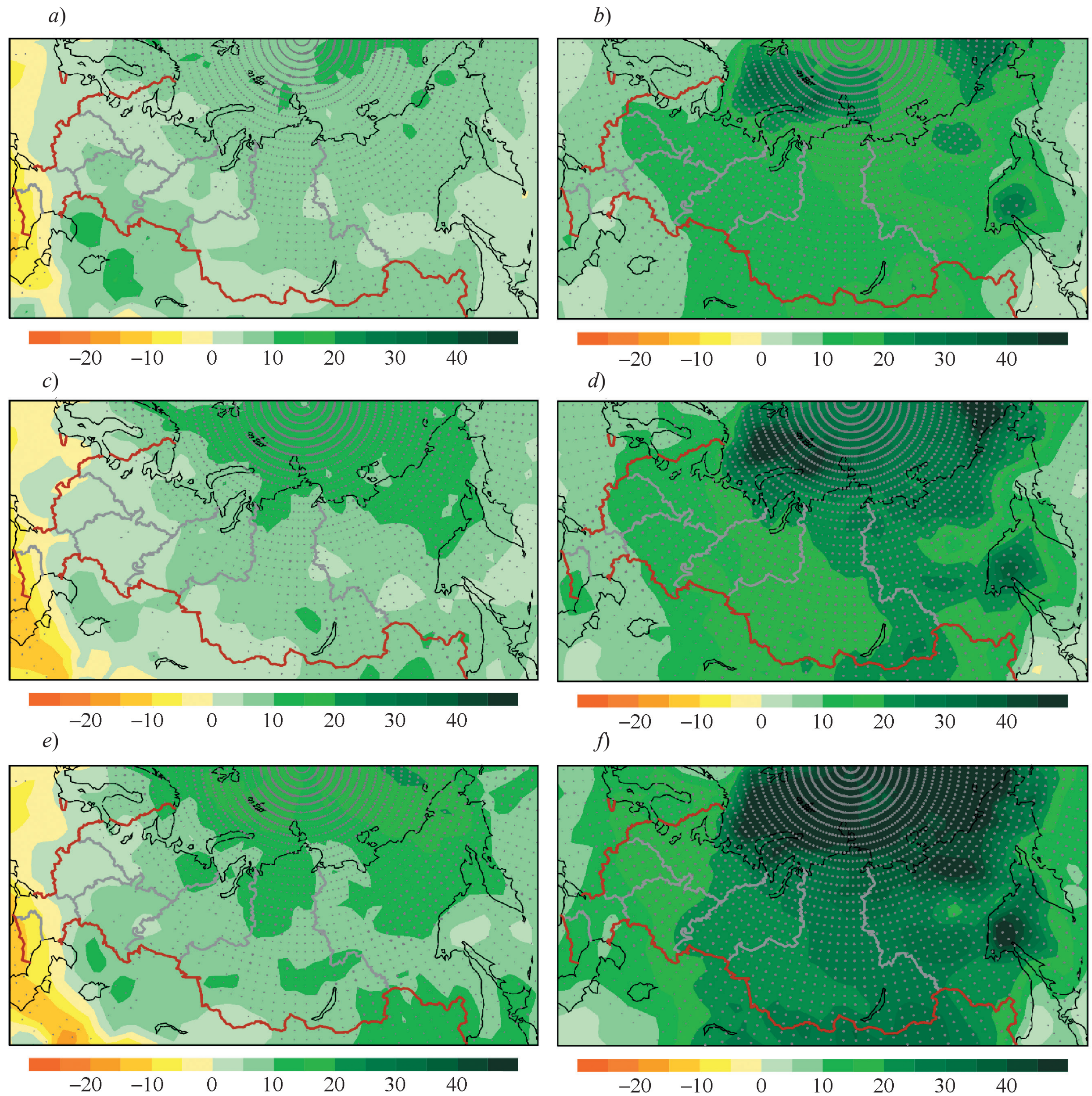

Fig. GS3.6. Changes of mean seasonal precipitation in 2011—2030 (*a*, *b*), 2041—2060 (*c*, *d*) and 2080—2099 (*e*, *f*) relative to the late 20th century in summer (*a*, *c*, *e*) and winter (*b*, *d*, *f*) derived from the ensemble of 31 CMIP5 models for the RCP4.5 scenario. Small dots show the regions for which more than 66% of models show changes of the same sign. Big dots show the regions for which more than 90% of models agree in the sign of changes.

In watersheds of the Lena and Yenisei and rivers of the Chukchi Peninsula the river runoff will increase considerably. The RCP4.5 and RCP8.5 scenarios indicate that by the middle of the 21st century the near-surface permafrost area is likely to reduce by 20 ± 7 and 25 ± 8% respectively; it will reduce by 31 ± 12 and 56 ± 18% respectively by the end of the 21st century. Model estimates clearly show that sea ice extent in the Russian Arctic and adjacent areas of the Arctic Ocean (Fig. GS3.8) will reduce throughout the 21st century. Therefore, perennial Arctic sea ice may disappear in the first half of the century.

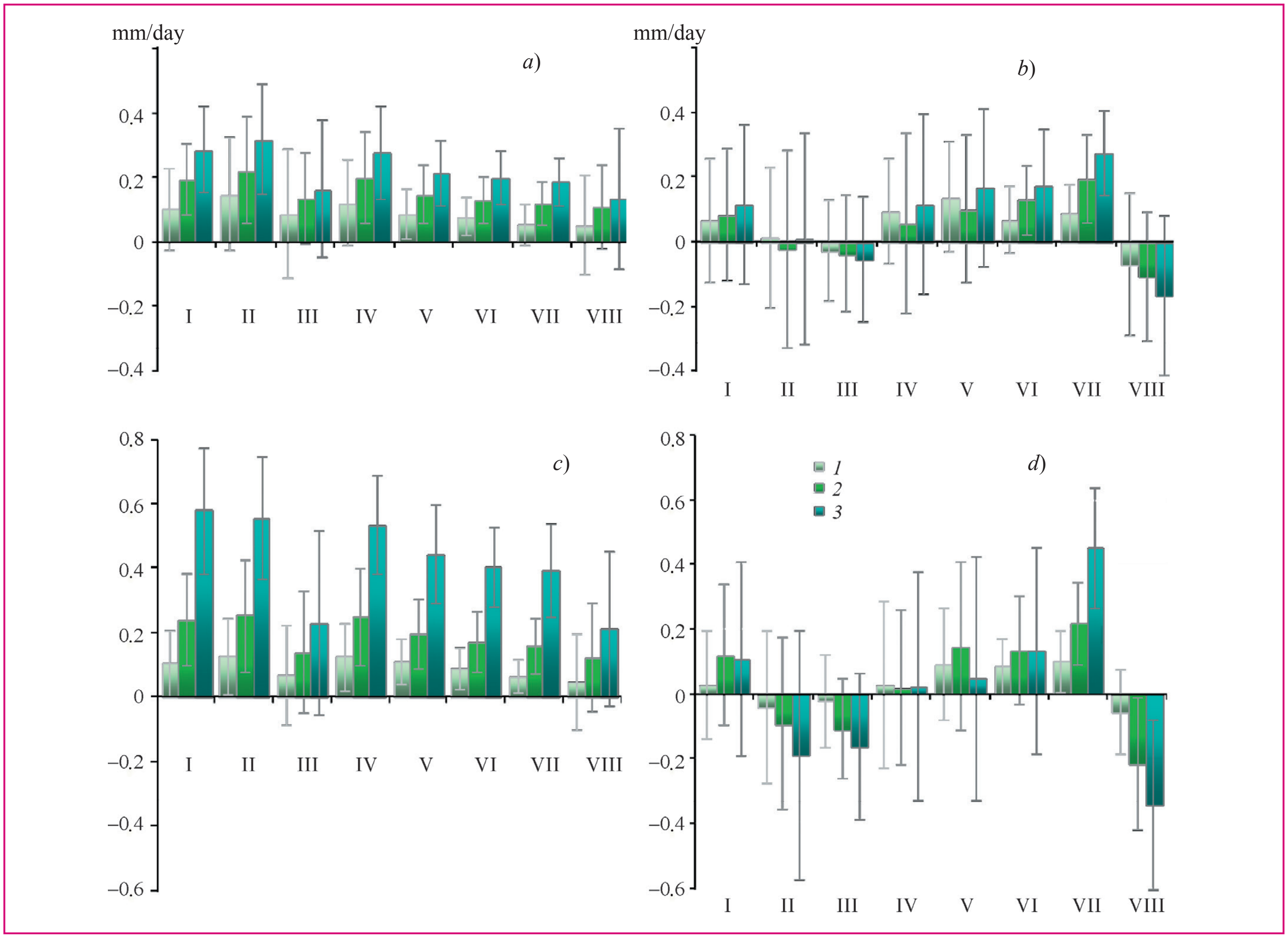

Fig. GS3.7. Changes of mean daily precipitation (mm/day) in January (*a*, *c*) and July (*b*, *d*) in 2011—2030 (*1*), 2041—2060 (*2*) and 2080—2099 (*3*) relative to the late 20th century for the Northwestern Federal District (I), Central Federal District (II), Southern Federal District (III), Volga Federal District (IV), Urals Federal District (V), Siberian Federal District (VI), Far Eastern Federal District (VII) and North Caucasian Federal District (VIII) derived from the ensemble of 31 CMIP5 models for the RCP4.5 (*a*, *b*) and RCP8.5 (*c*, *d*) scenarios. Grey vertical whiskers show an uncertainty range to which 90% of model estimates belong.

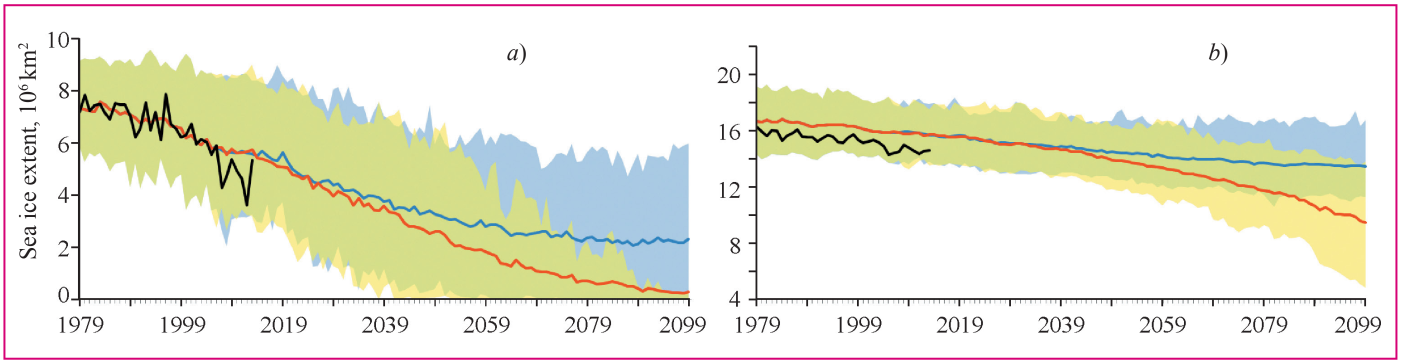

Fig. GS3.8. Evolution of sea ice extent in 1979—2099 in the Arctic in September (*a*) and February (*b*) from data of 30 CMIP5 models for the RCP4.5 and RCP8.5 scenarios (blue and red solid lines respectively) and inter-model spread within the 10th and 90th percentiles (blue and yellow shading respectively). The retrospective calculation results for 1979—2005 precede scenario-based simulations in each ensemble. For 1979—2013 sea ice extent is given on the basis of the NSIDC (National Snow and Ice Data Centre) observational data (black curve).

Section 4. IMPACTS OF CLIMATE CHANGE ON NATURAL TERRESTRIAL SYSTEMS

Terrestrial hydrological systems

In Russia river runoff is critically dependent on climatic characteristics of a watershed, primarily on the ratio of precipitation to evaporation. A dominant trend that has been detected for Russian rivers clearly shows an increase in the annual runoff (i.e. the annual renewable water resources). The annual river runoff in 1981—2012 relative to 1936—1980 increased by 204 km^3/year or 4.8% on average (Fig. GS4.1). River runoff increased in all Federal Districts. Its highest increase is observed in the largest rivers of the Arctic Ocean basin.

The essential feature of current changes in water regime of Russian rivers is substantial enhancement of water amount in the low water period, particularly in winter. Interannual variability of the runoff has also grown, and as a result anomalously high water and anomalously low water years and seasons have been observed.

Current changes in maximal river runoff in Russia are determined by conditions of the runoff formation. For considerable part of the EPR, where maximal water discharges are formed by spring floods, the maximal river runoff has considerably declined. In regions where maximal water discharges are formed by rainfall floods (the Black Sea coast of the Caucasus, the Kuban and Amur basins) the never-seen-before catastrophic floods occurred in the late 20th — early 21st century. During the extreme flood of 2013 resulted from about two months of intensive rainfall in the Far East of Russia and in the north-east of China, the maximal water discharges on more than 1000 km-long stretch of the Middle and Down Amur exceeded historical maximums for over a hundred year period of hydrological observations (Fig. GS4.2).

In the nearest decades, there are no reasons for expecting any considerable changes in annual runoff of major rivers in Russia due to climate change. For most of the country the increase of river runoff will most likely be insignificant (within 5%) lying within the range of its natural variability.

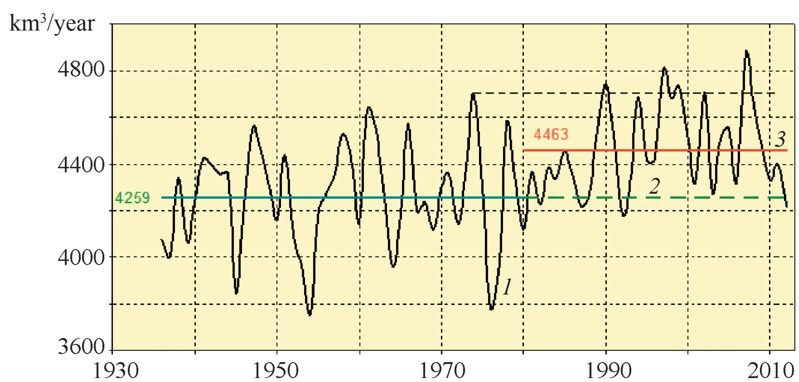

Fig. GS4.1. Long-term changes in the total annual river runoff in the Russian Federation (*1*). The figure shows norms for 1936—1980 (*2*) and 1981—2012 (*3*).

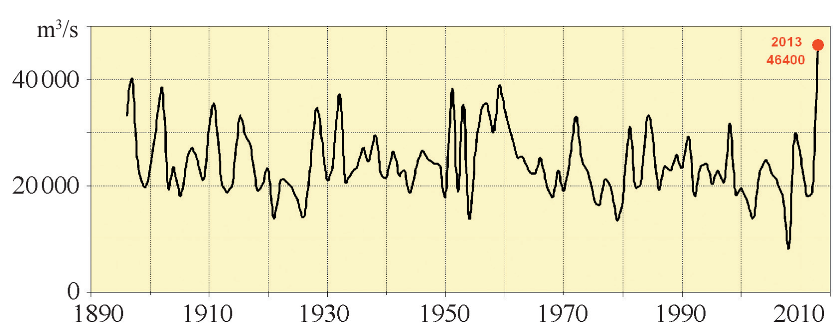

Fig. GS4.2. Long-term changes in the maximal water discharge in the Amur near Khabarovsk.

Model simulations conducted in the context of the current understanding of future climate in the 21st century show that the water regime of Russian rivers in the nearest two decades will be basically the same as observed in the recent 30—35 years. Expected winter temperature rise makes it possible to conclude that the current positive trend in winter river runoff will sustain in the nearest two or three decades. A relative share of spring runoff in the annual runoff is projected to decline.

Glaciers in the Arctic islands and mountain glaciers

All glacier systems in Russia have degraded due to climate warming as compared with 1950—1960.

In the last 50 years, the total area of glaciation in the Arctic islands has reduced by more than 720 km^2 and ice volume by approximately 250 km^2 (or 1.5%). The glacier shrinkage has accelerated in the 21st century. The length of ice-covered shores has become shorter. The ice loss due to iceberg calving has increased, as well as the average size of icebergs. This has raised risks for oil and gas production on the shelf and for navigation in the Arctic. Model scenario-based simulations show that these tendencies will sustain roughly until 2060. Afterwards, the number of icebergs will start to decline due to the shortening of length of ice-covered iceberg-producing shores.

On the continent in the Russian subarctic zone glaciers continue to shrink showing the most consistent trends in western and central parts influenced by the Atlantic air masses. Glaciers of the Kola Peninsula and Yamal had disappeared by the time the Catalogue of Glaciers of the USSR was published in 1950—1960. By now, glaciers of the Putorana Mountains have also disappeared. After 1960, glaciers of the Polar Urals and Taimyr Peninsula (the Byrranga Mountains) have already lost one forth of their area, particularly in the parts occupying valleys. Under climate change expected in the 21st century, these glaciers are projected to disappear by the middle of the century.

According to satellite images, in the Suntar-Khayata, Chersky and Menypilgyn Ranges located in the northeastern part of Russia, there used to be over 600 glaciers occupying the total area of about 370 km^2 in 2008—2012. They have retreated substantially since the 1960s. Since the late 20th century glaciers of the Chersky Range have shrunk by about 30% and glaciers of the Suntar-Khayata Range have shrunk by 20%.

According to satellite images, the area occupied by glaciers in the Koryak Highland and Kamchanka Peninsula is roughly 373 km^2 (237 glaciers). Most of Kamchatka glaciers are found in the Sredinny Range, where they descend on both sides. In 1950—2012 the area occupied by the glaciers shrank from 348 to 290 km^2. An example of a shrinking glacier in the Sredinny Range is given on Fig. GS4.3.

Degradation of the mountain glaciation in the south of the EPR and Siberia turned out to be

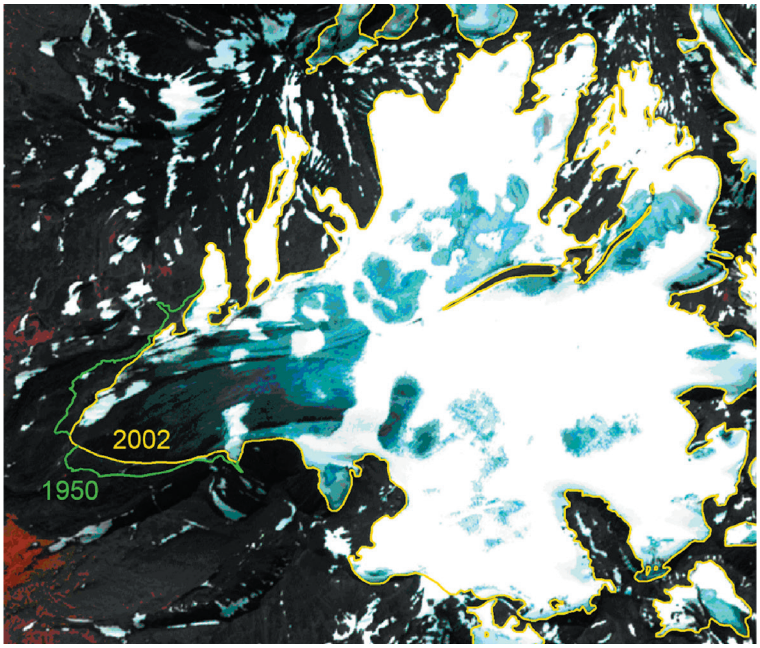

Fig. GS4.3. Shrinkage of the Slunin Glacier (one of the largest glaciers of the Sredinny Range) in 1950—2002.

even more substantial. Since the middle of the 20th century, the glaciers have shrunk by about 40% in the Caucasus, by 20% in the Altai Mountains and by no less than 30% in the Sayan Mountains.

Projections under existing scenarios of climate change expected in the 21st century (outcomes of climate simulations with the CMIP5 climate models) show that the same trends will sustain throughout the century. As a consequence, the glacier runoff, which was 1.9 km^3 per year for the Russian part of Caucasus and 1.4 km^3 per year for the Russian part of the Altai Mountains in the late 20th century, is expected to decline. Glaciers of the Northern Caucasus are expected to shrink at a rate of 5—8 km^2 until the end of the 21st century, and due to this the total area occupied by glaciers is expected to reduce from 765 km^2 to about 210 km^2 (under RCP4.5, the moderate scenario of anthropogenic impact on the climate system). The decrease of glacier runoff may lead to deterioration of water quality in glacier-fed and highland snow-fed rivers. Glacier meltwater stabilizes river runoff during the warm season. In this period, without glacier meltwater the river runoff may decline considerably.

Permafrost

The current increase in temperature of perennially frozen ground (PFG), i.e., permafrost, is about 1.5 times lower than the increase in surface air temperature. The most considerable changes occur in the low-temperature layer of PFG, while in the 0...–1°C layer the process of permafrost degradation is much slower. Permafrost temperature rise and taliks occur generally as the near-surface air becomes warmer and snow depth becomes higher. If precipitation in winter decreases, the thermal state of permafrost remains stable.

In the period of systematic observations (approximately since the middle of the 1990s) many monitoring sites have shown an increase in depth of PFG seasonal thawing. In Western Siberia it has increased by 1—2 cm and in the EPR by 2—6 cm. It should be noted that an increase in air temperature and an increase in depth of PFG seasonal thawing are not strictly synchronous. The influence of inter-annual variability on air temperature and precipitation is significant.

Intensity of cryogenic processes also does not strictly depend on the magnitude of temperature change. Such processes as the shoreline thermal abrasion and cryogenic landslides have cyclic dynamics depending on a variety of climatic factors. They become more intensive in areas of massive ice formation. Thermokarst dynamics depends on the ratio of precipitation to evaporation. Changes in hydrological conditions, snow accumulation, and vegetation may contribute to the new permafrost formation and cryogenic heaving even under climate warming.

Model simulations of permafrost evolution under climate warming show that the area of permafrost thawed at the surface will gradually expand and permafrost temperature will increase (Fig. GS4.4).

According to model simulations, the permafrost will thaw at the surface on most of the northern EPR by the middle of the 21st century; in Western Siberia the boundary of sporadic PFG at the surface will follow the Arctic Circle. By the end of the 21st century, PFG will completely thaw at the surface on about 50% of the present permafrost zone, and the permafrost table will go deeper.

Warming will not affect the boundary of relict permafrost in the north of the EPR and south of Western Siberia.

Natural terrestrial ecosystems

Changes in vegetation were observed all over the world in recent decades at all levels of its organization. The global relative rate of photosynthesis has increased by 5—10% due to CO_2 concentration rise. The growing season has been increasing by 0.29 day/year in the Northern Hemisphere and by 0.4 day/year in Eurasia on average. Primary productivity of plants in Northern Eurasia has been growing at a rate of 1.17% per year in 1982—2000.

Changes in the boundaries of biomes are expected basically to be as follows (Fig. GS4.5):

— tundra will shrink considerably (by 42%) as well as the larch range; larch will still occupy substantial area in the centre, but the rest of its actual range will be occupied by spruce;

— temperate mixed forest will cover large areas in the EPR and Scandinavia to the north of 60 °N; in the south of Eastern Siberia steppe will appear, in some places up to 60 °N.

In some regions forest vegetation expanded into mountain tundra and dark coniferous boreal forest moved into territories occupied by larch on plains.

Aridization of climate in the south of Eastern Siberia made steppes move to the north and steppe

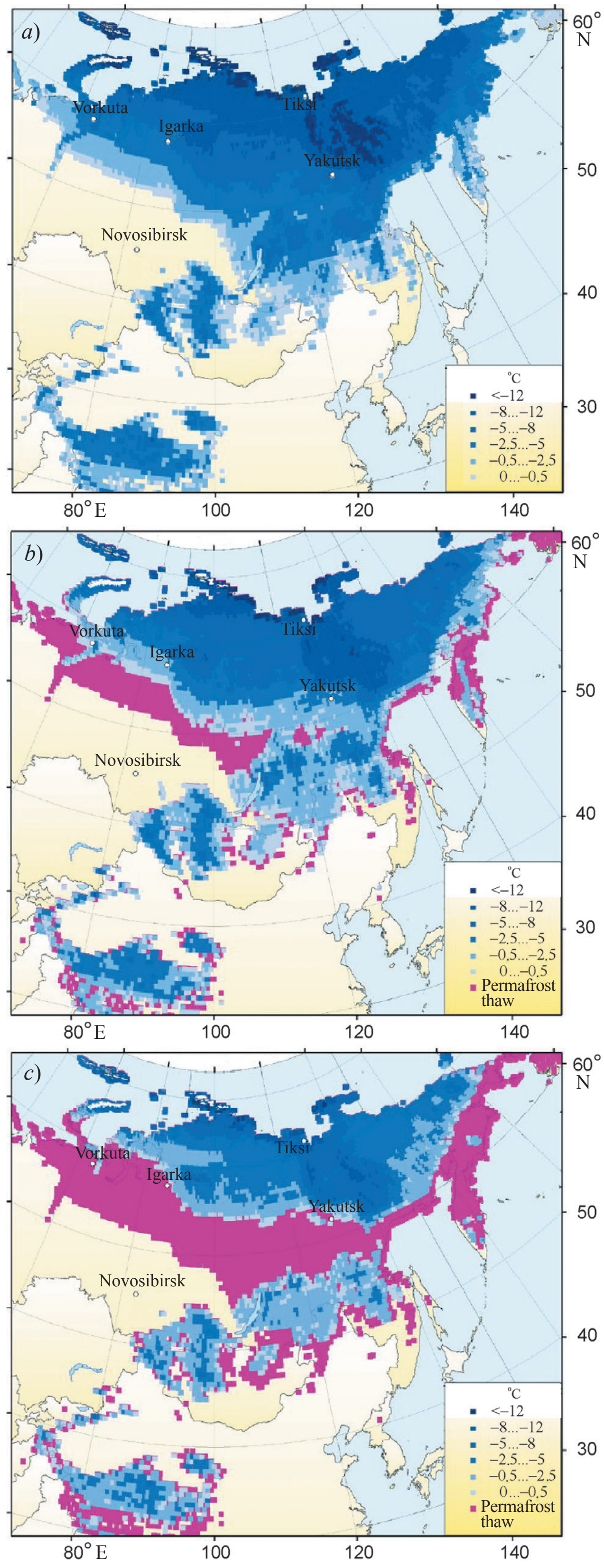

Fig. GS4.4. Annual mean ground temperature at the lower part of a layer of seasonal thawing (freezing) in Northern Eurasia for the following time intervals: 1990—2000 (*a*), 2040—2050 (*b*) and 2090—2100 (*c*). Areas of permafrost thawed at the surface are shown in pink.

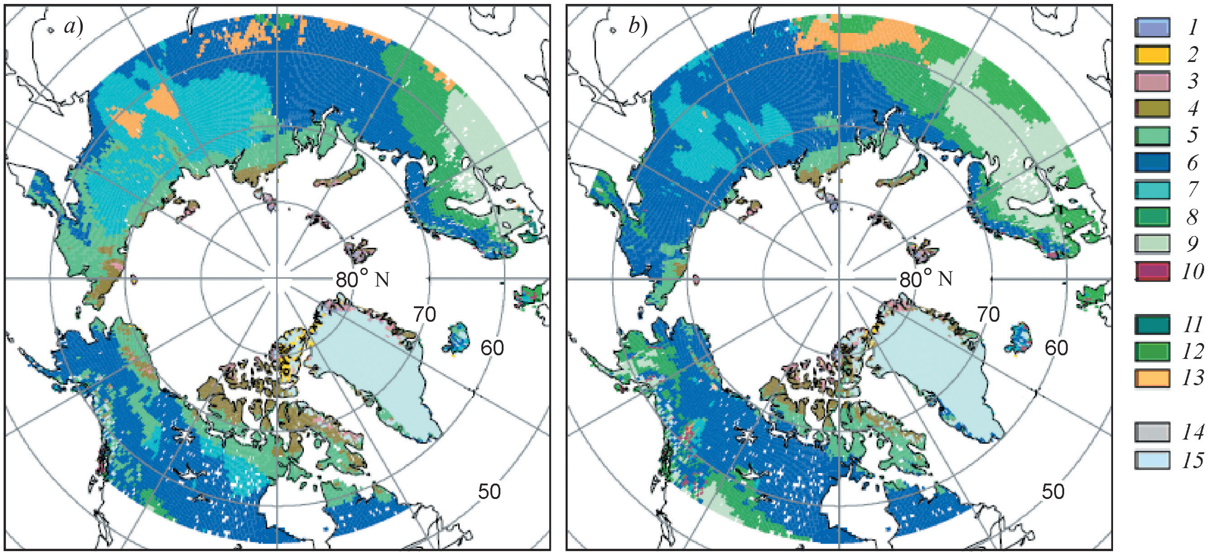

Fig. GS4.5. Distribution of vegetation north of 55 °N: *a*) current distribution according to the CAVM/GLC2000 database; *b*) calculated with the BIOME4 model under climate warming by 2 °C. *1*) barren land; *2*) graminoid tundra; *3*) creeping dwarf-shrub tundra; *4*) erect dwarf-shrub tundra; *5*) shrub tundra; *6*) evergreen boreal taiga; *7*) deciduous taiga; *8*) evergreen middle taiga; *9*) mixed boreal forest; *10*) mixed deciduous forest; *11*) evergreen deciduous forest; *12*) deciduous broad-leaf forest; *13*) xerophilous shrubs; *14*) desert; *15*) ice; derived from (Bala, Calderia, Mirin, et al., 2005).

mammals migrate respectively. The geographic range of polar bear reduced in the Arctic; the increase in mortality of Pacific walrus has been observed at the Chukchi Sea coast.

In the last 20—30 years, frequency of forest fires in Siberian Taiga, Evenkiya, Khabarovsk Territory and Far Northeast of Russia has increased by 30—50%. In 1973—2010, the total nidus area of forest pests and diseases has increased twofold.

Some ecological risks exist in the Altai-Sayan region: extinction of certain highland plants and lichens, reduction in the range of Siberian argali and population of Siberian reindeer.

Further deterioration of the Polar bear habitat is expected across the whole of the Russian Arctic (Fig. GS4.6).

The increasing risk of fires is expected in Russian forests. Spatial scale of pest-occupied areas and rate of their reproduction will lead to the bigger forest damage and mortality.

Ecosystems of wetlands are also definitely affected by the climate change. However, the available information is not sufficient to make any robust conclusions on possible directions and rates of the changes. Further observations and research should be conducted under relevant programmes taking into account natural diversity, different geographical conditions (including differences in climate changes), and different types of anthropogenic impacts.

Carbon budget in soils: consequences of climate change

In the long term, climate change will create conditions for an increase in CO_2 emission from soils and reduction in soil carbon stocks on most of the territory of Russia. The main reason is intensification, on average, of the heterotrophic soil respiration. CO_2 emission from soils in Russia is projected to grow by 6% on average by 2020, compared with the 1981—2000 baseline period; it will grow by 17% by 2050 (Fig. GS4.7). However, for some areas (e.g., in tundra or in northern coniferous forests) substantial growth in emissions will be typical, while other areas (rather small in size) will have a certain reduction in CO_2 emissions.

Emissions of CO_2 from soils of forest ecosystems may grow approximately by 15%. Under potential increase in the felling volumes and intensification of forest fires the total carbon budget of forest ecosystems is projected to decline.

Russia should develop a strategy and an integrated programme for the adaptation of forests to global

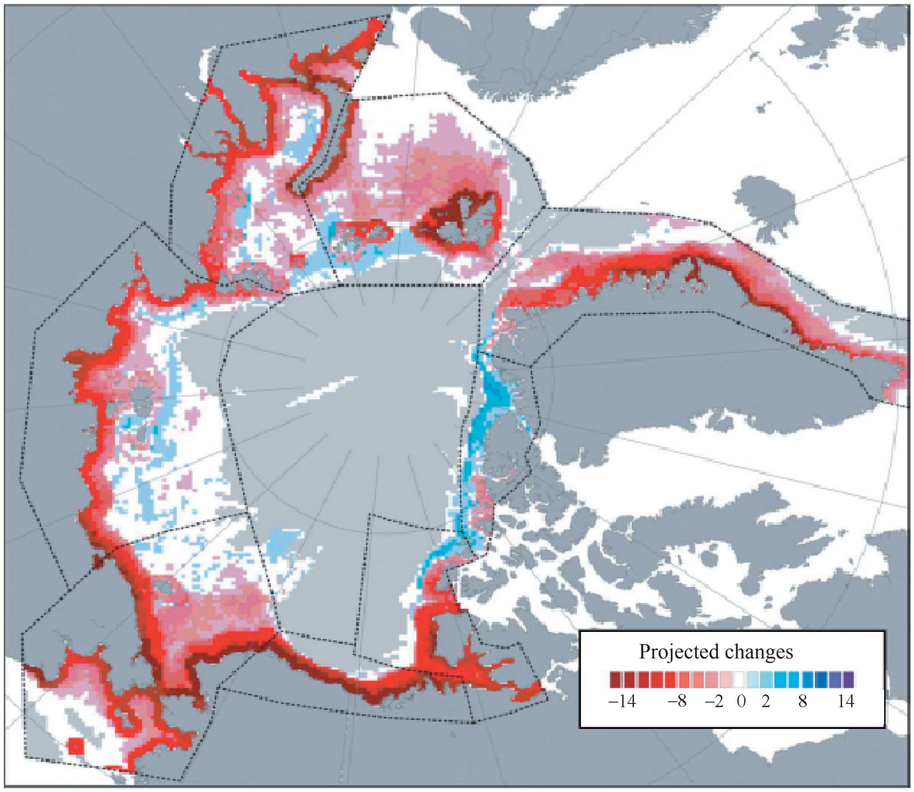

Fig. GS4.6. Projected changes in the polar bear habitat for 2041—2050 relative to 2001. Colour gradations show the cumulative number of months per 2041—2050 by which the longevity of conditions optimal for the polar bear decreased (red) or increased (blue). Adopted from (Durner, Douglas, Nielson et al., 2009).

climate change including genetic, forest management, institutional, social, and other measures.

Cropland soil carbon stocks in the EPR are expected to decline in the 21st century, if land use does not undergo any changes. In 70 years, the projected losses may be from 9 to 12% of the total carbon stock in the 0—20 cm layer.

Adaptation measures (use of crop rotation and crop planning best practices, change in seeding and harvesting time, change in the amount of fertilizers, adequate forage supply management, etc.) will make it possible to reduce the cropland soil carbon losses by 30—45%.

The current amount of carbon accumulation in fallow lands of Russia (74 ± 22 Gt C/year) may decline in the country as a whole during the 21st century. On most of the Asian part of Russia (APR) and Central Chernozem Region the decrease will be 11—32%, but in the North-Western Federal District and the Central Federal District carbon accumulation will grow by up to 27%. Emission of CO_2 from wetlands' soils will grow due to increased water and wind erosion, degradation, intensity of fires, etc. Adaptation measures for wetlands'soils should primarily include rewetting of previously drained lands.

Possible increase in thawing in the permafrost zone will contribute another 8—10 Mt/year to CH_4 emissions by the middle of the 21st century. Therefore, the global mean annual temperature may rise approximately by 0.012 °C. Elevated CH_4 emission in the shelf area of Eastern Arctic seas may add extra 0.01 °C to the global warming.

Possible adaptation for all types of soil includes measures on soil protection from degradation (protection from erosion, pollution and fire, reclamation, etc.).

Droughts and desertification

Droughts occur in all natural zones of Russia including those with low and high rainfall. Prolong droughts in drylands cause the aridization of these regions, the initial phase of desertification. The anthropogenic component of desertification relates to the degradation of drylands due to human activities.

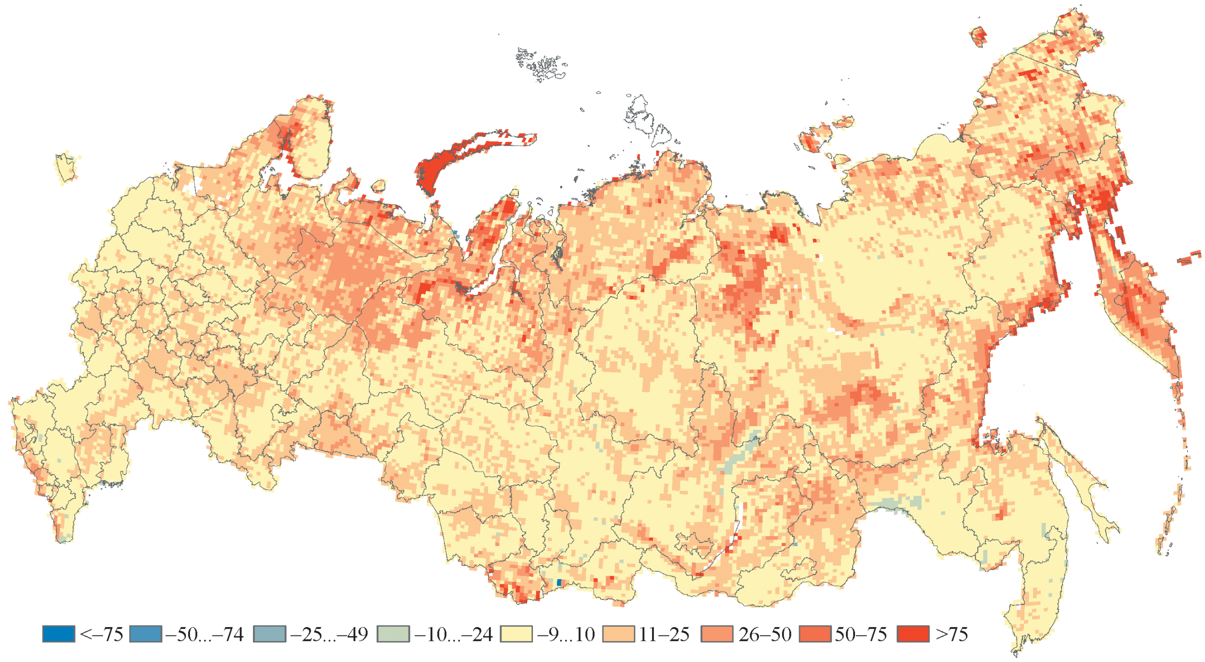

Fig. GS4.7. Projected changes in heterotrophic soil respiration by 2050 expressed as percentage relative to the 1981—2000 baseline period (based on simulations with the Main Geophysical Observatory regional climate model).

In the 20th century, droughts in crop production regions and pasture areas of Russia were developing against the background of a slow increase in the annual mean moistening observed since the 1930s until the late 20th century. Heavy and widespread droughts occurred in the EPR in the 1930s almost every year. Although in the subsequent decades droughts were less frequent than in 1931—1940, some decades (1951—1960, 1991—2000) showed a higher frequency. In the period of intensification of the current global warming (since the early 1980s) droughts increased in intensity and extent, but not in frequency.

Desertification of arid lands in the EPR takes place mainly due to anthropogenic load on ecosystems. An increase in the annual moistening observed from the late 1980s to the early 21st century has contributed to recovery of steppe and desert vegetation even under heavy anthropogenic load. Intensity of this recovery was also positively influenced by the temporal reduction in such a factor of anthropogenic desertification as overgrazing (which was due to stop or slowdown in growth of livestock population) in the late 20th century.

Most of current model simulations show that moistening in Russia will decrease by the middle of the 21st century, particularly in arid regions of the EPR. Frequency of droughts is projected to increase. A share of soil droughts will grow. Climatic component of desertification is likely to enhance. Droughts are projected to expand into territories to the north of the grain belt.

Adequate adaptation to expected more dry climate in southern regions of the Russian grain belt should include moisture-saving technologies, up-to-date practices of crop production and efficient use of fertilizers.

Adaptation to more frequent droughts in pasture areas should be aimed to strengthen the resilience of pasture ecosystems by preventing overgrazing and using technologies for the recovery and enhancement of pasture biopotential (efficient use of organic and mineral fertilizers, sowing of high bioproductivity grass, moistening).

Section 5. IMPACTS OF CLIMATE CHANGE ON NATURAL MARINE SYSTEMS

Arctic seas of Russia

Russian Arctic seas traditionally include the Kara Sea, the Laptev Sea, the East Siberian Sea and the Chukchi Sea, which are classified as the marginal seas of the Arctic Ocean. The White Sea and the Barents Sea also fall into the group of Arctic seas due to their geographical location.

Maritime activities in the Arctic seas of Russia as well as economic development of the northern regions depend significantly on climate (this issue is discussed in more detail in Section 6). For instance, climate, particularly frequency and intensity of extreme hydrometeorological events and ice conditions, influences the efficiency and safety of mining and marine transport operations as well as development and safe maintenance of infrastructure. Climate has a significant impact on the availability of marine biological resources, including conditions for and efficiency of fishery.

The analysis of surface air temperature changes in the Arctic showed that in most regions the air temperature had increased during the 20th century. The annual mean temperature in the area north of 60 °N in 2005 for the first time exceeded the level reached during the Arctic warming in the 1930—1940s. In 1981—2010, the annual mean temperature increase appeared to be statistically significant over all the Arctic seas. However, in different parts of “the marine Arctic” a rate of warming was different. In the White Sea the annual mean temperature increased by 2.1 °C on average. In the northern part of the Barents Sea in winter the temperature rise slightly exceeded 4 °C. In the Asian sector, including the Laptev Sea, the East Siberian Sea and the Chukchi Sea, it ranged from 0.4 to 1.1 °C.

The best indicator of climate change in the marine Arctic is sea ice. In the late 20th — early 21st century, sea ice extent in the Northern Hemisphere declined amid its significant interannual variations. The decline in the seasonal minimal sea ice extent (September) was particularly rapid over the last three decades. The absolute minimum for the whole period of instrumental observations was reached in September 2012. At the same time the drifting ice thickness has been declining. Ice in the Arctic seas is set 12 days later on average relative to 1965—1975. The latest ice formation was observed in the southwestern parts of the Kara Sea and the Chukchi Sea (on average, 21—22 days later than in other areas of the Arctic seas). Ice cover duration has reduced by 40 days compared to 1965—1975 and appeared to be 284 days on average.

The climate change consequences also have an ecological aspect. Ecosystems of the northern seas, the Arctic seas in particular, are very sensitive to external impacts. This relates to marine environment pollution (in the northern seas the marine pollution removal through natural processes usually goes much slower than in the southern seas), and to such basic characteristics of sea water as temperature and salinity. Climate change influences these parameters leading to modification of ecological processes in marine ecosystems and respective changes in species composition and productivity. As a result, commercial fish species and other marine organisms are affected.

The Baltic Sea

Long-term observations of changes and variability in the state of the Baltic Sea, including parameters of the climate system, indicate that both significant interannual variability and long-term trends have taken place.

Figure GS5.1 shows the maximal annual ice cover area in the Baltic Sea since 1720. The data are provided by the Finnish Meteorological Institute. Significant interannual variability is clearly seen as well as all gradations of the ice cover: extremely mild, mild, average, severe, extremely severe.

According to the model simulations, the water temperature in the Baltic Sea will continue to rise in the coming 80 years. This will lead to a decline in sea ice extent and reduction in ice cover duration. In the shipping industry and port operations this will reduce costs of icebreaking fleet assistance in winter pilotage of vessels to the port and, as a result, the cost of cargo shipping.

If sea level extremes and frequency of storm surge floods continue to increase, it will be necessary to further develop and improve the appropriate operational forecasting systems to ensure safety of shipping, reduce and prevent losses from catastrophic destruction of coastal facilities and provide timely warnings to inhabitants of the coastal areas.

Climate warming in the Baltic Sea region will contribute to the development of marine and coastal tourism. However, according to projections, low-oxygen or anoxic deep water areas in the Baltic’s Gulf of Finland may extend leading to deterioration of water quality in the Baltic Sea as a whole. The water

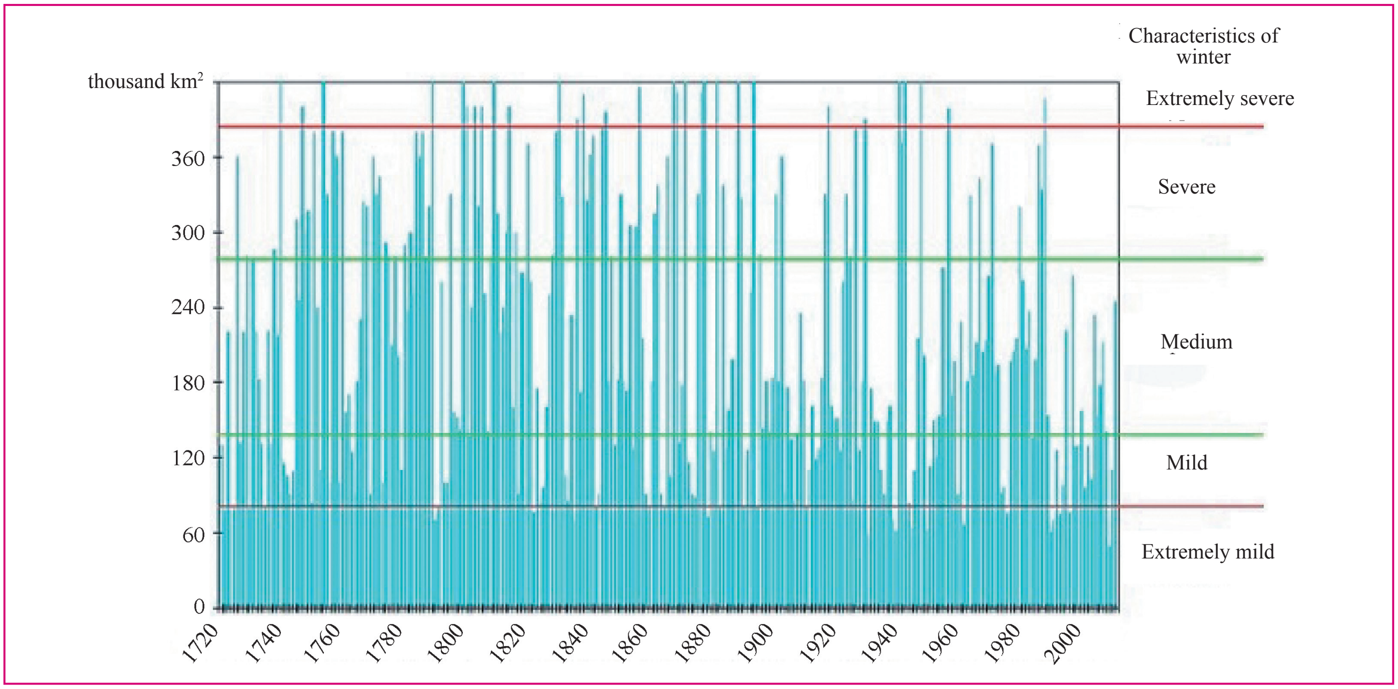

Fig. GS5.1. The long-term variability of the maximal ice cover area in the Baltic Sea for the period of historical observations from 1720 to 2010 (http://www.helcom.fi/BSAP_assessment/ifs/ifs2010/en_GB/iceseason/).

quality deterioration will lead to intensification of the eutrophication process with the following major consequences: intensive development of blooms of potentially toxic blue-green algae, reduced water clarity, shoreline fouling, changes in fish feeding resources and fish species composition.

Anoxic conditions of long duration never emerge in the shallow waters of the Curonian Lagoon and the Vistula Lagoon (the Kaliningrad shelf area). However, the present level of nutrients in the waters and consequent intensity of algae development are quite considerable. The higher water temperatures will contribute to the development of warm-water harmful algae, and eutrophication may grow to produce anoxic areas after intensive algal blooms. Therefore, the higher water temperatures will require environmental protection measures, particularly those decreasing nutrient load from land, to reduce eutrophication and improve water quality in the coastal areas of Russia.

The influence of climate change on fishery and biological resources is most noticeable. In particular, climate change has a considerable influence on commercial fish habitats, feeding resources and interspecies competition. The temperature regime plays an important role in the fish life processes and potentially warming may have a positive effect on fish population growth.

However, since low-oxygen or anoxic areas will considerably increase under warming by the end of the 21st century compared to the current situation (3 and 1.5 times respectively), salinity will decrease and eutrophication will increase, the fishing efficiency is expected to decline. This will result in the overall catch decrease and replacement of valuable commercial species by less valuable ones.

However, there is a certain potential for adaption of fisheries in the Baltic Sea to climate change. For that continuous monitoring of the main commercial fish species is needed both in the Baltic Sea and its coastal areas. Fishing and coastal fish-processing facilities should be reoriented on the basis of the monitoring data in due time and fishing operations should be optimized taking into account population of such fish species as herring, sprat or codfish. The existing methodologies for permissible catch assessment are reliable just for the short-term planning, but for the long-term planning new methods should be developed.

Development of the aquaculture as a separate branch of fisheries in the Baltic will enable it to adapt to climate change. It is necessary to implement extensive cultivation of marine organisms (filter-feeding mollusks and macroalgae) in addition to the fish rearing for sale (the intensive form of aquaculture).

It is reasonable to enhance the artificial reproduction of aquatic resources, including juvenile fish breeding, to replenish the Baltic Sea populations. Expansion of the network of fish hatcheries and nurseries will help not only to implement national programmes for aquatic biological resources, but also to meet the needs of commercial fish farms in fish stocking material.

Reclamation operations in the coastal areas should be an important component of fishery adaptation to climate change, since the costal areas with aquatic vegetation may be successfully used for marine and freshwater fish reproduction. As already stated, under climate warming accompanied by eutrophication and decreasing of salinity, the aquatic vegetation areas will grow contributing to the growth of carp species populations and the pike perch reproduction range.

Contrary to fisheries the aquaculture production in the Baltic Sea may grow thirty-fold (up to 400 thousand tons per year) compared to the current situation. Potential fish-rearing-for-sale (aquaculture) opportunities differ in different parts of the Baltic Sea.

Southern seas of Russia

The Southern seas (the Black Sea, the Sea of Azov and the Caspian Sea) are of importance for the national economy (fisheries, shipping, shelf gas and oil production and transportation, resort zones and ports located on the Russian coastal territories).

The basic consequences of climate change experienced in the last 30 years are common to all Southern seas of Russia, namely, sea surface temperature rise, decrease in salinity (and respective enhanced vertical stratification of waters), lower wind speed and sea level rise in the Black Sea and the Sea of Azov.

The tendency towards air (Fig. GS5.2) and sea surface temperature rise will ensure a longer holiday season on the Russian coast of the Black Sea and the Sea of Azov. The Russian coast of the Caspian Sea is not a resort zone so far.

Due to changes in the thermohaline structure of the Caspian Sea deep waters (enhancement of salinity (density) stratification), the ventilation in its deep water hollows has virtually stopped affecting the ecological conditions. The anomalous algal bloom occurred in the Southern Caspian in August-September 2005 with the affected area of nearly 20 000 km^2. Similar events are projected to increasingly occur in the Northern Caspian as well. Algal bloom may have an adverse effect on water quality and fisheries in the Russian sector of the Caspian Sea.

In 2006, 2008 and 2012 the anomalous algal bloom occurred in the open and coastal areas of the eastern part of the Black Sea. Algal bloom may adversely affect the resort zones, though the Russian coast should be less affected (except for the beaches of Anapa) due to the absence of the large-volume river runoff in Georgia, Russia and Abkhazia. However, this problem may be serious for the resort areas in the Sea of Azov.

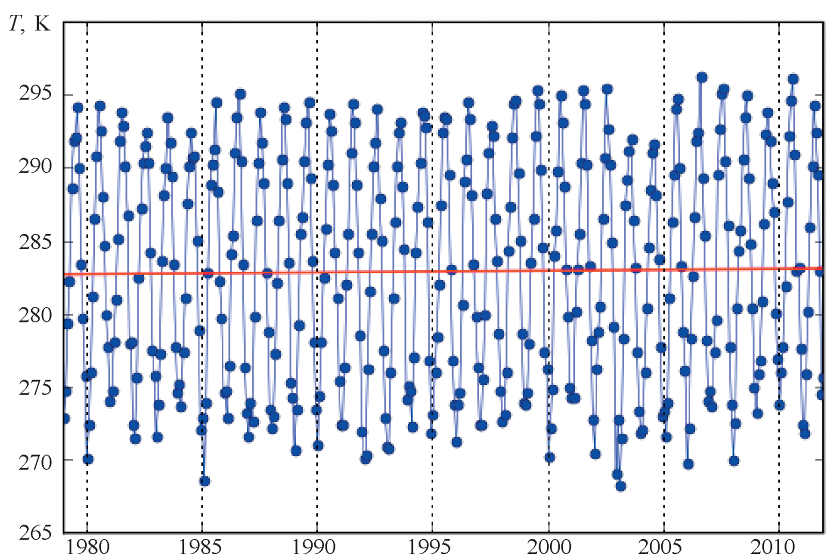

Fig. GS5.2. Seasonal and interannual variability of the monthly mean air temperature over the Black Sea (41—45 °N, 28—41 °E) in 1979—2011. The linear trend is $y = 0.001059x + 282.7$.

A rise of the Black Sea level in the nearest decades will not lead to serious problems for the coastal zone of Russia, however it will most likely contribute to the shoreline abrasion and certain flooding of infrastructure and settlements on the coast of the Sea of Azov. The rise of the Sea of Azov mean level by 0.5—1 m with the account of surge fluctuations will lead to significant further erosion of the coast. Russian cities located in these areas, such as Temryuk, Primorsko-Akhtarsk, Yeysk and Taganrog, may face a serious risk of flooding.

The 2.5 m rise of the Caspian Sea level between 1978 and 1995 had the following serious consequences: settlements and infrastructure were ruined in the broad coastal zone (50—70 km); 320 thousand hectares of farmland were inundated, the underground water table rose; soils were flooded and salted; railways, roads, power and telephone lines were damaged; operation of gas pipelines was disturbed; sea waters were polluted due to flooded and destroyed oil wells. In Dagestan alone 260 thousand people were caught up in the affected area. Overall, this sea level rise affected 7 million hectares of land, where 600 thousand people lived. The total damage to the economy of Russia attributable to the rise in the sea level, according to different estimates, ranged from 0.5 to1 billion USD. According to the WMO, the total direct damage to the Caspian States by 1995 was estimated at about 15 billion USD.

Despite the fact that in the late 2012 the Caspian Sea level was roughly 1.2 m lower than the maximal level of 1995 (Fig. GS5.3), it must be kept in mind that it may increase in the nearest decade and again reach –26.6 m as in 1995. It should be also taken into account that either minimal level of 1977 or the maximal level of 1995 were not predictable. (Here and elsewhere in this section sea level is given in the Baltic System of heights).

If the Caspian Sea level again reaches –26.0 m, many settlements and social and industrial facilities located in the coastal zone of Russia and other Caspian States may be ruined or damaged. Special engineering operations are needed to protect the coastal zone. The low slope of the coastal plain of Kalmykia allows sea water to go far inland from the coast, particularly during storm surges. Storm surges of 2 to 3 meters high may flood the territory 20—30 km inland from the coastal zone.

An increasing frequency of cold winters in the 2000s appeared to be unexpected amid ongoing regional warming. For example, in January 2012, the Sea of Azov, the Northern Caspian (shore ice was seen even in the port of Makhachkala), the Turkmenbashi Bay (the former Krasnovodsk Bay) in the Southern Caspian Sea and some ports of the Black Sea (including the port of Novorossiysk) were covered with ice. As a result, transport communications were seriously affected. According to some projections, a

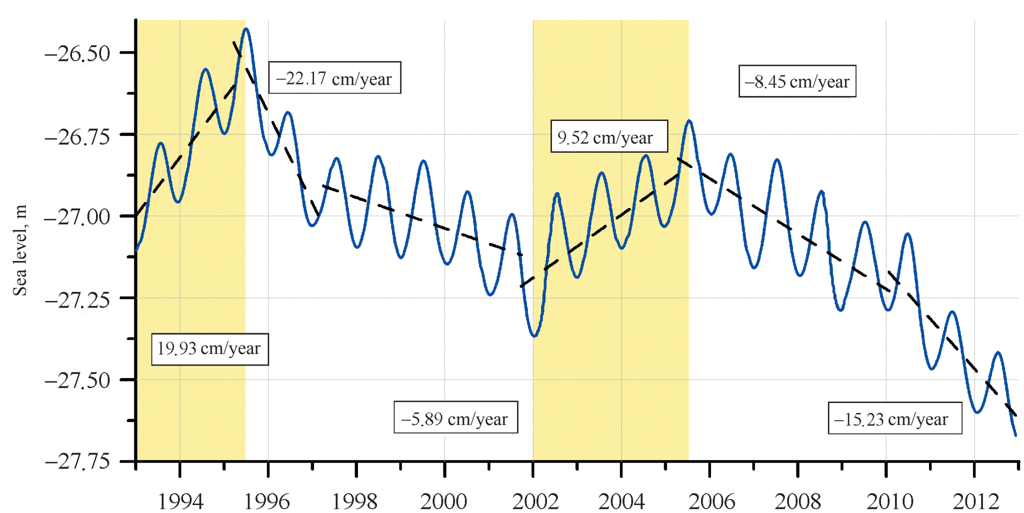

Fig. GS5.3. Seasonal (solid line) and interannual (dashed line) variability of the Caspian Sea level from January 1993 to December 2012 based on the altimetry data from T/P and J1/2 satellites. Sea level is given in the Baltic System of heights. Periods of sea level rise are highlighted in yellow.

series of cold winters may be expected in the regions of the Southern seas of Russia in the next decade.

However, the warming trend induced by the air and sea surface temperature rise and the consequent downward trend in sea ice extent and ice thickness will lead to a longer navigation period in the Sea of Azov and the Northern Caspian and reduce the risk related to operations of the offshore drilling platforms and pipelines in the Northern Caspian.

Far-Eastern seas of Russia

The weakening of the monsoon circulation was observed over the Far-Eastern Region until the second half of the 20th century. As a result, the air temperature has increased, while summer precipitation and water amount in major rivers (including the Amur) has declined. The only exception to this trend is the catastrophic Amur flood in 2013.

Climate change has its most pronounced effect on the ice cover in the Sea of Okhotsk. Sea ice extent has reduced by more than 20% in the last 56 years. Further decrease by 20—25% of the ice cover is expected by the end of the 21st century. Meanwhile in the Bering Sea and the Gulf of Tatar of the Sea of Japan this trend is not well-pronounced, while interannual and decadal fluctuations are most typical.

Changes in characteristics of monsoon and atmospheric processes over the Far-Eastern Region manifested themselves in the long-term changes of the water temperature as well, but the rate and character of the latter differ for different seas. The temperature increases most significantly in the surface waters of the Sea of Japan (1.72 °C/100 years). The rate considerably exceeds the average value for the global ocean (0.51 °C/100 years). The temperature of surface waters in the Sea of Japan is expected to increase by another 1.9—3.1 °C by the end of the 21st century. The increase in the temperature and reduction of oxygen content in deep waters are caused by the weakening of convective processes induced by climate warming. The temperature of intermediate and deep waters in the Sea of Okhotsk and the Bering Sea also shows an increasing trend. However, their interannual and decadal fluctuations are much more pronounced in comparison with the long-term linear trends.

Changes in the atmospheric processes and ocean characteristics have a significant influence on the fishing conditions.

Section 6. IMPACTS OF CLIMATE CHANGE ON ECONOMIC ENTITIES AND HUMAN HEALTH. ADAPTATION MEASURES

Human health

Three main factors could be pointed out for estimating impacts of the current climate change on human health in Russia.

Direct effects are related to changes in the temperature regime. They can be positive due to the higher thermal comfort in the cold season, particularly in the northern regions, leading to decreased incidence of hypothermia-related diseases and lower rate of extreme cold-related injuries. They can also be very negative. In several cities, including those located in the north of the country, more frequent heat waves are responsible for the deterioration of human health and additional mortality.

Indirect negative effects include, *inter alia*, deterioration of air quality primarily due to emission of combustion products from forest fires showing an increase in frequency and intensity under current climate change. Air quality also deteriorates in large cities due to adverse meteorological conditions preventing rapid removal of pollutants by air streams and contributing to accumulation of pollutants in the surface layer.

Heat waves, particularly combined with deterioration of air quality, are responsible for higher morbidity and mortality, particularly in risk groups (children, elderly people, people suffering from chronic respiratory and cardiovascular diseases).

Another important factor of indirect climate change effects on human health is the influence on epidemiologic situation. This is particularly evident in the years with mild winters. The West Nile fever outbreaks occurred in the last 15 years (1999, 2010, 2012) (Fig. GS6.1). Its geographic distribution has been expanding. Crimean haemorrhagic fever gradually moves northward. The incidence of tick-borne encephalitis increased in the northern regions and expanded into the territories that have never been affected before. Correlation between salmonellosis incidence and air temperature has been detected.

Under climate change observed in the 20th — early 21st century and expected in future in Russia and neighboring countries climatic ranges (i.e., geographic areas climatically suitable for sustainable existence of certain species) of vector species of many transmissive diseases have been and will be expanding northward, northeastward and eastward (Fig. GS6.2). This relates to the vectors of human malaria (mosquitoes of the *Anopheles maculipennis* group), vectors of arboviruses (mosquitoes *Aedes aegypti* and *Aedes albopictus*), vectors of tick-borne encephalitis, Lyme borreliosis, rickettsiosis (ixodic ticks *Ixodes ricinus* and *Ixodes persulcatus*). In most cases, climatic ranges are not expected to decrease. An exception is for *Ixodes persulcatus*. The western boundary of this species' climatic range will be shifting eastward throughout the 21st century. Climatic ranges of *Aedes aegypti* and *Aedes albopictus* are

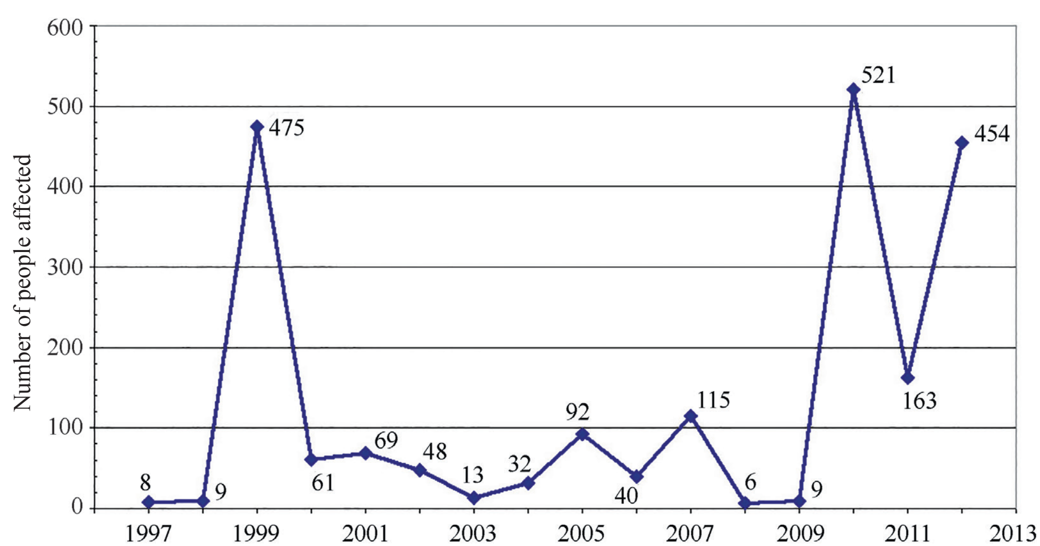

Fig. GS6.1. Incidence of West Nile fever in Russia.

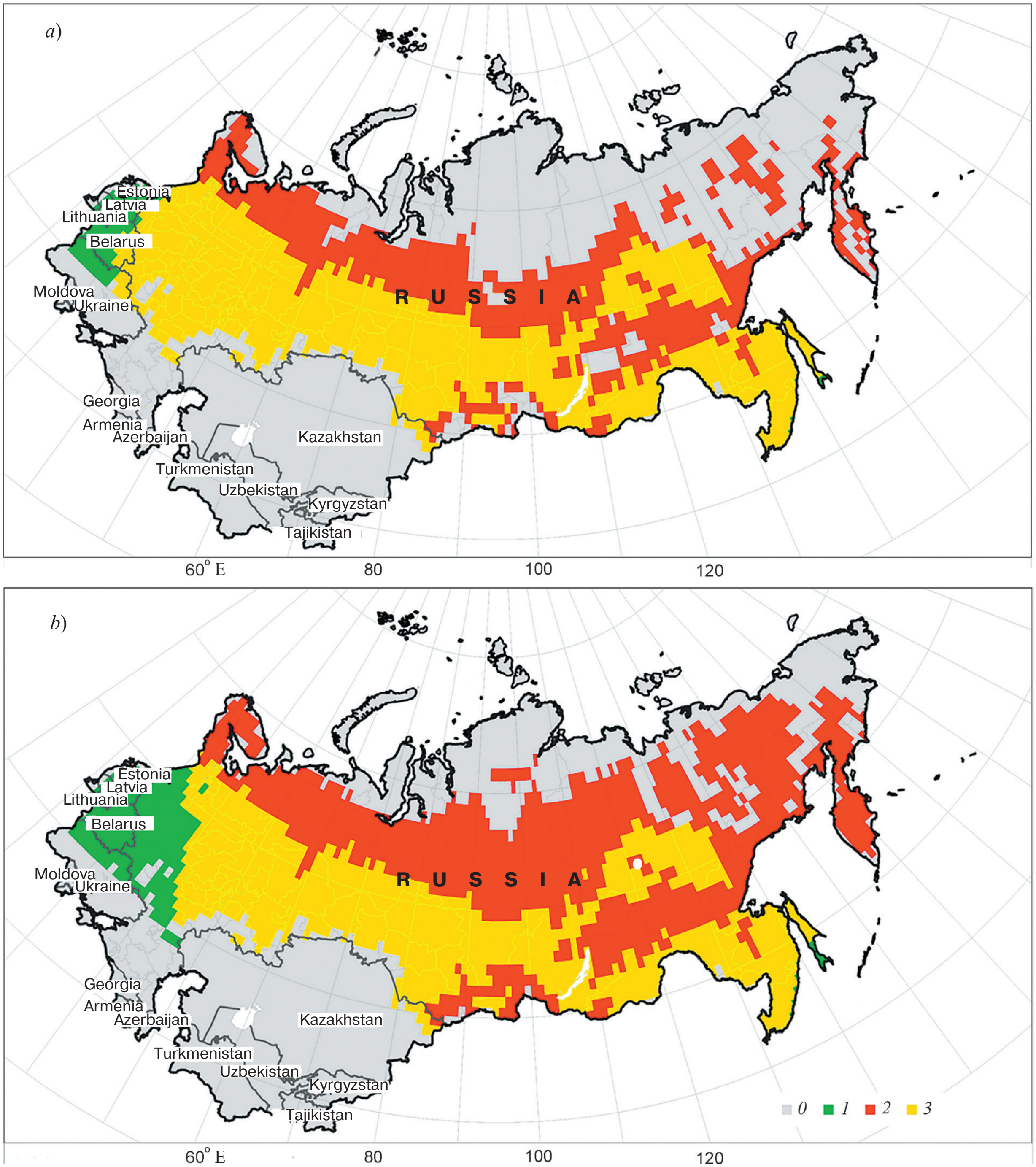

Fig. GS6.2. Projected changes in the climatic range of ixodic tick *Ixodes persulcatus* in 2080—2099 relative to 1981—2000 under RCP4.5, the moderate scenario of anthropogenic impact on the Earth's climate system (*a*), and RCP8.5, the extreme scenario of anthropogenic impact on the Earth's climate system (*b*). *0* — vector is not present in 1981—2000 as well as in 2080—2099; *1* — decrease of the range; *2* — expansion of the range; *3* — vector is present in 1981—2000 and will be present in 2080—2099.

expected to slightly decrease in high-mountain areas of the Caucasus in the late 21st century.

Consequences of climate change under RCP4.5 and RCP8.5, the moderate and extreme scenarios of anthropogenic impact on the Earth's climate system, are similar for the climatic ranges of the abovementioned vectors in the first half of the 21st century. Differences, namely, more significant expansion of ranges under RCP8.5, will show up in the second half of the 21st century (Fig. GS.6.2).

Climate change-related risk factors include not only the expansion of ranges and growth of population of the arthropod vectors, but also the similar increase in abundance and expansion of ranges of some vertebrates, primarily mouse-like rodents, who are the reservoirs of feral herd infections and biological hosts of vectors.

Climate change adaptation measures aimed at the reduction of negative effects on human health in Russia should differ considerably in different climatic regions taking into account a wide range of climate conditions in the country. In general it is possible to identify several main ways of adaptation: 1) mitigation plans for the cities exposed to heat waves; 2) enhancement of plans for epidemiological surveillance to control infectious diseases and appropriate prevention measures; 3) plans of inter-agency cooperation development, particularly, cooperation of meteorological service with health, social welfare and other services at the local (municipal, city-wide), regional and federal levels.

Construction, land transport, fuel and energy sector

The most noticeable consequences of the current climate change include changes in characteristics of the heating season.

The current tendency for shortening the heating season (up to 5 days/10 years in the north of the EPR) and increasing the average air temperature (up to 0.8°C/10 years in Central Yakutia) contributes to higher thermal efficiency of existing buildings and creates conditions to reduce energy demand in winter. According to projections with account of unequal distribution of the population, the most significant potentially achievable relative reduction in energy demand for heating of buildings is expected in the North-Western Federal District (Fig. GS6.3a). Energy demand for heating is projected to reduce roughly by 20% by the middle of the 21st century.

At the same time, overheating of buildings in the warm season is becoming an increasing problem. The index of energy demand for cooling of buildings has increased considerably in the south of the EPR in the last 20 years (by about 150 °C days/10 years). This index is expected to increase up to 700 °C days in the Southern Federal District by the middle of the 21st century (Fig. GS.6.3b). This will lead to appreciable changes in the interannual structure of energy demand.

The growing temperature-caused and humidity-caused damage for buildings and constructions has been observed in the recent decades due to increased number of cases, when temperature passes the 0°C line in the cold season (Fig. GS6.4), and to the growth of liquid and mixed precipitation in the cold

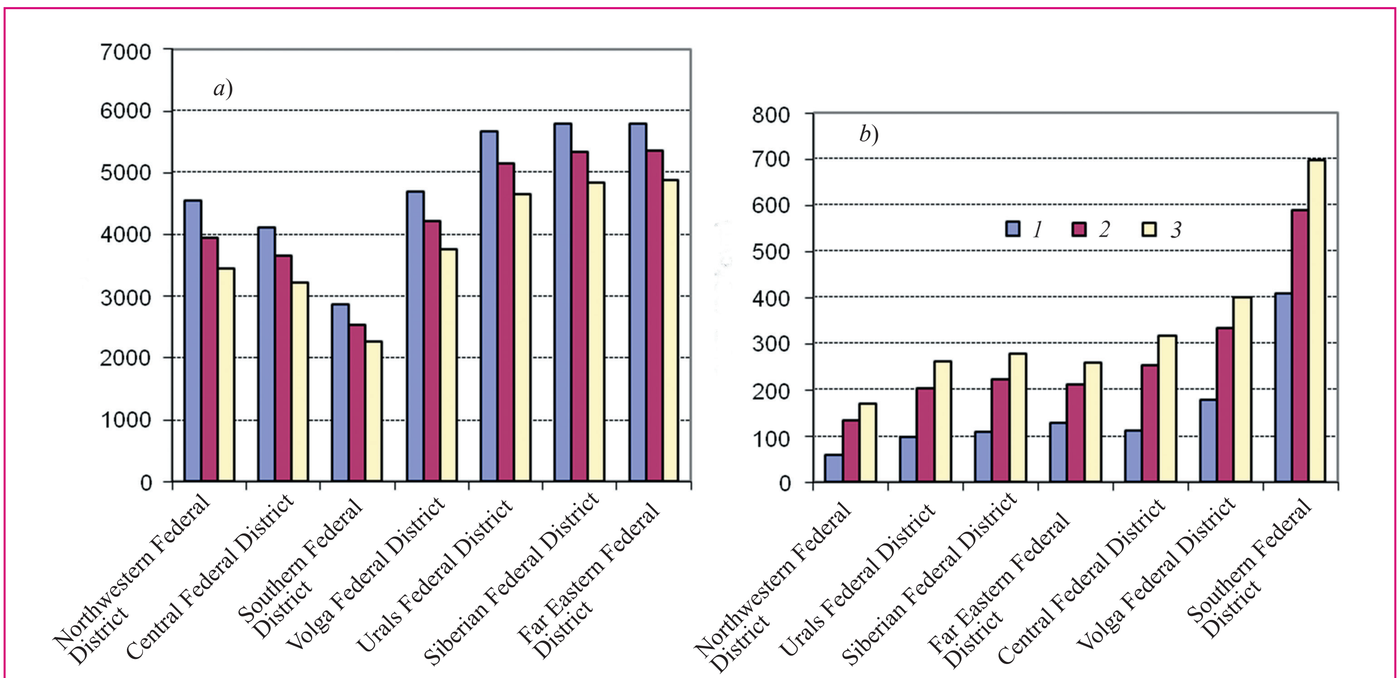

Fig. GS6.3. Regional estimates by Federal Districts of energy demand indices (°C · days) for heating (*a*) and cooling (*b*) of buildings calculated on the basis of model simulations (unequal distribution of the population is taken into account). *1*) 1981—2000; *2*) 2021—2040; *3*) 2041—2060.

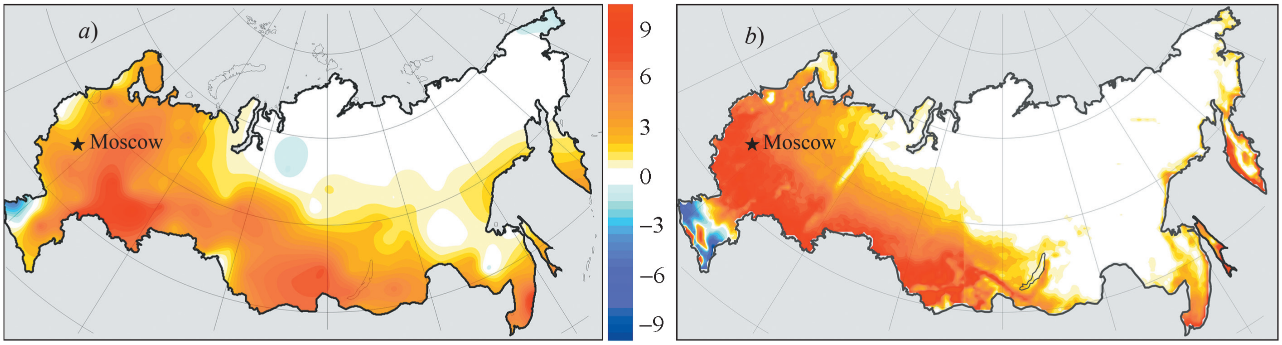

Fig. GS6.4. Changes in the number of cases, when air temperature passes the 0 ˚C line in the cold season (November — March) based on the observational data for 1981—2000 relative to 1951—1980 (*a*) and on the model simulations for 2041—2060 relative to 1981—2000 (*b*). Simulations are made with the regional climate model of the Main Geophysical Observatory (St.Petersburg, Russia).

season. In the future, it is reasonable to use moisture-proof engineering structures resilient to atmospheric impacts and materials resistant to freeze-thaw cycles.

Effects of climate change on the land transport infrastructure are negative in most cases. Roads and other infrastructure facilities deteriorate at a growing rate; operational, road safety and other expenses increase. The most dangerous consequences are expected due to rise in the intensity of precipitation. In some regions the probability of flash floods, landslides and mudflows increases with the potential damage to infrastructure. Pipelines in the regions with complicated hydrogeological conditions may become a source of serious environmental threats.

Under higher temperatures the efficiency of energy generation by thermal and nuclear power plants declines, losses on power transmission lines grow. In southern regions of Russia air temperature rise in summer may be accompanied by longer dry spells. Strengthening of this tendency by the middle of the 21st century may reduce the availability of water for cooling of power generation units, lower the shutdown threshold and raise the risk of emergency situations with the energy supply.

In terms of adaptation it is vitally important to build the power generation unit cooling systems able to work efficiently under extremely high temperature.

To get the full benefit from warming, new power generation technologies should be widely used in combination with comprehensive modernization of heat supply and thermal power systems. A higher level of technical maintenance of buildings is needed, as well as the development of regional energy systems intended for the elevated energy demand in summer.

Renewable energy sources

Nowadays, in nearly every region of Russia it is possible to use different types of renewable energy sources. The use of these sources does not lead to enrichment of the atmosphere with the greenhouse gases and therefore to subsequent warming. However, by and large, resources of this type of energy and efficiency of respective energy units tend to change along with climate.

The southern part of Russia and Yakutia have sufficient solar energy resources (Fig. GS6.5) that can be used for generation of electric and thermal power. Areas having the annual sunshine duration of about or over 2000 hours are considered to be potentially productive for the solar energy generation.

In Russia solar energy is mainly associated with the generation of thermal power on the basis of flat collectors successfully used in the Krasnodar Territory and Buryatia. A share of solar energy in Russia in the hot water provision is 55—60% in the middle latitudes and more than 75% in the southern latitudes.

According to projections of the future climate, changes in the total annual radiation coming to the land surface will not be significant in the 21st century (±2—4% of the current level). They will be caused primarily by changes in cloudiness. At the same time, substantial temperature rise expected by the middle and by the end of the 21st century will foster a wide use of solar power stations, particularly in the western and southern parts of the EPR (under warming the efficiency of their operation will increase).

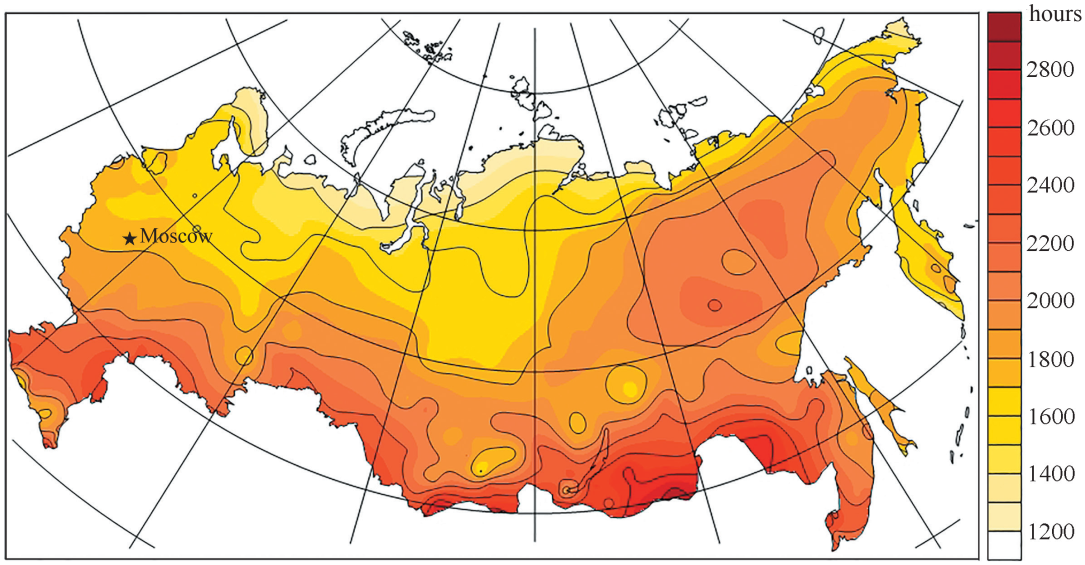

Fig. GS6.5. The current annual sunshine duration (hours).

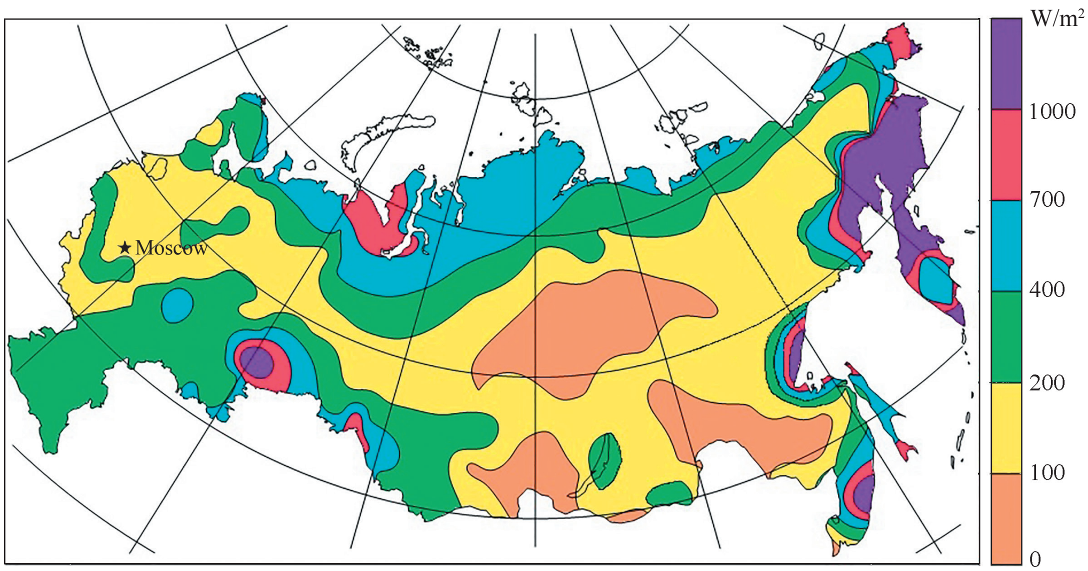

Fig. GS6.6. Zoning of the Russian territory according to specific power of the air stream (W/m^2) at a height of 100 m above the ground.

Many regions of Russia have a high potential of the wind energy (Fig. GS6.6). This creates opportunities for the development and implementation of wind turbines and stations. According to projections, no significant changes in the surface wind speed (and in the wind energy resources respectively) are expected on most of the Russian territory in the coming decades and by the end of the 21st century.

Small standalone wind energy systems are the most promising for Russia. Some positive steps have already been made in this regard. Several wind energy stations with capacity of up to 5 MW are in place at the moment.

The biomass-based energy branch in Russia is new, however it has a significant potential. Various sectors of Russian economy annually produce up to 300 million tons of biomass waste (dry weight). Conversion of such amount on the basis of biogas technologies only may produce up to 80 billion m^3 of biogas, which is the equivalent to 56 billion tons of natural gas. The influence of the current climate change on the biomass resource potential is still not clearly understood and may differ in different regions.

In Dagestan, the Northern Ossetia, the Stavropol Territory, the Krasnodar Territory, Kamchatka, the Kuril Islands and some other regions there are plenty of underground thermal water resources. Russia is able to produce the relevant high-performance energy-generating equipment. The Pauzhetskaya and Mutnovskaya geothermal power plants have been put into operation. In the Kransnodar Territory 12 geothermal fields are currently in place.

The surface layer ground-source heat (low temperature heat) based on ground-source heat pumps has been widely used in recent times. More than 700 pumps have been set up in Russia since 1992. They cover about 0.1% of the total heat energy demand. Under the temperature rise observed across most of Russia the heat pumps used as heating systems are expected to be more cost-effective by the middle of the 21st century (the permafrost zone is not taken into account here).

Existing estimates of current and expected climate change show that it will not have any serious effect on energy generation from renewable sources. If such an impact takes place it can be offset by adjustments in the energy unit design technologies.

Infrastructure facilities located in the permafrost zone

By the end of the first decade of the 21st century, the climate change had led to a decrease in the permafrost bearing capacity by 17% on average and by up to 45% in some regions relative to the 1970s. This poses a threat to infrastructure since the safety coefficient for constructions in Russia normally does not exceed 1.6. The man-induced factors such as salinization also decrease the bearing capacity of the ground. At present, 60% of buildings and constructions in Igarka, Dickson and Khatanga have deformations, 100% in settlements of the Taimyr Autonomous District, 22% in Tiksi, 55% in Dudinka, 50% in Pevek and Amderma, 40% in Vorkuta. About 300 constructions in the Norilsk region have deformations. Hazardous deformations affect railway, road and pipeline infrastructure. Up to 55 billion RUR are spent annually to correct deformations and maintain operation of pipelines.

According to projections, the accessibility of remote settlements in Russia currently serviced by ice roads will reduce by 13% by the middle of the 21st century. The territory, where ice roads are economically efficient, will reduce roughly by 1 million km^2.

Fig. GS6.7 shows a map of the geocryological hazard index based on the climate projection for the middle of the 21st century calculated with the HadCM3 model. The map shows areas with different probability of destructive geomorphological processes. Similar maps were also constructed for other future climates corresponding to other scenarios of anthropogenic impacts on the climate system.

The key adaptation strategy for buildings and constructions is to ensure permafrost thermo-stabilization using engineering tools and techniques such as thermosyphons, ventilation channels and cellars, strengthening of basements through the installation of additional piles.

Hydropower industry and water resources

Hydropower industry. The annual Russian rivers' runoff will most probably increase in the coming decades by about 5% of the current volume. This will not have a significant influence on the total annual hydropower generation in Russia. A considerable growth of river runoff in the low water period (primarily in winter) is generally favourable for the hydropower generation, but may require a revision of management procedures for water resources in reservoirs and cascades.

In the last three decades, the annual water inflow to reservoirs of the Volga-Kama cascade (VKC) increased by 8—26% due to the increased amount of precipitation in the Volga River basin; the winter inflow increased by 70—120% due to the air temperature rise. As a result, the total power generated by nine hydropower plants (HPPs) of the VKC has grown by 13%. The availability of water to ensure upstream water levels suitable for navigation has also increased. Hence, the observed changes in climate appeared to be beneficial for the hydropower generation by HPPs of the Volga-Kama cascade.

Estimates of the water inflow to reservoirs of the VKC based on projections of future climate showed that the expected increase is comparable to the changes that have already taken place in the last decades. The winter air temperature rise expected according to most of available projections makes it

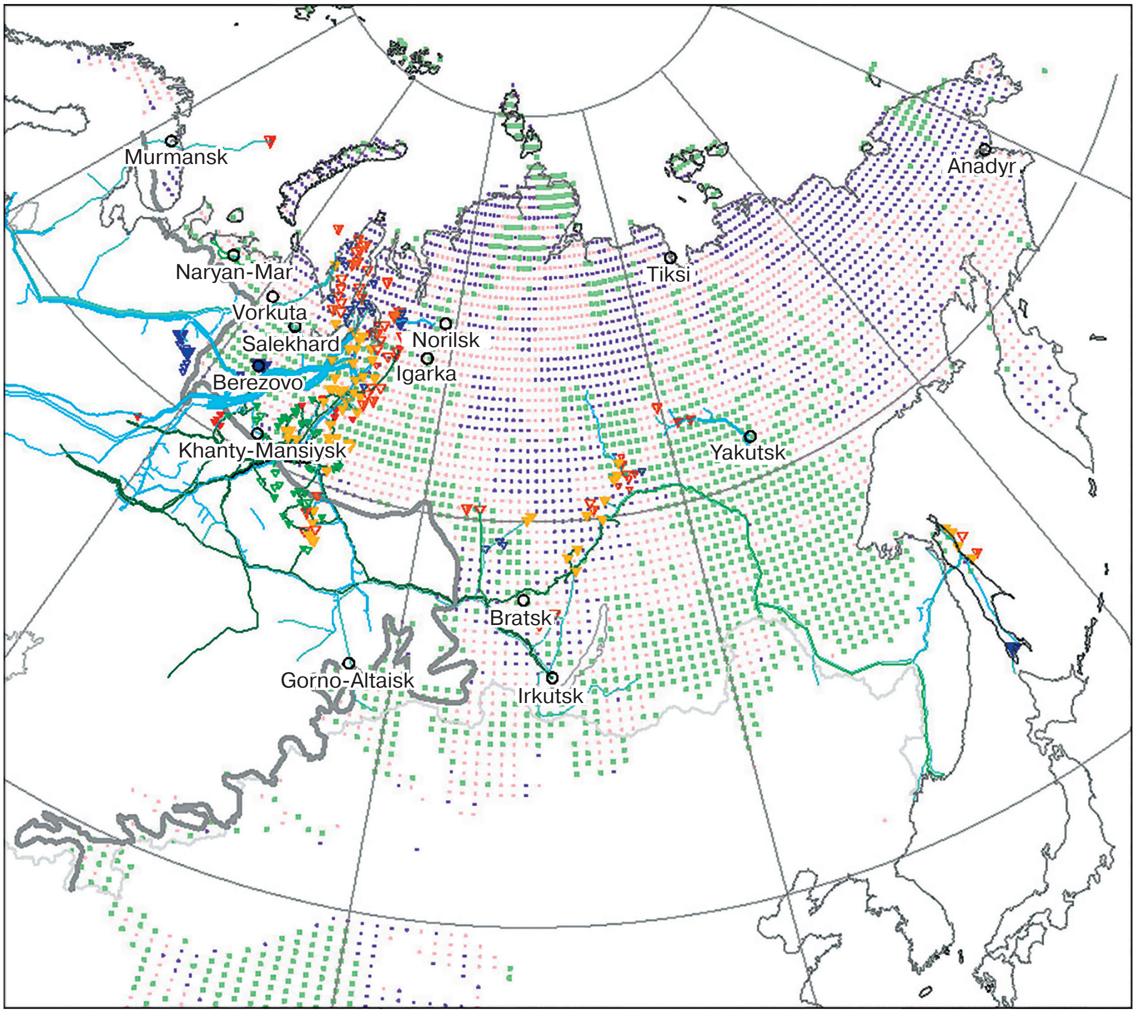

Fig. GS6.7. Geocryological hazard index for infrastructure facilities located in the permafrost zone. The entire range of values calculated for the index has been divided into three categories, which indicate areas with low probability (green dots), moderate probability (light yellow) and high probability (purple) of destructive geomorphological processes linked to permafrost degradation. Estimates are for the middle of the 21st century, based on climate projections computed with the HadCM3 global climate model.

possible to believe that in winter the inflow of water to reservoirs of VKC will continue to increase in the coming 20—30 years.

Adaptation measures may include the revision of procedures for water resources management in reservoirs and cascades to create the optimal conditions for runoff control taking into account interests of all the water users and the need to minimize environmental and social impacts.

Water resources and water availability. Distribution of water resources across Russia is highly unequal and in many cases does not correspond to population density and location of industrial and agricultural facilities. The most water-rich rivers of Russia are the Northern Dvina, Pechora, Ob, Yenisei, Lena, Amur. They flow in poorly populated and less developed regions. At the same time, watersheds of such rivers as Don, Kuban, Terek, Sulak and Volga flowing in the south of the EPR are situated in the most densely populated and economically developed regions. These regions account for 9% of the total water resources and 76% of the total population of Russia. Water resources of Russian rivers differ by a factor of hundreds, while water availability differs by a factor of thousands.

In future, the potential water availability per capita may grow by 5—10% for the entire Russia due to an increase in water resources expected in the context of current demographic tendencies. At the same time, in the densely populated regions of the

Central Federal District, the Southern Federal District and the North Caucasian Federal District it may reduce due to climate change, water consumption increase and population growth.

Hazardous and adverse hydrological events. Specific features of the current changes in frequency and magnitude of hazardous floods are determined by conditions of the formation of maximal water discharges. On most of the rivers in the southwestern and western parts of the EPR, where maximal water discharges are formed by spring flood, they tend to decrease by 20—40% due to elevated temperature in winter and increased number of thaws. Maximal water discharges increase in the regions where the maximal runoff is determined by rainfall floods, namely, in the North Caucasus, at the Black Sea coast, in the Far East and some other regions. Several extreme floods occurred there in recent years.

The catastrophic storm rainfall-induced flood occurred on the Adagum River (of the Kuban River basin) in summer 2012 and led to significant loss of life in Krymsk (the Krasnodar Territory). The never-seen-before rainfall floods, that caused considerable damage and sometimes loss of life, occurred in recent years also on other rivers of the North Caucasus and Black Sea coast and in some other regions of the country.

The extreme flood of 2013 resulted from about two months of intensive rainfall, covered a vast territory in the Far East of Russia and in the north-east of China.

Summer precipitation patterns may become more extreme in the Caucasus mountain regions, Siberia and the Far East by the middle of the 21st century leading to more frequent and higher rainfall and snow-and-rainfall floods.

Adaptation measures may include construction and reconstruction of flood barriers and flood-control reservoirs, creation of floodplain storage capacities, relocation of people from at-risk to safe territories and to other settlements and regions.

An increase in the interannual variability of runoff (interannual variability of seasonal runoff in particular) may lead to both, anomalously high water and anomalously low water periods and seasons. Damage from low water periods is sometimes comparable with damage from floods, since low water periods impede operation of water intake facilities, jeopardize water supply of settlements and enterprises, reduce hydropower generation, complicate river navigation, and deteriorate water quality. For instance, water supply of Norilsk and the "Norilsk Nikel" metallurgical complex was jeopardized due to the anomalously low water amount in the Norilo-Pyasinsk water system of the Taymyr Peninsula in summer 2013.

Air temperature rise in summer may lead to more frequent extreme lack of water in rivers by the middle of the 21st century, particularly in the APR.

In terms of adaptation measures it is possible to reserve water in reservoirs, transfer water from other river basins, diversify sources of water supply, reduce transmission losses, implement recycling technologies for industrial water consumption.

Maritime activities in the Arctic

The most impressive response to the evolving global warming at the regional scale is a decrease in the extent and depth of sea ice in the Arctic. Future ice conditions along the Northern Sea Route (the Northeast Passage) are important for designing new transport and ice-breaking ships, choosing new navigable passages, keeping control of Russia over shipping in the economic zone. Conditions for the navigation in high latitudes will become more favorable, and, year-round arctic navigation routes may be opened. At the same time, since sea ice remains during some period of a year and complicated ice conditions may take place (Fig. GS6.8), the Russian ice-breaker fleet should be maintained and further developed.

Difficult environmental and climatic conditions of the Arctic shelf give rise to serious marine infrastructure risks and increase the cost of business projects. Particularly serious risks relate to ice phenomena: ice compression; impacts of large ice sheets, icebergs, ridges and hummocks; ice gouging; early ice cover formation, etc. Additional risks may arise due to coastline erosion and permafrost degradation.

Under the ongoing warming in the Arctic it is recommended to make projections taking into account all the risks mentioned above and to include the relevant recommendations into the environment-related regulatory documents to be used in the Arctic shelf development projects.

The current knowledge is not sufficient to clearly determine consequences of the climate change for productivity of commercial fishery species and their feeding resources. In general, marine systems are adapted to variability of environmental conditions. Therefore, situation in the fishery sector depends primarily on catch volumes, including factor of overfishing of valuable species.

A basic document determining the international legal regime of sea and ocean areas, including the Arctic Ocean, is the United Nations Convention on the Law of the Sea ratified by the overwhelming majority of states. In Article 234 of the Convention maritime transport activities in the high latitude economic zone are directly linked with ice cover. The boundary of the economic zone and the outer limits of the continental shelf of Russia are measured from the coastline. The longer ice-free period combined with increased wind and wave activity and temperature rise will accelerate the coastline retreat to several kilometers per century.

In the exclusive economic zone the coastal state has sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the sea-bed and of the sea-bed and its subsoil. If ice conditions become more favorable, the resource-related interests of other states may expand only into areas outside the exclusive economic zone and the continental shelf. Projections of changes in ice conditions for the 21st century show that ice cover will remain on the passages of the Northern Sea Route for more than six months in a year. Russia can use these projections as a basis for regulation of shipping in its Arctic exclusive economic zone.

It should be noted that the uncertainty remaining in the estimates of future climate is just a small part of the uncertainty in the possible developments of the regional economic system.

The Arctic warming observed currently and further expected in the 21st century is generally beneficial for maritime economic activities, including shipping and hydrocarbon production on the shelf. Adaptation to some consequences of climate change is needed, for instance to adverse meteorological conditions (more storms in an ice-free area, increased impact of waves, increased spray freezing, etc). New standards should also be developed for construction of coastal engineering structures, particularly in places, where coastline erosion and permafrost degradation take place.

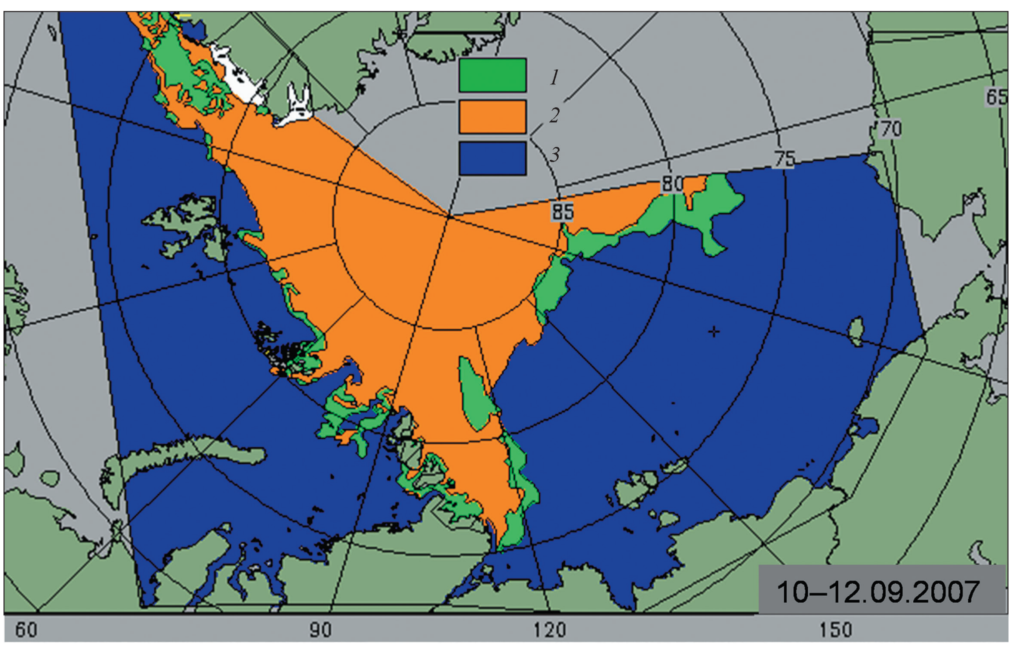

Fig. GS6.8. The Taymyr Ice Massif (aggregation of ice with concentration of 9/10ths to 10/10ths, extending from the Central Arctic along Severnaya Zemlya to the coast of Taymyr) blocked the Northern Sea Route near the Strait of Vilkitsky even in September 2007, when sea ice in the Arctic reached a record low extent. Ice map for 10—12 September 2007 (http;/www.aari.ru/projects/ESIMO/index.php). *1*) ice concentration is from 1/10ths to 6/10ths; *2*) ice concentration is from 7/10ths to 10/10ths; *3*) ice-free water.

Agriculture

Climate change in Russia observed in 1976—2012 showed differences in impacts on agriculture across regions.

Positive impacts were as follows: in Russia as a whole availability of heat for crops increased at an average rate of 96°C · days/10 years, average temperature became higher in the cold season, vegetation period (a period with the mean daily temperature above 10 °C) became 14—16 days longer on average. Changes in moistening in agricultural regions were beneficial in general, except for some areas of Siberia and Central Chernozem region.

Shifts of ranges of some pests and crop disease agents appeared to be the negative consequence of climate warming. They are expanding northward and eastward into areas, where habitat conditions became more attractive. Due to environmental changes some of the pests and crop disease agents became more aggressive and harmful.

According to projections of future climate based on a wide range of concepts, further warming, given the current level of moistening and soil productivity, should lead to an increase in bioclimatic potential and crop productivity in Russia by the middle of the 21st century (Fig. GS6.9a). However, if the annual mean air temperature continues to grow, bioclimatic potential and crop productivity may reduce considerably in some regions by the end of the 21st century, compared to the current situation (Fig. GS6.9b). Crop yield losses are also expected due to the gradual northward and eastward expansion of

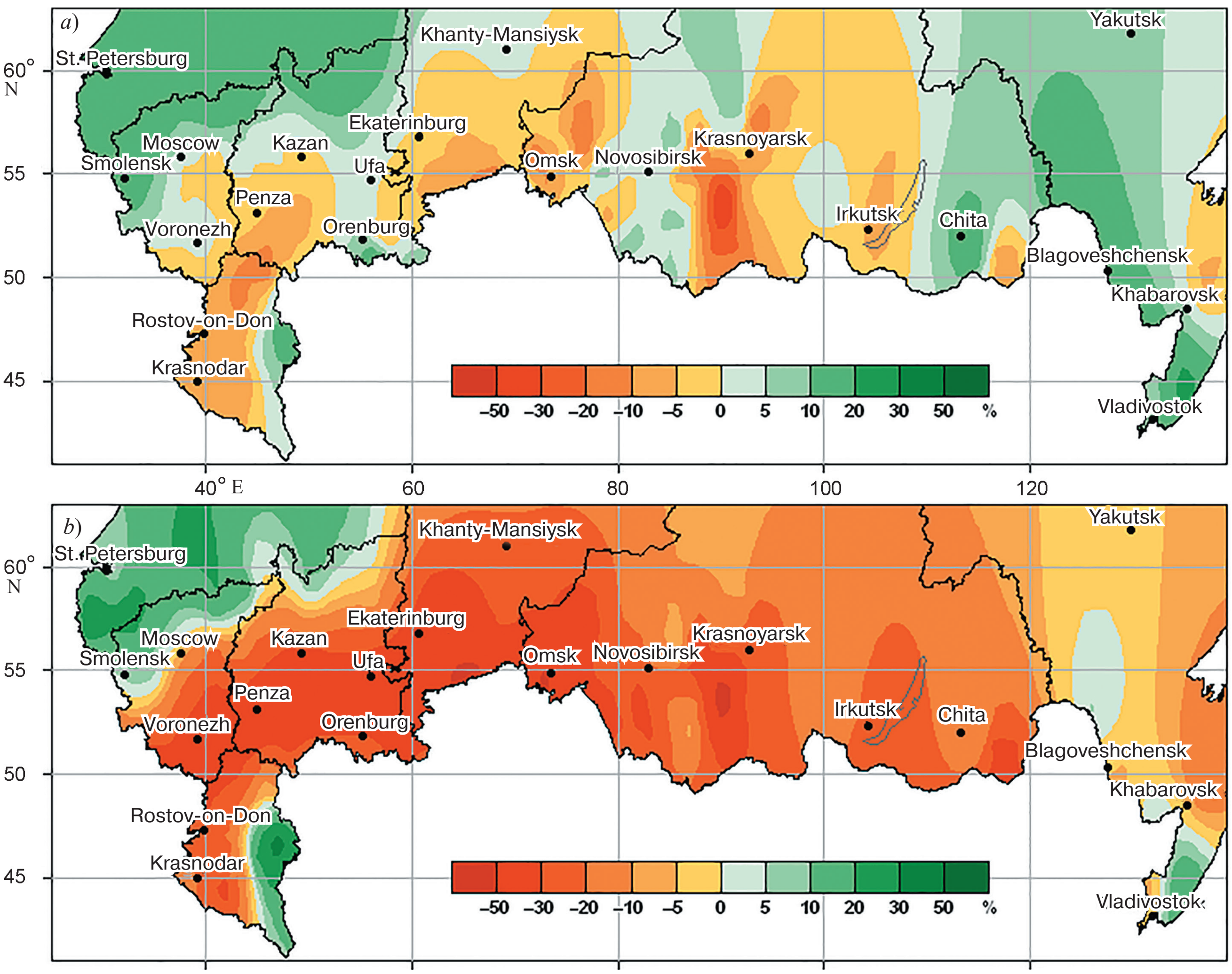

Fig. GS6.9. Changes in spring cereal crops productivity in Russia in the 21st century relative to the 1981—2000 baseline period. Calculations are made for the average climate under RCP8.5, the extreme scenario of anthropogenic impact on the Earth's climate system, for 2011—2030 (*a*) and 2080—2099 (*b*).

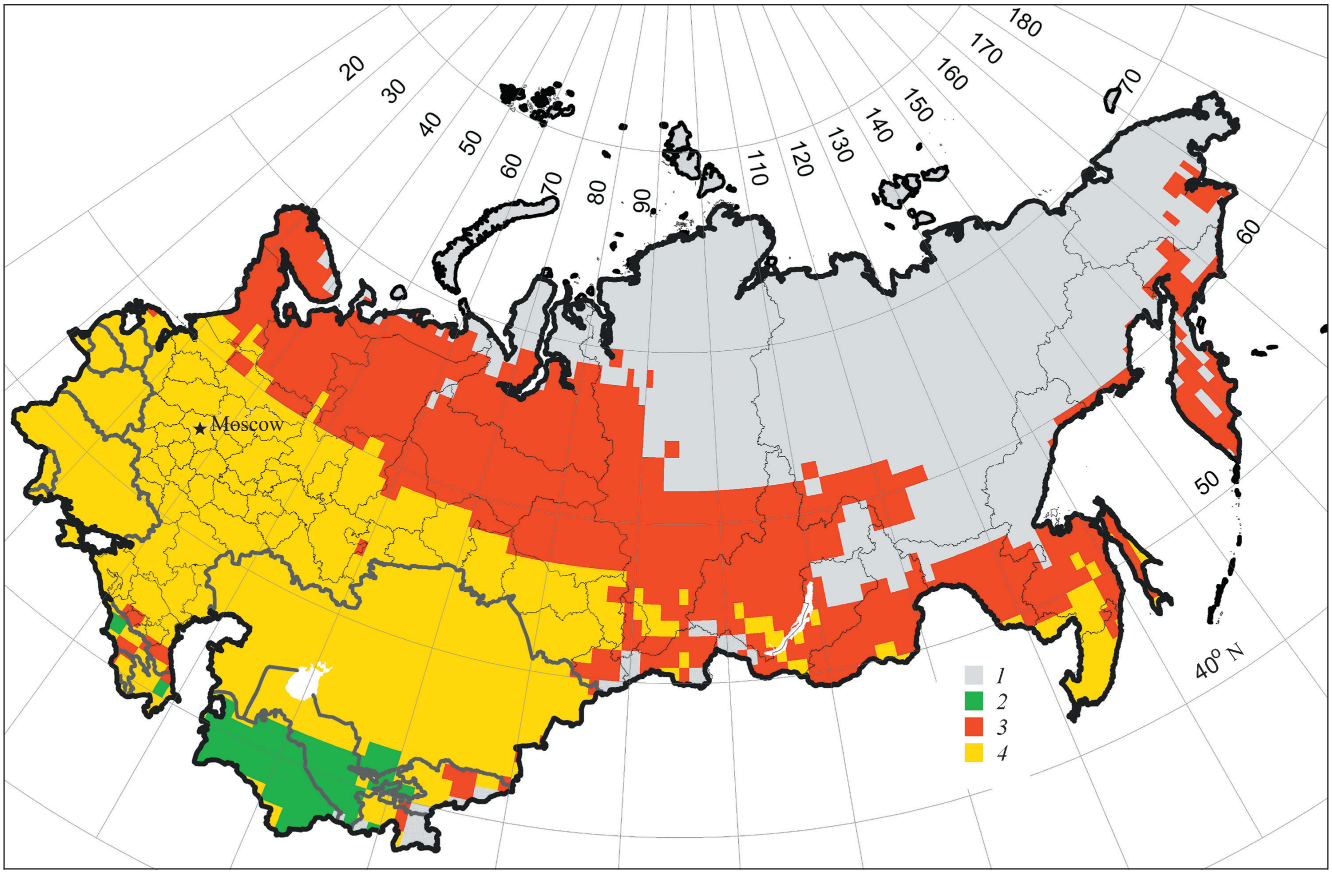

Fig. GS6.10. Possible expansion of the Colorado beetle climatic range by 2080—2099 relative to the 1981—2000 baseline period. Calculations are made under RCP8.5, the extreme scenario of anthropogenic impact on the Earth's climate system. *1*— territory outside the range during both periods; *2* — reduction of the range; *3* — expansion of the range; *4* — territory of the range during both periods.

ranges and growth of harmfulness of different pests and crop disease agents, including Colorado beetle (Fig. GS6.10) and some locusts.

Adaption of agriculture to climate change expected in Russia in the 21st century should be based on the following pillars: 1) development of the agricultural sector in the non-chernozem zone (the Central Federal District and the North-Western Federal District; 2) optimization of winter-to-spring crop ratio; 3) expansion of sowing of more heat-loving and postharvest crops; 4) development of irrigated farming; 5) strengthening and development of plant control and protection services, particularly at the boundaries of the present-day ranges of the main climate-sensitive pests and crop disease agents.

Forestry

The annual losses of forest stands in Russia in the last 20 years were about 300 thousand ha. Moreover, annual estimates of the losses clearly showed an upward trend. More than 70% of the total losses of forests in 1992—2008 were attributed to forest fires. In 2003—2012, forests were lost on the territory of 2531.6 thousand ha due to fires, which is about 60% of the total losses of forests in this period.

Forest fires occur and develop only during long periods of dry weather, but more than 90% of fires are caused by humans. About 15% of forests are lost due to extreme weather conditions, namely, hurricane-force wind, severe frost, etc. It is comparable with lost of forests resulting from attacks of pests and

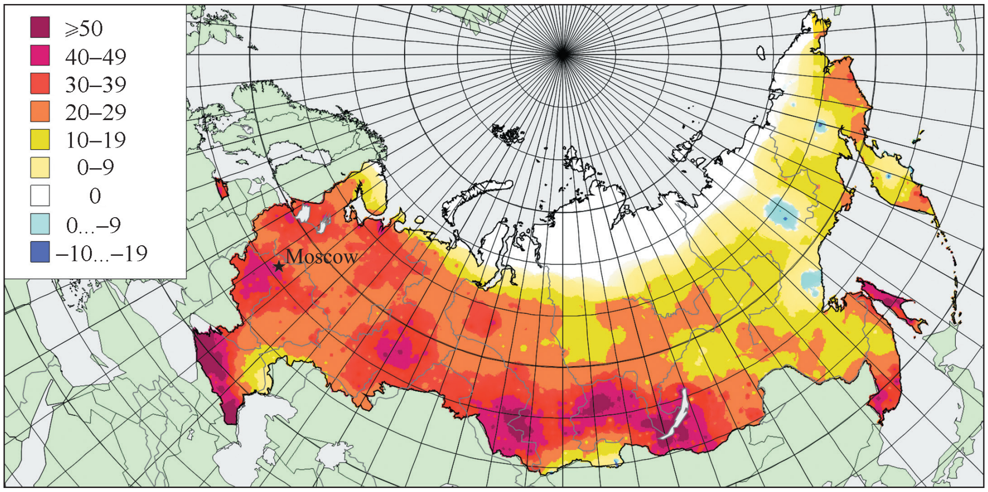

Fig. GS6.11. Projection of changes in the average number of the flammability risk days per year (May — September) in 2080—2099 relative to 1981—2000.

diseases. It must be emphasized that attacks of pests and diseases are most harmful when forests are affected by extreme weather. Although the long-term gradual warming is a factor that theoretically may affect forest productivity, it does not always make itself evident in estimates based on measurement data. A small signal often is not detected amid the significant interannual variability.

According to available projections, the extremeness of climate will grow in the 21st century. Loss of forests due to direct impacts of weather anomalies will increase, in some years it will also increase due to pests and diseases, but most of all forests will suffer from fires. For instance, under RCP8.5, the extreme scenario of anthropogenic impact on the Earth's climate system, in the entire EPR, in the Western Siberia and partly in the Eastern Siberia the flammability risk period is expected to be 20—29 days longer by the end of the 21st century; in some areas it will increase by 30—50 days (Fig. GS6.11). Under RCP4.5, the moderate scenario of anthropogenic impact on the Earth's climate system, the flammability risk period is expected to increase by 10—19 days in the same regions.

For the mitigation of expected negative consequences of climate change more advanced methodologies for monitoring and reliable regional prediction are needed as well as technologies for the efficacious suppression of foci of forest fires and reproduction of pests and diseases. As for pests and diseases, special attention should be given to biological methods of control.

CONCLUSIONS

The current climate change in Russia could be in general characterized as continued warming at a rate 2.5 times higher than the global warming. Moreover, the slowing tendency exhibited at the global level so far is not manifested on the territory of Russia.

Beyond the increasing surface air temperature the climate change in Russia also reveals itself in all the components of the climate system, including changes in the hydrological regime, ice cover of seas, extremeness of climate.

From the middle of the 20th century, changes in concentrations of greenhouse gases have made the main contribution to the observed temperature increase on the territory of Russia. However, natural external forcings are also significantly manifested in the interannual temperature variations. For a considerable part of Russian territory, anthropogenic contributions to changes of extreme seasonal and daily temperatures have been detected, which are broadly consistent with observed global warming. The analysis of extreme weather events, the hot summer of 2010 in the European part of Russia (EPR) in particular, showed that while such extreme conditions are generated mainly by inherent variability of the climate system, the general warming induced by anthropogenic impacts considerably augments the likelihood of their emergence.

According to estimates provided by the state-of-the-art climate models, throughout the 21st century Russia will continue to be a region where climate warming is considerably higher than the average global warming. It is expected that other climate characteristics will also change significantly, and in various parts of Russia these changes may differ substantially. It should be noted that outcomes of the recent research generally agree with the previous projections of climate change, both for the globe and for the territory of Russia, including projections presented in the first "Assessment Report on Climate Change and its Consequences in Russian Federation" (AR_RF-1) published in 2008.

The observed and projected climate changes in Russia cause numerous and often important (both negative and positive) consequences for natural and economic systems and for humans.

Various changes in natural terrestrial systems in Russia are related to the climate change. The total annual river runoff increases; at the same time, a seasonal redistribution in favour of low-water season and an increase in the interannual variability are detected. The glaciation of mountains and Arctic islands is mainly degrading. In plain regions, there exists expansion of an area of the permafrost thawed at the surface; temperature of the permafrost becomes higher. Vegetation period becomes longer, primary production of ecosystems increases. Forest vegetation moves into mountain tundra; dark coniferous boreal forest moves into territories occupied by larch on the plain. There is no desertification due to climate factors in Russia, and with the reduced load (reduced cattle grazing) the opposite process, namely, conversion of deserts into steppes, is more likely to be observed. Droughts tend to be more intensive and cover larger territories, but long-term trends in drought frequency have not been found.

Under existing climate change scenarios for the 21st century most of these tendencies will sustain and even become more pronounced. However, some tendencies may change to opposite, i.e. a sign of the effects may reverse. For example, the expected climate change may deteriorate the ability of natural terrestrial systems to retain carbon. This will lead to increasing emissions of greenhouse gases (carbon dioxide and methane) to the atmosphere. Under higher temperatures, insufficient moistening, and increased anthropogenic loads on steppes projected climate change may foster desertification.

In some regions, in contrast to the overall tendency for a decrease in the maximal spring flood runoff, significant positive anomalies of maximal rainfall flood runoff may occur. In rivers, increased maximal water discharges are observed in the regions where maximal runoff is determined by rainfall floods, namely, in the Northern Caucasus, on the Black Sea coast, in the Far East and some other regions. In recent years extreme floods occurred in these regions. In the future, by the middle of the 21st century, extremeness of precipitation in mountain regions of Caucasus, in Siberia and in the Far East may grow leading to more frequent and higher rainfall and snow-and-rainfall floods.

Global climate change will lead both to considerable changes in the climate of seas and to respective consequences for marine ecosystems, maritime economic activities (including transport, opportunities for mining operations, fishery, etc.) and conditions for recreation. The consequences are diverse and often different for different seas and may be both positive and negative. They include changes in sea surface temperature and vertical temperature and salinity distributions, and algal bloom. Despite warming, ice conditions may become more complicated. The mean level rise of the World Ocean expected by the end of the 21st century is not critical for the open seas.

Marine climate in Russia is changing most considerably in the Arctic. A substantial reduction in sea ice extent is detected (the absolute minimum of sea ice extent since the beginning of instrumental observations was reached in September 2012), as well as reduction in drifting ice thickness and duration of ice cover period. Current model estimates suggest that these tendencies will remain unchanged throughout the 21st century and that perennial Arctic sea ice may disappear it its first half. However, expected growth of economic and other activities in the Arctic will require that the Russian ice-breaker fleet be maintained and further developed.

Climate change has a pronounced impact on human health in Russia. More frequent and longer heat waves (i.e. long periods of dry and hot weather) result in higher morbidity and mortality, particularly in risk groups (children, elderly people, people suffering from chronic respiratory and cardiovascular diseases). These negative impacts are often aggravated by deterioration of air quality due to both adverse weather conditions and forest and peat-land fires. Due to climate change in the 20th century, habitats of some vectors of dangerous human diseases have altered (expanded, in most cases). Tick-borne encephalitis, Lime disease, malaria, Crimean haemorrhagic fever and West Nile fever are amongst them. These tendencies of negative climate change impact on human health will mostly continue throughout the 21st century.

In addition to affecting human health, forest fires have direct impact on forest ecosystems and timber production. Climate change in the 20th century resulted in higher flammability in a substantial part of forests, particularly along the southern forest boundary. It is expected that over the 21st century this tendency will strengthen and cover larger territories including those in the northern regions.

In the last quarter of the 20th — beginning of the 21st century, an increase in the available heat, higher average temperature in the cold season, and longer duration of the vegetation period favourably affected the crop production in Russia. Changes in moistening in agricultural regions were beneficial in general, except for some areas of Siberia and Central Chernozem region.

Northward and eastward shifts of ranges of some pests and crop disease agents appeared to be the negative consequence of climate warming. According to projections, climate conditions will remain favourable for crop production till the middle of the 21st century, but it will begin to deteriorate by its end. Negative influence of some pests and crop disease agents will grow.

The seasonal redistribution of river runoff in favour of low water season observed in Russia since the late 20th century is beneficial for the hydropower generation. In the EPR in the last three decades there was a considerable increase in water inflow to reservoirs of the Volga-Kama cascade due to increased amount of precipitation in the Volga River basin. In the nearest decades these tendencies will sustain. In future, the potential water availability per capita may grow in Russia as a whole, but in the densely populated areas of the EPR its reduction may be expected due to climate change, water consumption increase and population growth.

Warming makes it possible to reduce energy demand for heating of buildings in winter. However, overheating of buildings in summer is becoming an increasing problem. Elevated energy demand for air conditioning combined with lower efficiency of energy generation and transmission under high temperatures will raise the risk of emergency situations with the energy supply.

Even today, in nearly every region of Russia it is possible to use different types of renewable energy sources. The use of these sources does not lead to increasing concentration of greenhouse gases in the atmosphere and therefore to subsequent warming. Climate changes expected in the 21st century may not negatively affect renewable energy resources in Russia.

There is a steady tendency towards accelerated ageing and reduced longevity of buildings and engineering constructions due to climate change. Increased frequency of extreme temperatures deteriorates the quality of asphalt road cover. The increase of precipitation, in its amount and intensity, raises the risk of embankments erosion. Increased intensity of heavy showers is particularly hazardous, since it contributes to higher likelihood of river rainfall floods, landslides and mudflows with potential damage to infrastructure, as well as higher risk of additional morbidity and mortality in humans.

Of special note are climate change-related risks for economic entities in the permafrost regions (the permafrost covers more than two thirds of the Russian territory). In the last four decades warming of the permafrost has already led to a decrease in the bearing capacity of the frozen ground. The concurrent man-induced factors amplify the negative effect. Items of railway, road and pipeline transport infrastructure undergo hazardous deformations.

The aforementioned current tendencies related to impacts of climate change in Russia on energy demand, constructions and road infrastructure, economic entities in the permafrost region are very likely to sustain throughout the 21st century.

Apart from climate change-related actual and potential risks for natural and economic systems and humans there are apparent opportunities to make an effective use of positive consequences of climate change. Therefore, the need to accelerate elaboration of response strategies at different levels, namely, federal, regional and municipal, has become quite evident. Such strategies may not only reduce damage from negative consequences of climate change, but may also increase benefits from positive consequences. The top priority of these strategies should include a system of adaptation measures of various spatial and temporal scales based on the results of scientific analysis of climate change and its consequences including the results presented in this report.

SECOND ROSHYDROMET ASSESSMENT REPORT ON CLIMATE CHANGE AND ITS CONSEQUENCES IN RUSSIAN FEDERATION

General Summary

ВТОРОЙ ОЦЕНОЧНЫЙ ДОКЛАД РОСГИДРОМЕТА ОБ ИЗМЕНЕНИЯХ КЛИМАТА И ИХ ПОСЛЕДСТВИЯХ НА ТЕРРИТОРИИ РОССИЙСКОЙ ФЕДЕРАЦИИ

Общее резюме

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