SPECIAL REPORT

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Russia: Impact of Climate Change to 2030
A Commissioned Research Report

THE NATIONAL INTELLIGENCE COUNCIL SPONSORS WORKSHOPS AND RESEARCH WITH NONGOVERNMENTAL EXPERTS TO GAIN KNOWLEDGE AND INSIGHT AND TO SHARPEN DEBATE ON CRITICAL ISSUES. THE VIEWS EXPRESSED IN THIS REPORT DO NOT REFLECT OFFICIAL US GOVERNMENT POSITIONS.

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Russia: The Impact of Climate Change to 2030

A Commissioned Research Report

Prepared By
Joint Global Change Research Institute and
Battelle Memorial Institute, Pacific Northwest Division

The National Intelligence Council sponsors workshops and research with nongovernmental experts to gain knowledge and insight and to sharpen debate on critical issues. The views expressed in this report do not reflect official US Government positions.

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Scope Note

Following the publication in 2008 of the National Intelligence Assessment on the National Security Implications of Global Climate Change to 2030, the National Intelligence Council (NIC) embarked on a research effort to explore in greater detail the national security implications of climate change in six countries/regions of the world: India, China, Russia, North Africa, Mexico and the Caribbean, and Southeast Asia and the Pacific Island States. For each country/region we are adopting a three-phase approach.

- In the first phase, contracted research—such as this publication—explores the latest scientific findings on the impact of climate change in the specific region/country.
- In the second phase, a workshop or conference composed of experts from outside the Intelligence Community (IC) will determine if anticipated changes from the effects of climate change will force inter- and intra-state migrations, cause economic hardship, or result in increased social tensions or state instability within the country/region.
- In the final phase, the NIC Long-Range Analysis Unit (LRAU) will lead an IC effort to identify and summarize for the policy community the anticipated impact on US national security.

EastLink Consulting, LLC, collaborating with the Joint Global Change Research Institute (JGCRI) and Battelle, Pacific Northwest Division (Battelle, PNWD), developed this assessment on the climate change impact on Russia through 2030 under a contract with SCITOR Corporation. The Central Intelligence Agency's Office of the Chief Scientist, serving as the Executive Agent for the DNI, supported and funded the contract.

This assessment identifies and summarizes the latest peer-reviewed research related to the impact of climate change on Russia, drawing on both the literature summarized in the latest Intergovernmental Panel on Climate Change (IPCC) assessment reports and on other peer-reviewed research literature and relevant reporting. It includes such impact as sea level rise, water availability, agricultural shifts, ecological disruptions and species extinctions, infrastructure at risk from extreme weather events (severity and frequency), and disease patterns. This paper addresses the extent to which regions within Russia are vulnerable to climate change impact. The targeted time frame is to 2030, although various studies referenced in this report have diverse time frames.

This assessment also identifies (Annex B) deficiencies in climate change data that would enhance the IC understanding of potential impact on Russia and other countries/regions.

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Executive Summary

Russia is already experiencing the impacts of climate change in the form of milder winters; melting permafrost; changing precipitation patterns; the spread of disease; and increased incidence of drought, flooding, and other extreme weather events. Many of these observed climate impacts are having concrete, negative effects on Russians' quality of life. By 2030, Russia will start to feel the impacts of climate change in relation to both water and food supply. Nonetheless, a significant portion of the country's senior leaders continue to voice the view that a warming climate is a net benefit for Russia. Russia has a number of attributes that provide a greater capacity for resilience than some other industrialized countries and most developing countries. However, **as the impacts of climate change continue and intensify over the coming years, Russia's capacity to adapt and protect its people will be severely tested.**

The most important impacts of climate change in Russia will likely include the following:

- **Energy. A warming climate holds the possibility of milder and shorter heating seasons, which in turn may lead to reduced Russian energy demand. Increased water availability—particularly along those Siberian rivers that are used for hydroelectric power—should result in increased power production in certain parts of the country. However, existing and future energy infrastructure for the all-important petroleum industry will experience more pronounced challenges—structural subsidence, risks associated with river crossings, and construction difficulties as permafrost thaws earlier and deeper, impeding the construction of vital new production areas.** These latter challenges have the potential for a material, negative impact on the single-greatest source of revenue to the Russian state—the oil and gas industry.
- **Water.** Many parts of Russia's massive territory will experience increases in the availability of water, including much of Siberia, the Far North, and northwestern Russia. This change will bring certain positive impacts—including for hydroelectric generation (above). However, managing the increased flows will pose other problems, especially when these increased flows coincide with extreme weather events such as downpours, or springtime ice-clogged floods. In addition, increasing water shortages are predicted for southern parts of European Russia, areas that already experience significant socioeconomic and sociopolitical stresses. Moreover, a number of densely populated Russian regions that are already subject to water shortages are expected to face even more pronounced difficulties in decades to come.
- **Agriculture. As growing seasons become longer and precipitation patterns change, using lands for agricultural purposes that previously would have been too far north—too cold for too much of the year—will become possible.** Raising new crops and new varieties of crops that are currently grown in Russia also could become possible. However, a changing climate may not be hospitable to expanded agriculture. A key question is whether the longer growing seasons and the warmer Russian agricultural lands will result in increased yields. Yields of existing crops may fail and whether new crops will succeed remains to be seen. **Agriculture will become more reliant on irrigation (especially in the southern parts of European**

Russia), pesticides and herbicides, and more vulnerable to droughts and other extreme weather.

- **Migration. Russia, which is already the number two destination for immigrants (after the United States) is likely to experience greater migration pressure from Central Asia, the Caucasus countries, Mongolia, and northeastern China.** These latter areas are expected to experience increased water shortages and resulting economic stress. In addition, internal migration pressures may occur as residents in Russia's many northern cities face increasing economic and climate-related challenges.
- **Accentuation of existing socioeconomic and sociopolitical stresses. Russia is better equipped to deal with the impacts of climate change than many of its neighbors. Nonetheless, by 2030, climate change appears likely to accentuate some of the stresses that currently plague Russia.** Some of the most affected regions are areas where already socioeconomic and sociopolitical relations are attenuated and unsettled. Most of the impacts of climate change will manifest themselves in smaller cities and in the Russian countryside. For example, the long-turbulent North Caucasus region will be drier, hotter, and less prosperous than it is today. The Primorskiy Kray and the Russian Far East, which have long struggled to develop peacefully next to China, appear likely to experience even greater migration pressures, which could exacerbate longstanding cross-border tensions.

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Annexes:

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Introduction and Background

Current Climatology of Russia[i]

Russia has the largest amount of land area of any country in the world. Most of this area is more than 400 kilometers from the sea, with the center of the country being almost 4,000 kilometers from the sea. The terrain ranges from grassy steppes in the south to frigid tundra in the polar north. The treeless, marshy tundra comprises almost 10 percent of the country. Russia's topography includes the world's deepest lake and Europe's highest mountain, and its landscape contains all the major vegetation zones of the world except a tropical rain forest. More than half of the country is above 60° north latitude and is covered with snow for almost half of the year.

Less than one percent of Russia's population lives in the northernmost part of the country, from the Finnish border to the Bering Strait. This area, shaped by glaciation in the last ice age, continues to be subject to erosion by frost weathering. Rivers here flow north to the Arctic Ocean, often hampering drainage of lakes and ponds across the tundra. Summer nights, called "white" nights, are so short that dawn comes shortly after dusk. Vegetation above the permafrost consists mostly of mosses, lichen, and dwarf trees and shrubs.

Russia's large forested region, called the taiga, comprises an area about the size of the United States and contains primarily coniferous trees such as spruce, cedar, larch, and fir. The region includes most of European Russia, and about one-third of Russia's people live there. The annual average temperature of this region is below freezing; the northern part of this region is one of the coldest inhabited areas on Earth.

The steppes, often imaged as typical Russian landscape, are treeless, grassy plains occasionally interrupted by mountain ranges. Located from south of Moscow to the Black and Caspian seas, this is the only region that has a relatively temperate climate and is suited to agriculture. However, the region occasionally experiences catastrophic droughts and short, intense periods of precipitation. At the southernmost part of the region, a narrow subtropical climate warms the edges of the Black Sea and provides Russia's only warm resort area.

Most of Russia receives little precipitation. In the south and east, mountain ranges prevent Indian and Pacific Ocean winds from bringing precipitation and warmer temperatures inland. The highest levels of precipitation are in the northwest region of the country, with levels decreasing toward southeast and European Russia. The wettest areas are along the Pacific coast and near the Caucasus. A monsoonal climate along Russia's Pacific coast brings seasonally high amounts of precipitation, reversing the direction of winds in summer and winter.

In winter, steady winds tend to blow from the south and southwest across most of the country. In summer, winds come from the north and northwest. This reversal of the winds causes less temperature variation than might be expected between winter and summer. For January, the average temperatures are -8 degrees Celsius (°C) in St. Petersburg, -27°C in the West Siberian Plain, and -43°C at Yakutsk (east-central Siberia, at about the same latitude as St. Petersburg). In the summer, the Arctic islands average 4°C, and the southernmost regions of Russia average 20°C.

Projected Regional Climate Change

Climate Observations

Temperature trends over most of the Arctic and northern Russia before about 1920 were likely dominated by natural variability.[ii] It is difficult to explain increasing temperatures since 1920 without including the impacts of human emissions of greenhouse gases. Average temperatures over the past decade are the warmest ever measured in the documented history of climate records in Russia. Studies by Roshydromet,[iii] the Federal Service for Hydrometeorology and Environmental Monitoring, show that annual average temperatures over Russia have increased significantly during the past 10 years; the models suggest a continuation of this trend over the next five to 10 years. Such conclusions are supported by the findings of other Russian agencies, the Russian Academy of Sciences in particular, and by most foreign scientists (Figure 1).

Data collected by the Roshydromet surface network of hydrometeorological observations show that during 1990-2000 the mean annual surface air temperature increased by 0.4°C. (During the previous hundred years, the increase was only about 1.0°C.) Warming is more evident in winter and spring and more intensive east of the Urals.[iv]

Temperatures in the Arctic are rising at almost double the rate of the global average. In many inland Arctic regions, surface air temperatures have warmed 0.2°C per decade over the past 30 years. Sea ice in the Arctic has decreased by 3 percent per decade between 1978 and 1996, and summer sea ice thickness has decreased by 40 percent since the 1950s.[v] Precipitation at high latitudes has increased by 15 percent over the past decade, with most of this increase occurring over the past 40 years.[vi] Arctic summers are now warmer than at any time in at least the past 400 years.

The fourth Intergovernmental Panel on Climate Change (IPCC) climate change assessment (AR4)[vii] reported that in areas of the boreal north, the liquid precipitation season has become longer by up to three weeks over the past 50 years. Increasing winter temperatures in the northern regions has considerably changed the ice regime[1] of the region's water bodies. Comparing the years 2010-2015 with 1950-1979, the assessment predicts that, in the later period, ice cover duration on the rivers in Siberia is expected to be 15-27 days shorter and maximum ice cover thinner by 20-40 percent. Also, an annual increase of 5 percent was observed in river flow, with a winter increase of 25-90 percent over the base flow due to increased melt and thawing permafrost.

Winter snowfall and snow depth in the Northern Hemisphere's high latitude regions have increased during the past few decades; this trend is likely to be associated with increasing precipitation related to surface air warming. This trend is supported by significant positive trends in winter temperatures across much of the former Soviet Union in the past 50 years.[viii]

Most recent research shows that Siberian permafrost temperatures rose considerably during the latter half of the 20th century, although the extent to which this can be attributed entirely to climate warming is currently unknown. Recent research revealed positive warming trends for all permafrost regions in response to positive trends in air temperature, with the strongest warming trend in regions of continuous permafrost. A slight cooling trend is found only for the topmost soil layers in regions of seasonally frozen ground at the southern margins of the region draining into the Arctic.

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[1] An ice regime is a region of generally consistent ice conditions. Ice types are measured in a range from grey ice (0-.15 m) to permanent ice (>3 m). See ftp://ftp2.chc.nrc.ca/CRTreports/ISOPE_98_IRS_database.pdf.

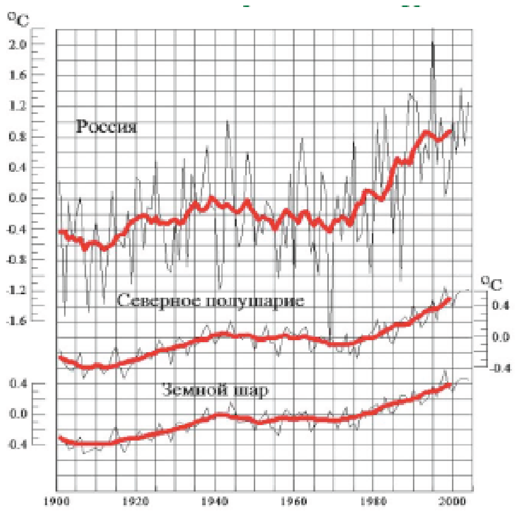

Figure 1. Surface air temperature increase in Russia, the Northern Hemisphere, and the world, 1900-2004. Source: Dobrolyubova, Julia, *Climate Change Effects and Assessment of Adaptation Potential in the Russian Federation* (Moscow: Russian Regional Environmental Centre, November 19-20, 2007), slides.

Melting permafrost serves as another revealing indicator of climate change. Significant areas of the Russian permafrost zone, which covers 60 percent of the country (the largest such region in the world falling under a single nation's jurisdiction), clearly show a trend of temperature increase in the top layers of frozen ground from the 1970s to the 1990s, corresponding with the warming of the atmosphere. Although climate change in European Russia is less severe than in Siberia, the change in the condition of frozen terrain is no less substantial. In the past 20-30 years, temperatures in the frozen ground of Russia's European Arctic and Subarctic have increased between 0.22 and 1.56°C, matching increases in the number and thickness of taliks (thawed underground pockets). These observations suggest a progressive increase in seasonally thawing soil, as well as a 14-80 percent increase in thawed pockets of soil in individual regions of the Russian Arctic.[ix]

Areas of seasonal frost have also shifted noticeably northward, and the area of isolated and sporadic pockets of frozen soil has decreased.[x] Although deeper layers of frozen soil are insulated against thawing by icy strata and organic soil and vegetation, models suggest that deeper seasonal thawing may change the composition of plant and animal communities.[xi] Natural tundra will likely grow smaller disappear entirely as a result.[2] [xii]

Satellite-derived measurements of snowfall show a spring and summertime decrease, likely due to increased temperatures. Snow accumulation over Russia accounts for about 5 percent of fresh water discharge to the Arctic Ocean. Significant changes in fresh water discharge have affected the salinity, sea ice distribution and circulation of the Arctic and nearby oceans. North of 50° N

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[2] The source does not provide an exact date of when natural tundra depletion may occur, other than mentioning that the change in composition of plant and animal communities is already occurring: "Although deeper layers of frozen soil are insulated against thawing by intermediate icy strata and a layer of organic soil and vegetation, models demonstrate that further deepening of seasonal thawing as a result of rising air temperatures may upset that balance. Should this happen, it will change (and this is already occurring) the composition of plant and animal communities, and existing natural complexes of the tundra may severely dwindle, or disappear entirely." http://assets.panda.org/downloads/wwf_arctica_eng_1.pdf

latitude, annual precipitation has increased by about 4 percent over the past 50 years, especially over Russia's permafrost-free zone and the entire Great Russian Plain. Over northern Russia, snow is providing a declining fraction of total annual precipitation.

The 20th century saw a trend of increased river output from the six largest Eurasian rivers flowing into the Arctic Ocean.[xiii] A similar trend is found in the climate simulation for the same period by the Hadley Centre's coupled climate model when the effects of manmade greenhouse gases are included. This finding is in line with predictions that global warming will cause changes in the water cycle.

Studies have shown that runoff in the Lena River increases in winter, spring, and (especially) the summer; and discharges decrease in autumn. These changes in seasonal streamflow characteristics indicate a hydrologic regime shift toward early snowmelt and higher summer streamflow, perhaps due to regional climate warming and permafrost degradation in the southern parts of Siberia. Winter snow accumulation is a major influence on summer and autumn discharge of the Ob and Yenisey Rivers and can affect winter and spring discharges of the Lena River, suggesting the importance of topography and permafrost conditions to river discharges in high-latitude regions.

Climate Predictions (Modeling)

Although Global Circulation (or Climate) Models (GCMs) can be used to infer climate changes in specific regions, developing models that have a high resolution sufficient to resolve local and regional scale changes is preferable. There are many challenges in reliably simulating and attributing observed temperature changes at regional and local scales. At these scales, natural climate variability can be relatively larger, making it harder to distinguish long-term changes expected due to external forcings.

The procedure of estimating the response at local scales based on results predicted at larger scales is known as "downscaling." The two main methods for deriving information about the local climate are (1) dynamical downscaling (also referred to as "nested modeling" using "regional climate models" or "limited area models"), and (2) statistical downscaling (also referred to as "empirical" or "statistical-empirical" downscaling). Chemical composition models include the emission of gases and particles as inputs and simulate their chemical interactions; global transport by winds; and removal by rain, snow, and deposition to the earth's surface.

Downscaled regional climate models rely on global models to provide boundary conditions and the radiative effect of well-mixed greenhouse gases for the region to be modeled. There are three primary approaches to numerical downscaling: (1) limited-area models, (2) stretched-grid models, and (3) uniformly high resolution atmospheric GCMs (AGCMs) or coupled atmosphere-ocean (-sea ice) GCMs (AOGCMs).

The magnitudes and patterns of the projected rainfall changes differ significantly among models, probably due to their coarse resolution. The Atlantic and Pacific Oceans are strongly influenced by natural variability occurring on decadal scales, but the Indian Ocean appears to be exhibiting a steady warming. Natural variability (from ENSO, for example) in ocean-atmosphere dynamics can lead to important differences in regional rates of surface-ocean warming that affect the atmospheric circulation and hence warming over land surfaces. Including sulfate aerosols in the models damps the regional climate sensitivity, but greenhouse warming still dominates the changes. Models that include emissions of short-lived radiatively active gases and particles suggest that future climate changes could significantly increase maximum ozone levels in already polluted regions. Projected growth of emissions of radiatively active gases and particles in the models suggest that they may significantly influence the climate, even out to year 2100.

Stabilization emissions scenarios assume future emissions based on an internally consistent set of assumptions about driving forces (such as population, socioeconomic development, and technological change) and their key relationships. These emissions are constrained so that the resulting atmospheric concentrations of the substance level off at a predetermined value in the future. For example, if one assumes the global CO_2 concentrations are stabilized at 450 parts per million (ppm) (the current value is about 380 ppm), the climate models can be tuned to produce this result. The tuned model predictions for regional climate changes can be used to assess specific impacts at this stabilization level. A more detailed discussion of the ability of the models to project regional climate changes can be found in Annex A.

Climate Projections of Future Temperature and Precipitation

The IPCC AR4 does not include predictions specifically focused on Russia. Most of the country is included within a modeling region referred to as Northern Asia (NAS). Warming in this region is expected to be well above the global mean—consistent with the more general result that high latitudes will (and are) warming more than low latitudes (see Figure 2). This warming is particularly great in autumn and early winter when sea ice is thinnest and the snow depth is insufficient to blur the relationship between surface air temperature and sea ice thickness. Precipitation is also very likely to increase (Annex A).[xiv]

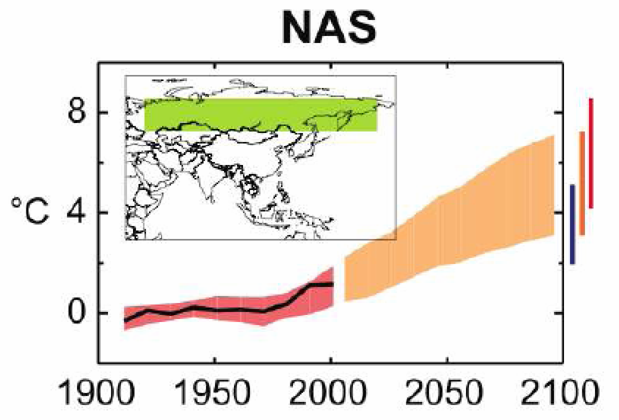


Figure 2. IPCC projected temperature increases for Northern Asia (NAS) (including Russia). Temperature anomalies with respect to 1901-1950 for the NAS land region for 1906-2005 (black line) and as simulated (red envelope) by multi-model datasets incorporating known forcings; and as projected for 2001-2100 for the A1B scenario (orange envelope). The bars at right represent the range of projected changes for 2091-2100 for the B1 (blue), the A1B (orange) and the A2 (red) scenarios. Source: Climate Change Risk Management Ltd, "Climate Change in Russia: research and impacts" (May 2008), hyperlink (accessed February 17, 2009): http://www.uk-russia-ccproject.info/documents/Impacts_in_Russia_Report_2008.pdf

The Arctic is extremely vulnerable to climate change.[xv] The region is warming much more rapidly than the global average. The IPCC report states that the winter warming of northern high latitude regions by the end of the century will be at least 40 percent greater than the global mean, based on a number of models and emissions scenarios. Temperature increases for the central Arctic are projected to be about 3-4°C during the next 50 years. Even an optimistic scenario for projecting future greenhouse gas emissions yields a result of a 4°C increase in autumn and winter average temperatures in the Arctic by the end of this century. Recent satellite data show that the area covered with perennial ice in the Arctic Ocean has receded significantly in recent years, falling to nearly half the area observed in 2005.

During the 21st century, the thaw depth will increase substantially, summer soil moisture will eventually be reduced, and a poleward movement of the permafrost extent is expected. Based on three global climate models (Canadian Climate Center scenario, GFDL scenario and ECHAM scenario), a 30-40 percent increase in active layer thickness for most of the permafrost area is projected, with the largest relative increases concentrated in the northernmost locations.[xvi]

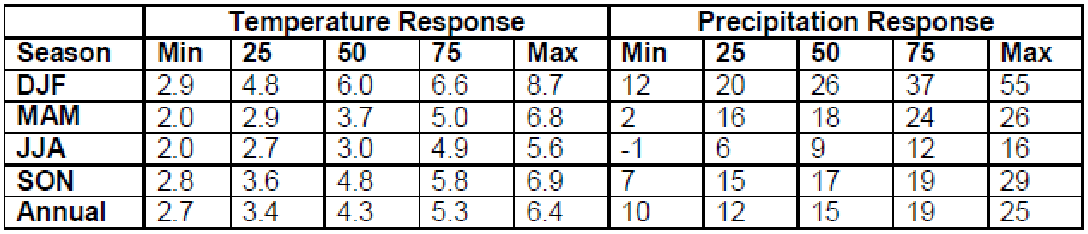
Regionally, the changes are a response to both increased temperature and increased precipitation (changes in circulation patterns). In a few regions, Siberia for example, the amount of snow is projected to increase because of the increase in precipitation (snowfall) from autumn to winter. Consistent results from the majority of the current generation of models show, for a future warmer climate, that a poleward shift of storm tracks occurs with greater storm activity at higher latitudes.[xvii]

Most models ignore the effect of land cover change in future projections. Past and future changes in land cover may affect the climate in several ways, causing changes in albedo, in the ratio of latent to sensible heat, and therefore in surface temperature, and in CO_2 fluxes to and from the land. No coupled AOGCM has included all the effects of land cover changes. The general consensus is that land cover changes may be very important at the regional level, where these changes occur.

At the regional level, the Russian Federation has considerable experience in climate modeling, with three centers of research: St.Petersburg V.A. Fock Institute of Physics; Institute for Numerical Mathematics (INM) in Moscow, and the Oboukhov Institute of Atmospheric Physics in the Russian Academy of Sciences (IAP-RAS) in Moscow. Both the INM and the IAP-RAS have their own climate models, although only the former submitted simulation data as part of the IPCC fourth assessment process.

Table 1 shows the 2080-2099 temperature and precipitation projections from a set of 21 global models. The numbers represent average (mean) changes from the period 1980-1999 over the 21 models. For each season, the minimum, 25 percent, 50 percent, 75 percent, and maximum changes are shown. For example, for the winter (DJF, or December, January and February), the average minimum temperature increase is 2.9°C, and the average precipitation change is +12 percent.

The five-to-10-year projections of the Russian hydro-dynamical climate models[xviii] match very well with the model projections of the IPCC AR4[xix], when the same scenarios and assumptions are used.[xx] These projections suggest that the mean annual surface air temperature over Russia will increase over the next five to 10 years by 0.60°C±0.2 from the annual mean temperature in the year 2000. The increase in temperature will vary by region, but by 2015 the average winter temperatures will have increased by an additional 1°C. In summer, the increase is only expected to be 0.40°C. During this same period, annual averaged precipitation is projected to increase by 4-6 percent, with the increase being as much as 7-9 percent north of Eastern Siberia.[xxi]



	Temperature Response					Precipitation Response				
Season	**Min**	**25**	**50**	**75**	**Max**	**Min**	**25**	**50**	**75**	**Max**
DJF	2.9	4.8	6.0	6.6	8.7	12	20	26	37	55
MAM	2.0	2.9	3.7	5.0	6.8	2	16	18	24	26
JJA	2.0	2.7	3.0	4.9	5.6	-1	6	9	12	16
SON	2.8	3.6	4.8	5.8	6.9	7	15	17	19	29
Annual	2.7	3.4	4.3	5.3	6.4	10	12	15	19	25

This table is **UNCLASSIFIED.**

Table 1: Regional averages of temperature and precipitation projections from a set of 21 global models in the MMD for the A1B scenario for the region of Northern Asia (NAS: 50°N, 40°E: 70°N, 180°E). The table shows the minimum, maximum, median (50 percent), and 25 and 75 percent quartile values among the 21 models, for temperature (°C) and precipitation (percent) change. The changes are calculated as the 2080-2099 mean with respect to the 1980-1999 mean. DJF=December January February, MAM= March April May, JJA=June July August, SON=September October November. Source: Table 11.1 in IPCC [Intergovernmental Panel on Climate Change]. *Climate Change 2007: the Physical Science Basis*, ed. S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M.M.B. Tignor, H.L. Jr. Miller, and Z. Chen (Cambridge: Cambridge University Press, 2007).

Maximum temperature increases are expected to occur in the winter in the Arctic.[xxii] By the middle of the 21st century, temperatures are projected to rise as much as 4-5°C in the Arkhangelsk region, the Komi Republic, the Yamalo-Nenets Autonomous Area, and over Taimyr.[xxiii] Temperature increases in the summer in these regions are small. However, in the southern regions, such as in the Northern Caucasus, the Volga region, and in the south of Western Siberia, an increase of 2–3°C is projected.

According to an assessment done by the World Wildlife Fund (2008),[xxiv] an appreciable increase in winter precipitation totals is expected by 2050—notably, a 30 percent increase on the Taymyr Peninsula and a 15-20 percent increase in Chukotka and the Barents Sea region. This increase in precipitation is expected to continue throughout the second half of the century. Total precipitation will more than double current values in the eastern Russian Arctic, consequently forming a deep layer of snow and reducing the period of soil freeze in winter. Alternatively, summer precipitation totals will increase only 5-10 percent by 2050, and 10-20 percent by the end of the 21st century, with the increase being slightly larger in the eastern part of the Arctic. An increase in the frequency of heavy rainfall is forecasted for the same region, effectively accelerating coastline erosion. Throughout the Arctic, there will be more rainfall than evaporation, despite predicted increases in evaporation due to warming.[xxv] The result is the formation of bogs[3], more likely prominent along the central and eastern Arctic coast.

Trends of wintertime snow mass accumulation vary over the country. In European Russia (that is, Russia east of the Urals) and south of Western Siberia snow mass is expected to decrease compared with long-term mean values. By 2015 a 10-15 percent decrease is expected. In most of the rest of Russia, snow accumulation is expected to increase by 2-4 percent.[xxvi]

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[3] According to the US Environmental Protection Agency, bogs are "characterized by spongy peat deposits, acidic waters, and a floor covered by a thick carpet of sphagnum moss. Bogs receive all or most of their water from precipitation rather than from runoff, groundwater or streams. As a result, bogs are low in the nutrients needed for plant growth, a condition that is enhanced by acid forming peat mosses." See http://www.epa.gov/owow/wetlands/types/bog.html.

Projected changes in annual river runoff vary across the country. Winter runoff is projected to increase from 60-90 percent in the Central and Volga Federal Districts, and from 5-40 percent in other Federal Districts. In the Black Earth area and in the south of the Siberia Federal District, springtime river runoff is projected to decrease by 10-20 percent.[xxvii]

Permafrost and Arctic Ice Projections

According to a collaborative report led by Climate Change Risk Management (CCRM),[xxviii] seasonal thaw depths are predicted to increase around 2050 by more than 50 percent in the northernmost permafrost regions, and 30-50 percent elsewhere. By 2100, it is predicted that almost 60 percent of current permafrost regions will thaw and freeze on a seasonal basis.[xxix] Increased precipitation contributes to the thawing of frozen soils and is projected to lead to a 14 percent increase in freshwater discharge into the Arctic Ocean. Modelers warn that there are significant uncertainties in model projections of changes to the permafrost.[xxx]

A coupled climate-permafrost model was used by Anisimov and Renava (2006)[xxxi] to calculate changes in permafrost extent and thickness for three timeslices. Model results predict a reduction of near-surface permafrost area by 11 percent, 18 percent, and 23 percent by 2030, 2050, and 2080, respectively. Contractions of near-surface permafrost over these same periods are 18 percent, 29 percent, and 41 percent, respectively.

Despite the uncertainties, most modelers agree that seasonal thaw depths will increase by more than 50 percent in the northern Russia, including much of Siberia and the Far East; and by 30 percent to 50 percent in most other permafrost regions.[xxxii] Figure 3 shows the projected changes in active-layer permafrost thickness in northern Eurasia by 2050. Increased methane emissions from the melting permafrost will be a significant feedback on radiative forcing and climate change. Projected changes in the permafrost to the year 2050 are shown in Figure 3.

Most models project that summer ice will decline much more rapidly than winter ice.[xxxiii] Arctic sea ice is projected to decrease more rapidly than other sea ice.[xxxiv] Some scientists suggest that the Arctic Ocean could be ice free in summer in the next 10-20 years.[xxxv]

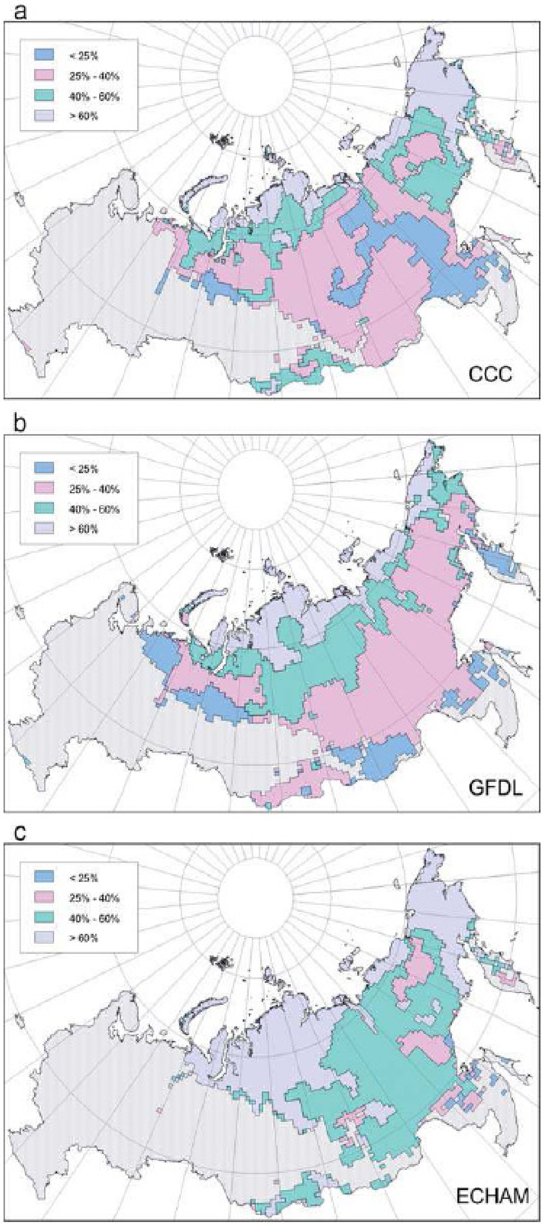

Figure 3. Projected 2050 changes of the active-layer permafrost thickness in northern Eurasia, relative to present-day simulations, based on forcing from three different global climate models: (a) CCC (Canadian Climate Center) scenario; (b) GFDL scenario; (c) ECHAM scenario (From Anisimov and Reneva 2006). Source: Climate Change Risk Management Ltd, “Climate Change in Russia: research and impacts” (May 2008), http://www.uk-russia-ccproject.info/documents/Impacts_in_Russia_Report_2008.pdf (accessed February 17, 2009).

Projections of Changes in Agricultural Growing Seasons

The decline in the number of very cold winters in many regions across Russia has led to better conditions for growing winter crops. In the Central Black-Earth and Volga regions, the frequency of very cold winters has decreased from an average of 18-22 percent in the period up to 1990 to 8-10 percent in the past several years.[xxxvi] In Northern Caucasia, this frequency has been reduced from 10 percent to 4 percent.

Conditions for growing corn have improved in many areas of European Russia. In the Stavropol Territory, "climate-related"[xxxvii] corn yield has increased 30 percent over the past 20 years, but in parts of Asian Russia (e.g., the Baikal), corn yield has decreased.

From 1970 to 2000, the growing season (with air temperatures above +5°C) lengthened by an average of approximately 5-10 days over much of the agricultural region in European Russia. However, frost-free periods did not lengthen.[xxxviii]

If this trend continues, agricultural production may increase significantly by 2015. The growing season is likely to be significantly lengthened. Both the growing season and duration of frost-free days may be increased on the order of 10-20 days per year.[xxxix] Many plant species may experience a northward migration of growing boundaries. On the Siberian rivers and in the Kama River basin, a reduction of the freeze period of as many as 15-27 days is expected by 2010-2015.

Changes in the Frequency or Strength of Extreme Climatic Events

Changes in the frequency of extreme events may be one of the most damaging consequences of climate change. Climate change over the past 10-20 years in Russia has been linked to extreme events, including heat waves, floods, and fires. The IPCC assessment[xl] reports a substantial increase in the number of days with more than 10 millimeters of rain in Siberia, causing a 50-70 percent increase in surface runoff. There were also a significant increase in the number of fires in Siberian peatlands and more frequent flooding in Russian Arctic rivers due to heavy rain and earlier breakup of river ice.[xli] Satellite measurements show that vegetation fires, mostly forest fires, occurred over about 10 million hectares during 1997-2003. Outbreaks of disease-carrying insects also occurred in the northern part of the country, where outbreaks have never been observed in the past.[xlii]

Observations suggest that large floods are already more frequent.[xliii] By 2015, there is likely to be more flooding in river basins in the Archangelsk Region, the Komi Republic, the Ural area, and in the basins of Enisei and Lena.[xliv] In the Arctic, increased water discharges occurring earlier in the spring may be blocked by ice jams, causing the duration of inundated flood plains to increase from the current 12 days to 24 days. In the past five years, the Lena, one of the world's 10 largest rivers, has experienced two floods more severe that any previous recorded flood.[xlv]

Ice-jam-induced floods in the Lena River Basin are expected to double by 2015. Flooding in the Far East and the Maritime areas is expected to double or triple. In the mountain and submountain regions of Northern Caucasia (Republics of North Caucasia, Stavropol Region) and in the Western and Eastern Sayan Mountains, more mudflow and landslide hazards are expected.[xlvi] In St. Petersburg, the probability of a disastrous flood is expected to increase in the next 5-10 years.[xlvii]

The average annual discharge of fresh water from the six largest Eurasian rivers to the Arctic Ocean increased by 7 percent between 1936 and 1999.[xlviii] Peterson et al. (2002), Wu et al. (2005) and Shiklomanov et al. (2006)[xlix] project Russian river discharges will continue to increase at an accelerated rate. The average projected change in annual discharge in large Russian rivers is around 15 percent (range: -12 to 45 percent).[l] Annual discharge in the Yenisey, Ob, Lena and Kolyma rivers are projected to change by 6-45 percent, -12-45 percent, 12-45 percent, and 10-45 percent, respectively.[li] All experienced significantly larger increases in winter discharges—as much as 325 percent in a high-sensitivity scenario (4ºC).[lii]

Over this century, increases in the frequency and intensity of heat waves are expected in western and central Europe, possibly including parts of Russia. A record-breaking heat wave occurred in central Europe in summer 2003. This event was the hottest since instrumental records began around 1780 (1.4°C above the previous warmest in 1807) and is very likely to have been the hottest since at least 1500.[liii]

Hazardous events due to the changes in permafrost are expected to increase by 2015.[liv] Melting of permafrost islands will lead to increases in landslides, mudflows, and other dramatic and abrupt changes in the landscape.[lv] When a glacier recedes, unstable glacial lakes are formed that increase the likelihood of glacier-related outbursts and debris slides. Glacier retreat between 1985 and 2000 has resulted in a 3-6 percent increase in the proportion of glaciers covered by debris, increasing the melt rate and the likelihood of glacier-related significant events such as rock and mud slides.[lvi]

On both the Baltic and Pacific coasts, a rise in sea level may result in the coastline being more vulnerable to tsunamis. Studies of the Baltic region have stressed the possibility that tsunami activity could profoundly affect the coastline. Some of the largest tsunamis ever observed have occurred along the Pacific coast, which is prone to tsunamis. The IPCC 2007 assessment identifies the Baltic and White seas as areas of probable increased flooding and erosion.[lvii]

Over large areas of Russia, the number of both high-intensity and mid-intensity fire-hazard days is expected to increase. By 2015 the number of fire-hazard days may increase by more than five days in a season on most of the territory. The areas most likely to experience an increased duration of fire-hazard days (more than 7 days in a season) include areas south of the Khanty-Mansi Autonomous Area; and in Kurgan, Omsk, Novosibirsk, Kemerovo and Tomsk Regions, Krasnoyarsk and Altai Territories, Sakha-Yakutia Republic.[lviii]

Impacts of Climate Change on Human-Natural Systems

In Russia, the socioeconomic impact of climate change has long been controversial. Some of Russia's most prominent climate scientists have argued persistently that a warming climate will bring net positive benefits for a cold, massive country whose territory includes vast expanses of permafrost and undeveloped forests, while others posit some unmitigated negatives. While the debate continues among Russian observers, the weight of scientific evidence points to a more complicated picture—some significant benefits, as well as profound problems for human systems that have the potential to challenge Russia's ability to respond.

Economic Growth and Development

The Russia that will face the unfolding impacts of climate change between now and 2030 is a Russia newly grown accustomed to relative wealth. No longer is it the economic basket case that it was in the 1980s and 1990s. In fact, until the global financial crisis began to bite in Russia in late 2008, the country had ridden a decade-long wave of economic good fortune following the crash of the Russian ruble in August 1998.

Russia is extraordinarily dependent on its extractive industries and commodity production. In addition, the country's development has been highly uneven, with most wealth concentrated in the capital, Moscow. Only a modest trickle-down effect has occurred in smaller cities, and virtually none has occurred in rural areas. Most of the impacts of climate change will manifest themselves in smaller cities and in the Russian countryside.

Another consideration that relates to the advance of climate change impacts is the role of the government in people's everyday lives. During Soviet times, government was highly intrusive but simultaneously was the source of considerable private skepticism. ("We pretend to work; they pretend to pay us," was one of the core folk wisdoms.) Government did, however, provide services that ensured a minimum standard of living for nearly all citizens. In today's Russia, many people have arguably even less expectation that the government will provide for their minimum requirements. But if climate change begins to wreak serious humanitarian impacts, such as recurrent massive flooding or the collapse of aging infrastructure, and if the government is not in a position to respond in a commensurate way, one of the key questions will be whether climate change prompts political unrest. For the time being, we judge this to be a significant, but unresolvable open question.

Energy Systems

The stable operation of energy systems is a major technological challenge for a country as massive as Russia. It is also a matter of vital importance to everyday Russians, whose day-to-day survival depends on the timely availability of heat and power in the face of Russia's severe climate. Energy systems are no less of a matter of survival for the Russian economy, which stays afloat largely due to petroleum exports. For these reasons, the impacts of climate change on Russian energy systems are of exceptionally great importance.

The seasonality and geographical scope of climate change across Russia have significant implications for Russian changing energy demand between now and 2030. As is mentioned above, mean temperature increase in Russia by 2030 is projected to be significant nationwide, although more pronounced in the north and east of the country than in the south and west, and more pronounced in winter and spring than in the summer or fall.[lix]

As shown in Figure 4, the projected climate warming is expected to lead to a reduction in the length and intensity of the heating season, which has the potential to result in reduced energy consumption for heating. Roshydromet projects that on average, by 2015, the heating season will be three to five days shorter across the entire country.[lx] In the eastern regions of Primorskiy Kray, Sakhalin, and Kamchatka, the heating season may be more than five days shorter by 2015. Some regions may experience little if any reduction in the length of the heating season. These trends are projected to extend and intensify by 2030 and beyond.

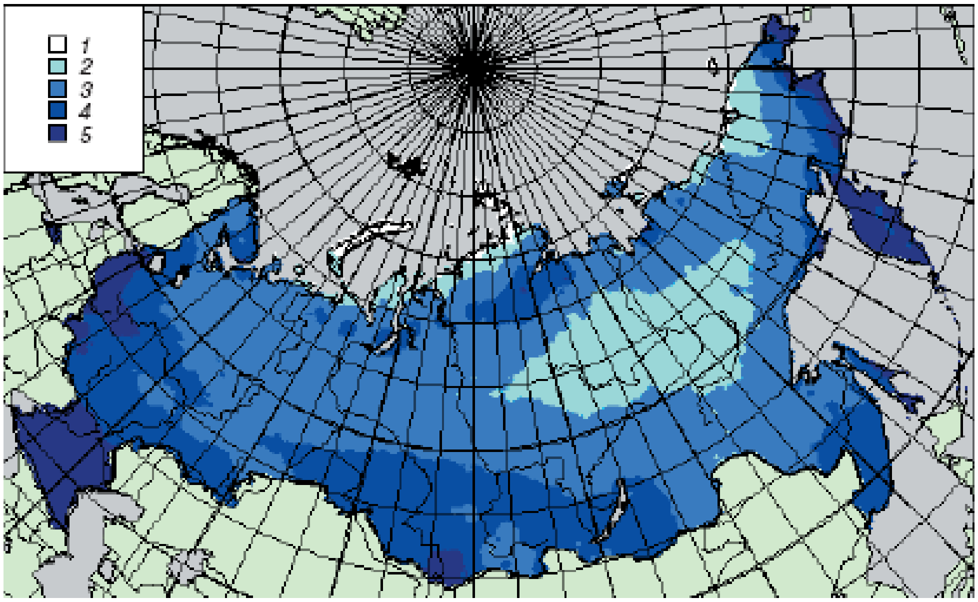

Figure 4. Reduction in duration of the heating season. <u>Legend</u>: Zone 1 shows ***<u>reduction</u>*** of the length of the heating season by 0.0-1.9 percent, Zone 2 -- 2.0-3.9 percent, Zone 3 -- 4.0-5.9 percent, Zone 4 -- 6.0-7.9 percent, Zone 5 -- 8.0-10.0 percent. Source: Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), "Assessment Report on Climate Change and its Consequences in Russian Federation" (Moscow, 2008).

In areas that experience this change, residents and workers may experience greater indoor comfort, as heating systems and building envelopes will be better able to cope with the heating load.

For those regions that do experience a reduction, the extent of the related energy savings is a matter of some debate, even in official Russian government projections. According to analysis presented in 2005 and 2008 by the Russian Federal Service on Hydrometeorology (Roshydromet), the reduction in heating days resulting from a warmer climate may not translate into saved fuel. Even if there are fewer total heating days, they may stretch out over the same period of the year—or even longer[lxi] —because of increased temperature variability.[lxii]

This Roshydromet analysis contrasts with the Russian Federation's Fourth National Communication under the UN Framework Convention on Climate Change, which was submitted in 2006. According to the Fourth National Communication, the reduction in heating requirements by 2025 will result in a net fuel savings of 5-10 percent nationwide (and greenhouse gas emissions reduction of 2 percent).[lxiii] If the latter projection proves accurate, the saved fuel could provide a significant economic benefit, and potentially a significant balance-of-payments benefit, provided that the saved fuel was exported instead of being consumed domestically.

Just as a changing climate is expected to affect energy demand in Russia, so too will it affect energy supply. On the supply side of the ledger, the changing climate may affect hydroelectric power production, electricity transmission and distribution systems, and petroleum production and transportation systems.

Hydroelectric power production will realize some benefit, and some negative impacts, associated with the increase in flows of rivers that are used for hydroelectric production. As is true with the question of the length of the heating season, the net benefit or cost in 2020 remains ambiguous.

Many of the major Russian rivers will experience increased water flows due to glacial melt and selective regional precipitation changes. For the most part, this change will offer opportunities for increased power production. According to Roshydromet, the Volga-Kamsk Cascade will experience a net increase of 10-20 percent in water flows. The reservoirs throughout the Northwest Federal District will experience a 5-10 percent increase, and the massive Siberian power dams along the Angarsk-Yenisey, Vilyu, Kolyma, and Zeya will experience increases ranging as high as 15 percent. In addition, certain hydro-electric reservoirs in the southern part of the country will experience reductions in productivity due to reduced water flow. Nonetheless, operating regimes for all power dams will require review in light of anticipated climate change, according to Roshydromet. In addition, there will be increased challenges related to managing head and tail waters in the face of increased flows, and particularly in relation to increased incidence of extreme downpours.[lxiv]

Another energy supply-related impact from climate change to 2030 will relate to electricity transmission systems. One form of the heightened risk to power transmission will come from permafrost melt and the resulting creation of thermokarst and other unstable soil conditions. High-voltage power lines will be one of the many kinds of structures that will be susceptible to damage as upper soil layers thaw and re-freeze. One particularly vulnerable transmission system will be the lines serving the Bilibino nuclear power plant on the Arctic coast and running from the town of Chersk to Pevek.

Another heightened risk for power transmission systems will be increased wind load on power stanchions, as on other large structures. Power lines in the North Caucasus, as well as in the regions of Murmansk, Arkhangelsk, Leningrad, portions of Sakha (Yakutia), Irkutsk, Magadan, Khantiy-Mansiysk, and Evenkia will be exposed to 20 percent increases in wind force and may need to be reconstructed or reinforced as a consequence.[lxv]

Climate change by 2030 appears unlikely to sufficiently affect the Russian electric power sector as to lead to significant national security implications for the Russians. However, major power system failures could lead to serious human hardship and could therefore conceivably fuel political dissatisfaction in Russia. If a major portion of one of Russia's regional power grids were destabilized by the failure of a major power dam, or if power supply lines failed due to unusually abrupt winds in the North Caucasus, for example, one could envision the potential for localized instability.

If the hydropower and power transmission industries face challenges as climate change intensifies, even greater challenges face the petroleum industry, with likely greater significance for the Russian economy and state. In today's Russia, oil and gas are the predominant components of economic performance. Together they represent on the order of 60 percent of total exports and one-third or more of state revenues.[lxvi] Russia learned, starting in late 2008, that its economy was therefore at risk of significant volatility in case of a downturn in global energy prices, and diversifying the economy away from extractive industries is a stated goal of the Russian government. However, for the foreseeable future, the core of Russia's economy will remain oil and gas.[lxvii]

This in turn means that Russia's economy is highly vulnerable to climate change impacts that affect the current or future operations of the petroleum sector. Many areas that are currently the focus of exploration and production activity will be more difficult to exploit. Pipeline and rail transportation systems that cross major rivers and permafrost will be subjected to unprecedented stresses and strains, many of which were not anticipated when initial design parameters were established. Critical new upstream development areas, such as the Yamal Peninsula, will be more complicated to reach by land and harder to develop in the face of thawing permafrost and shorter winter seasons.

The Russian petroleum industry has traditionally centered in West Siberia and the Volga region, with transportation links extending to European portions of Russia and then to western and central European markets. The Russian gas industry has centered on three super-giant fields in the Nadym-Pur-Taz region—the Urengoy, Yamburg, and Medvezh'ye fields. At present, in addition to thousands of producing oil and gas wells, Russia has roughly 50,000 kilometers of oil pipelines and roughly 150,000 kilometers of gas pipelines, most of which were constructed in the 1980s under Soviet rule. There are also scores of processing plants and refineries distributed across Russia's massive territory.[lxviii] (See Figure 5 for a map of existing and planned pipelines and gas production regions.)

The core climate-related vulnerability facing oil and gas pipeline systems is that these systems were designed and built with the presumption of a stable climate. The thousands of river crossings did not provide margins of error to accommodate the increased water flow that will result from climate change by 2030. They were not constructed using horizontal directional drilling techniques that allow deeper and more secure passage under riverbeds. Underwater river crossings in several key producing and transit regions are thought to be particularly at risk—the upper and lower Volga and its tributaries in the regions of Nizhegorodskaya, Orenburg, Perm, Samara, Saratov, Ulyanovsk, Bashkortostan, Tatarstan, Tyumen, Novosibirsk, and Sakhalin among others.[lxix]

In addition to climate-related risks for river crossings, oil and gas pipelines and other facilities are at risk in permafrost regions. In these areas, pipelines and other structures are typically constructed above ground to allow thermal insulation to avoid thawing the soil. In the period to 2030, however, these regions will experience deeper seasonal thawing, resulting in structural subsidence and weakened integrity of pipelines and other petroleum-industry installations.

The permafrost zones are also exceptionally important for the future development of oil and especially gas production. Russian gas production has been the basis of not only Russian export earnings but also Russia's controversial, growing politico-economic power vis-à-vis central and western European neighbors, as was demonstrated again in early 2009 during the Russian-Ukrainian gas crisis.

Maintaining Russian gas exports is therefore a matter of highest national priority. There has been a dramatic decline of production at the Urengoy, Yamburg, and Medvezh'ye fields that have been the core of Russian gas production since the end of the Soviet period.[lxx] New production is crucial for Gazprom to realize its production targets and satisfy both domestic requirements and export consumers in coming years.[lxxi]

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Three of the key areas that the Russians expect to produce new gas will keenly feel the effects of a changing climate by 2030. First, the Yamal peninsula is an Arctic region that is a vast wealth of untapped gas prospects. According to some Gazprom projections, it could account for as much as 200 billion cubic meters (bcm) of gas production per year by 2020, and 360 bcm per year by 2030.[lxxii] However, developing Yamal will be significantly complicated by a changing climate. Supplies that will need to be brought in by land will require the construction of new roads and rail links, which will be tricky with the growth of thermokarst. Previous techniques, like the use of seasonal ice roads will be more problematic due to the shorter cold season. New above-ground pipelines and other elevated installations will have to be constructed using deeper foundations to avoid structural damage from subsidence.

A second key area for new Russian gas production is the Barents Sea. Here, one massive new field called Shtokman is to be developed some 550 kilometers north of the Kola Peninsula, with a projected annual production of around 90 bcm of gas.[lxxiii] This hugely challenging technical undertaking, which will require the construction of ice-capable production platforms in more than 300 meters of water, is especially difficult because it is so far offshore that it is beyond the range of helicopters, yet it is vulnerable to seasonal pack ice and vicious storms. In the face of a rapidly changing Arctic climate, vessels traveling to Shtokman will have to navigate increasingly severe waters and endure bitter winter storms.

A third key projected area for the Russian gas industry is Eastern Siberia and the Russian Far East. Here too, climate change in the period to 2030 will pose increasing complications—melting permafrost, swollen rivers, more frequent and severe storms and more prevalent incidence of traditionally atypical forms of disease. As mentioned above, the Russian gas industry has traditionally been oriented toward customers within Russia and in neighboring European countries. However, in the past decade, Gazprom and the Russian government have identified the goal of moving to the East and developing gas resources that can feed to the Pacific Rim. The official Eastern Gas Program released in August 2007 projects total extraction of 100 bcm/year by 2030.[lxxiv] New fields are being developed in the Sea of Okhotsk, near Sakhalin Island. Other prospects are being pursued as far west as the area to the north of Lake Baikal (e.g., the Kovykta field) and in the Sakha Republic (Yakutia). All of these projects will require major new construction with countless major and minor river crossings and a significant number of permafrost operations. This development will therefore be vulnerable to the same kinds of challenges from climate impacts as have been discussed above.

Food Production and Drinking Water Supply

Russia will experience a mix of positive and negative impacts on food and water supply in the period to 2030. The net impacts in these important areas will depend heavily on the extent to which adaptation measures can be implemented in an affordable and timely manner, but doing so will be difficult.

Experts project that Russia will experience an increase in total water supply in the period to 2030. According to Roshydromet, in the aggregate Russia will experience an 8-10 percent increase in water volume by 2015—the equivalent of a 12-14 percent increase per capita—with these trends expected to continue in the years that follow.

That said, different regions will experience significantly different changes in their respective water supply. The northern and northwestern portions of European Russia, as well as the central Volga, many of the non-Chernozem lands, the Urals, and the Russian Far East will experience increasing water availability. In the dams along the Volga-Kamsk Cascade, water flows are projected to increase by 10-20 percent by 2015, as mentioned above. In the Northwest federal district, dams will see a 5-10 percent increase over the same period. And some of the key Siberian rivers systems—the Angarsk-Yenisey, the Vilyu, the Kolyma, and the Zeya—will experience flow increases by up to 15 percent.[lxxv]

On the other hand, many other parts of Russia will experience worsening water shortages, including densely populated industrial regions that are projected to experience increases in water demand of 5-25 percent.[lxxvi] In the Chernozem lands, these water-poor areas will include the Belgorod, Voronezh, Kursk, Lipetsk, Orel, and Tambov regions. In the south, Kalmykia, Krasnodar, Stavropol, and Rostov regions will face increasingly challenging water situations, with reductions in water supply on the order of 5-15 percent.[lxxvii] In southwestern Siberia, the list will include Altay, Kemerovo, Novosibirsk, Omsk, and Tomsk. Across a key southern belt, a whole host of Russian regions will face mounting, and serious, water problems. Included in this list will be both certain key agricultural lands (more on food supply below), and also a number of key industrial regions. Even the capital and the Moscow Oblast' will face "particularly acute" water supply problems.[lxxviii]

Regarding food supply, the longstanding popular presumption in Russia has been that a warmer global climate would translate into a significantly more hospitable Russian environment for agricultural production. Indeed, there are several respects in which climate change by 2030 will reduce longstanding challenges for Russian agriculture. First and foremost, growing seasons have already become longer and are predicted to become longer still.[lxxix]

Accompanying this change will be a reduction in the frequency of winter temperatures that are sufficiently bitter to damage winter plantings. More sensitive varieties of winter plantings will be possible in much of Russia by 2030, and it will be possible to plant existing varieties farther north than would have been the case in the past.[lxxx] For example, it will be possible to plant longer-ripening grains and late-ripening sugar beets as far north as Moscow.[lxxxi] Interestingly, the longer growing seasons will not be accompanied by an increased frost-free period except in the Northwestern, Central, and Volga federal districts.[lxxxii]

Based on temperature ranges expected by 2030, it will also be possible to introduce entirely new crops that are not widely grown in Russia today. For example, the projected temperature of the north Caucasus and the lower Volga will be well suited to intensive agriculture for crops that are typically found in Central Asia and the south Caucasus at present—crops such as cotton, grapes, tea, citrus, and other fruits and vegetables.[lxxxiii]

A key question, however, is whether the longer growing seasons and the warmer Russian agricultural lands will result in increased yields. In fact, this does not appear to be assured—at least not based on the crops that are currently raised. Many of the current "bread basket" areas of Russia—including the Black Earth or Chernozem lands, the lower Volga region, and the southern part of Siberia—will experience reductions in grain yields resulting from reduced precipitation—reductions in yields of more than 22 percent by 2020. Warmer average temperatures will produce better grain yields in some parts of the country that have not traditionally served as the heartland for grain production. Regions such as the Northwest and Central federal districts and the Volga-Vyatsk region are expected to see a 10-15 percent increment in grain yields. Nationwide, according to Roshydromet, grain yields could shrink by more than 11 percent by 2020.[lxxxiv]

Plant diseases and pests will become a more serious challenge in many parts of Russia. In the southern part of European Russia and in western Siberia, locusts are expected to be increasingly common. Already they are found more frequently than was the case two or three decades ago, and they are expected to be even more prevalent in the future in the Stavropol, Kalmykia, Volgograd, Astrakhan, Saratov, and Rostov regions, and in some parts of southern Siberia.[lxxxv] In northwestern Russia, farmers are experiencing an infestation of Colorado potato beetles, which are now found in Karelia. In coming years, as mild winters become increasingly common, they are expected to spread into southern parts of the Arkhangelsk region and the Komi Republic.[lxxxvi]

A third question that arises about future agriculture is whether human management and distribution systems, and rural society itself, will be able to adapt in a timely manner to manage new crops, new supply chains, and requirements. Indeed, rural Russia has typically been resistant to change. In addition, supply, distribution, and management issues have historically posed great hurdles for Russian agriculture. A key question will be whether a true national market for food and agricultural products develops, or whether Russian regions persist in semi-national, semi-intra-region forms of agricultural trade.[lxxxvii]

Additional challenges for agriculture by 2030 will come from the increased frequency of severe weather events. Periods of drought in key agricultural regions are expected to be 50-100 percent more frequent by 2015, with the trend line continuing thereafter.[lxxxviii]

By 2030, Russia will start to feel the impacts of climate change in relation to both water and food supply. To maintain stable food supply, significant changes will be required in terms of varieties that are planted, the lands that are used for agriculture, and the extent and intensity of pesticide and irrigation use. All of these solutions are theoretically possible, but none will come easily or inexpensively. All will test the ability of Russian authorities and Russian agriculture to adapt quickly as climate change impacts are felt.

Transportation Systems

Transportation systems are another aspect of Russia’s socioeconomic life that will experience major impacts from climate change by 2030. For the most part, these impacts will entail the need for significant adaptations, which will imply significant capital requirements. This will be true for Russia’s extensive rail networks as well as its more limited road networks. However, in relation to river transportation and especially Far North maritime transport, a changing climate will open new and likely beneficial possibilities.

Russia’s railways are the backbone of its goods and passenger transportation system, with over 87,000 kilometers of railroads stretching across most of the country.[lxxxix] The system is a state-owned monopoly that moves 1.3 billion passengers and 1.3 billion tons of freight annually, which represents 83 percent of all freight in Russia (not counting petroleum pipeline operations).[xc] The rail system is most highly developed in the European part of Russia and along the southern reaches of Siberia. Nonetheless, a significant portion of the rail system—such as the Baikal-Amur Mainline (BAM)—cross permafrost zones, so they will be subject to the same risks of subsidence and structural weakening from permafrost melt as well as increased vulnerability at river crossings from increased Siberian river flows, as discussed above.

Russia's road transport systems are much less significant for cross-country transportation, but they too will be affected by climate change. Some of the impacts may be positive, in that reduced winter snowpack in European Russia (where the road system is much more developed and much more used than in the Arctic or the Far East) may reduce road hazards and wear and tear on existing roads. Other impacts will be negative, however. The increase in weather variability, with elevated risks of severe storms and downpours, may lead to elevated dangers for road transportation and risks of mudslides and erosion in mountainous areas and near rivers and floodplains. In the Far North and Far East, where wintertime ice roads have been a means of wintertime survival, shorter cold seasons will result in significantly reduced road transport capacity.[xci]

River transport, which is another key element of Russia's total transportation system, will experience both new problems and benefits from climate change to 2030, varying by region. In areas such as the Don River Basin in Russia's southwest, where there will be a reduction in total water flow, river navigation may encounter serious challenges. Extensive, and expensive, dredging may be required to allow continued barge and river freighter traffic.

In other areas, where river flows will significantly increase, such as along the major Siberian river systems and in the northwest of the country, river transport may be enhanced and facilitated. The exception to this rule may occur in areas where the earlier arrival of spring weather and the more pronounced melt-off of winter snow and ice lead to river ice jams and flooding.[xcii]

Another potentially significant transportation impact from climate change is the increased possibility of sea passage through Arctic waters. The so-called Northern Sea Route (NSR) that runs from near the island of Novaya Zemlya to the Bering Strait offers the prospect of up to a 40 percent savings in sea distance for journeys between northern Europe and Pacific Rim ports in either North America or northeastern Asia.[xciii] By 2020, the navigation season along the NSR will increase from around 36 days at present to around 40 days per summer.[xciv] Furthermore, the reduction in the extent of Arctic ice will allow vessels to travel in deeper waters farther from shore. Nonetheless, Arctic Sea shipping will not be without its share of challenges. Icebergs will continue to pose hazards to navigation, and bitter storms may produce significant wave action.

Human Health

Climate change may present Russia with a host of new and unwelcome challenges by 2030—both in the form of dangers related directly to climate and in the form of pest-borne disease.

In the case of direct effects, the combination of more frequent droughts and heat waves has had an impact on vulnerable populations in Russia already.[xcv] By 2030, as extreme weather events become more prevalent, this kind of increased risk to human health will rise further, particularly affecting the aged and infirm, especially for those unable to afford residential air conditioning.

Historically, Russia's bitter winters served as a check on the populations of many disease-carrying pests. Rodent populations, mosquitoes, and ticks were limited by the rigor of the seasons.

In recent years, however, these historical factors have receded. For example, according to one report, Russia's current rodent population is ten times higher than historical norms. Worse yet, one-third of the rodent population is estimated to carry one of the viruses that cause hemorrhagic fever with renal syndrome (or HFRS), which is a deadly illness if not caught early in its course.[xcvi] Incidences of HFRS spike after each occurrence of an unusually mild Russian winter.

As in other northern countries, mosquitoes have always been a summertime challenge in Russia. (Due to the poor quality of the housing stock, mosquitoes were often an unexpected wintertime challenge too; they would live through the winter in standing water in Russian basements, as many Western students and diplomats experienced.) But by 2030, they are expected to pose an increasing public health threat. As may as 250,000 Russians suffer from latent, local forms of malaria. West Nile and Denge Fever are reported to be spreading across the country as well.[xcvii]

Ticks are another disease vector that will grow worse by 2030. Tick encephalitis, Lyme disease, and tick rickettsiosis (Rocky Mountain Spotted Fever) are three of the diseases that are spreading increasingly aggressively across Russia.

Intestinal diseases are also a risk for Russia in the period to 2030. This risk will be especially significant in southern European Russia and the northern Caucasus region, where fresh water supply and water quality are expected to deteriorate as a result of climate change.[xcviii] However, even in distant Yakutia, in 2002, early spring flooding, which will also be increasingly common in Siberia by 2030, triggered a massive outbreak of enteric fever.[xcix]

Coping Capabilities in Facing Natural Disasters

Russia is better equipped than many other countries to respond to disasters resulting from climate change, certainly much better equipped than most of its regional neighbors. The central entity involved in governmental response to natural and manmade disasters is the Russian Federation Ministry of Civil Defense, Emergency Situations, and Disaster Response (known in Russia by the shorthand "Ministry of Emergency Situations," and often referred to in the West as "Emercom"). This organization brings together many of the functions that fall under the US Department of Homeland Security, including the Federal Emergency Management Agency (FEMA) and the Coast Guard, as well as local fire departments all across the country.[c] It is a proud, well-recognized organization that has earned public respect for its involvement in responding to a number of tragic occurrences in recent years.

Of particular significance for response to climate change impacts will be the Ministry's units with responsibility for forest fire prevention and response, maritime emergencies, flood protection and response, and search and rescue. The Ministry is Moscow-based but has regional centers across Russia, including several in southern Siberia that could be especially important in ensuring timely response to climate change-related disasters.

Another important component of Russia's coping capacity comes from the Russian Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet or Hydromet). Hydromet is the rough equivalent of the US National Oceanic and Atmospheric Administration (NOAA) and is active in monitoring, assessment, analysis, and prediction of weather and climate. Hydromet operates the Russian weather service, including over 1,600 meteorological stations across Russia,[ci] as well as serving as the leading scientific organization and the lead Russian representative for international negotiations and scientific undertakings related to climate change. Its research institutes work in close collaboration with institutes under the Russian Academy of Sciences, as well as leading Russian participation in the IPCC and other scientific assessment and forecasting activities.

Despite the considerable capabilities of both of these governmental organizations to analyze and respond to natural disasters, Russia will face a number of challenges in this context. Effective adaptation to climate change will require the application of huge resources and, more difficult, careful policy reforms. For example, policymakers will have to decide what to do with the residents of Russia's outsized northern urban centers. These Arctic cities are a monument to the sensibilities of Soviet planners—and an economic disaster.[cii] Thawing permafrost will pose more problems for these cities, and many of these cities sit on or near the banks of the Siberian rivers that will experience significant increases in flows and increased risks of flooding. Yet mass relocation would be both costly and politically challenging.

Other Urban Infrastructure

In the period to 2030, climate change could have a variety of impacts on urban infrastructure in Russia. Some of these impacts have already been discussed above, such as the potential for a reduction in heating requirements and heating loads that could accompany an increase in wintertime temperatures.

Another broad category of impact—but a negative one—is projected sea-level rise. This impact has the potential to bring significant challenges to a host of Russian cities and port complexes. Particularly vulnerable is Russia's second city, St. Petersburg, which is already regularly at risk of flooding when strong winds blow to the east from the Gulf of Finland. This vulnerability will only rise as sea level rises and storm surges grow more intense.[ciii] The risks of catastrophic flooding in St. Petersburg before 2030, and of consequent damage to both the economy and to unique historical buildings, is great.

St. Petersburg is not the only city at risk. The level of the Black Sea has been rising since the 1920s, and the rate of rise has increased significantly since the 1980s (currently about 2 centimeters per year).[civ] This will affect Russia's main warm water port complex at Novorossiysk, where dry cargoes, crude oil, and refined petroleum products are all exported. It will also affect Russia's main Black Sea military base, which is at Sevastopol, in neighboring Ukraine. Outside the Black Sea area, Russia's vital deepwater Atlantic basin port at Murmansk, which comprises both military and civilian capacity, will also be at risk to rising sea levels, as will the Pacific Rim ports, including Vladivostok and others.

As a general matter, Russia's population is projected to experience significant risks in the period to 2030 and beyond from extreme weather events—floods, torrential rains, severe winds, tornados, hurricanes, and the like. Officially designated dangerous hydrometeorological events across all of Russia have been growing markedly more common for the past decade-plus.[cv] This trend is expected to continue to 2030 and afterward. Russia's major urban centers may experience periods of drought combined with heat waves. In such circumstances, the risks of heat-related or disease-related illness could rise significantly.

International Issues

The international treatment of the Arctic over the next 20 or so years and questions of immigration related to climate change will affect Russia.

Greenhouse warming may bring greater changes in the Arctic than anywhere else on the planet. As has been discussed above, pronounced warming is already eroding the polar ice cap, and the thermal qualities of open water are contributing in turn to further warming and further melt-off.

This all translates into the Arctic being a much less imposing and more hospitable place than it has been in the past. Summers will bring increasingly extensive open seas that will facilitate speedy sea transportation of goods between northern Europe and the Pacific coasts of North America and northeastern Asia.[cvi] (See transportation discussion above.) New ports are being built along the Russian Arctic coast.

In addition, the warmer Arctic is engendering increased interest on the part of all of the littoral states in off-shore development. In 2007, the Russian polar scientist and politician Artur Chilingarov led an undersea expedition intended to bolster Russian claims that the Arctic is predominantly within the exclusive economic zone of Russia. One of Chilingarov's key arguments is that the undersea Lomonosov Ridge extends from Russian territory and therefore validates Russia's claim to half of Arctic Ocean. Complicating matters further, there is no clear agreement as to the legal regime that should govern competing claims in the Arctic.[cvii] Chilingarov's expedition culminated with the depositing of a Russian flag on the sea bottom, some 2.5 miles below the surface. "The Arctic has special geopolitical importance for Russia," Chilingarov later said.[cviii]

Given that Russia is not alone in its strong economic and security interests in the Arctic, climate changes that affect the Arctic could prompt the development of new military bases and activity. In late January 2009, military and political leaders from NATO met in Reykjavik, Iceland, to discuss how to manage the opportunities and challenges posed by a warming Arctic. The Secretary-General of NATO, Jaap de Hoop Scheffer, told the assembled audience, "Climate change is not a fanciful idea. It is already a reality, a reality that brings with it certain new challenges, including for NATO. Several Arctic rim countries are strengthening their capabilities, and military activity in the High North region has been steadily increasing."[cix] It is thus possible to imagine a significant increase in military presence in the Arctic, beyond what has been the case since the end of the Cold War.

Another international issue facing Russia is climate-related migration. Already today, Russia is the world's second biggest destination for migration (after the United States), attracting an estimated seven million migrants in 2008, of whom only about four million were legal.[cx] At present, most migrants present in Russia are from the countries of Central Asia and the Caucasus, and they seek economic opportunity to help support families in their countries of origin. Many migrants are involved in construction, other manual labor, and trading, especially in foodstuffs. In the Russian Far East and Primorskiy Kray, there are also a significant number of temporary workers from northeastern China. In short, today's migration to Russia seems to be significantly motivated by the "pull" phenomenon of economic opportunity.

By 2030, migration may become more of a "push" phenomenon. Water availability is projected to become an increasingly serious challenge in Central Asia, Mongolia, and northeastern China, and simultaneously droughts are projected to become more frequent. Glacial-fed rivers are at risk of becoming more and more depleted by 2030.[cxi] The ability of the Central Asian states to adapt to a changing climate may well be more limited than is the case with Russia. In turn, migration may become a source of instability within Russia, especially in difficult economic times. Already today, nationalist and reactionary political and social groupings are committing increasing numbers of hate crimes in Russian cities and towns. A Moscow-based nongovernmental organization that monitors hate crimes recorded over 500 attacks against foreigners in 2008, a one-third increase over 2007.[cxii]

Adaptive Capacity

The impacts of climate change will be felt differentially, depending upon how well a society can cope with or adapt to climate change, that is, its adaptive capacity. Adaptive capacity is defined by the IPCC as "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."[cxiii] Although the specific determinants (or "drivers") of adaptive capacity are a matter of debate among researchers, there is good agreement that economic, human, and environmental resources are essential elements. Some components of this adaptive capacity are near term, such as the ability to deliver aid swiftly to those affected by, e.g., flooding or droughts. Other components include a high enough level of education so that people can change livelihoods, sufficient unmanaged land that can be brought into food production, and institutions that provide knowledge and assistance in times of change. For instance, Yohe and Tol[cxiv] identified eight qualitative "determinants of adaptive capacity," many of which are societal in character, although the scientists draw on an economic vocabulary and framing:

1. The range of available technological options for adaptation.
2. The availability of resources and their distribution across the population.
3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed.

4. The stock of human capital, including education and personal security.
5. The stock of social capital, including the definition of property rights.
6. The system's access to risk-spreading processes.
7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves.
8. The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

Russian Adaptive Capacity in a Global Context

Researchers have only recently taken on the challenge of assessing adaptive capacity in a comparative, quantitative framework. A comprehensive global comparative study[cxv] of resilience to climate change (including adaptive capacity) was conducted using the Vulnerability-Resilience Indicators Model (VRIM—see box below).

Adaptive capacity, as assessed in this study, consists of seven variables (in three sectors), chosen to represent societal characteristics important to a country's ability to cope with and adapt to climate change:

Human and Civic Resources

- *Dependency ratio:* proxy for social and economic resources available for adaptation after meeting basic needs.
- *Literacy:* proxy for human capital generally, especially the ability to adapt by changing employment.

Economic Capacity

- *GDP (market) per capita:* proxy for economic well-being in general, especially access to markets, technology, and other resources useful for adaptation.
- *Income equity:* proxy for the potential of all people in a country or state to participate in the economic benefits available.

Environmental Capacity

- *Percent of land that is unmanaged:* proxy for potential for economic use or increased crop productivity and for ecosystem health (e.g., ability of plants and animals to migrate under climate change).
- *Sulfur dioxide per unit land area:* proxy for air quality and, through sulfur deposition, other stresses on ecosystems.
- *Population density:* proxy for population pressures on ecosystems (e.g., adequate food production for a given population).

Adaptive capacity for a sample of 10 countries from the 160-country study is shown in Figure 6 (base year of 2005). There is a wide range of adaptive capacity represented by these countries. Russia ranks high, both in the sample and overall:

- Russia ranks 32nd and Libya 34th (in the highest quartile).

- Indonesia ranks 45th, Belize 48th, Mexico 59th, and China 75th (in the second quartile).
- The Philippines ranks 91st and India 119th (in the third quartile).
- Morocco ranks 136th and Haiti 156th (in the lowest quartile).

Any country-level analysis must take into account the comparative ranking of the country.

Methodological Description of the Vulnerability-Resilience Indicator Model (VRIM)

The VRIM is a hierarchical model with four levels. The vulnerability index (level 1) is derived from two indicators (level 2): sensitivity (how systems could be negatively affected by climate change) and adaptive capacity (the capability of a society to maintain, minimize loss of, or maximize gains in welfare). Sensitivity and adaptive capacity, in turn, are composed of sectors (level 3). For adaptive capacity these sectors are human resources, economic capacity, and environmental capacity. For sensitivity, the sectors are settlement/infrastructure, food security, ecosystems, human health, and water resources. Each of these sectors is composed of one to three proxies (level 4). The proxies under adaptive capacity are as follows: human resource proxies are the dependency ratio and literacy rate; economic capacity proxies are GDP (market) per capita and income equity; and environmental capacity proxies are population density, sulfur dioxide divided by state area, and percent of unmanaged land. Proxies in the sensitivity sectors are water availability, fertilizer use per agricultural land area, percent of managed land, life expectancy, birth rate, protein demand, cereal production per agricultural land area, sanitation access, access to safe drinking water, and population at risk due to sea level rise.

Each of the hierarchical level values is composed of the geometric means of participating values. Proxy values are indexed by determining their location within the range of proxy values over all countries or states. The final calculation of resilience is the geometric mean of the adaptive capacity and sensitivity.

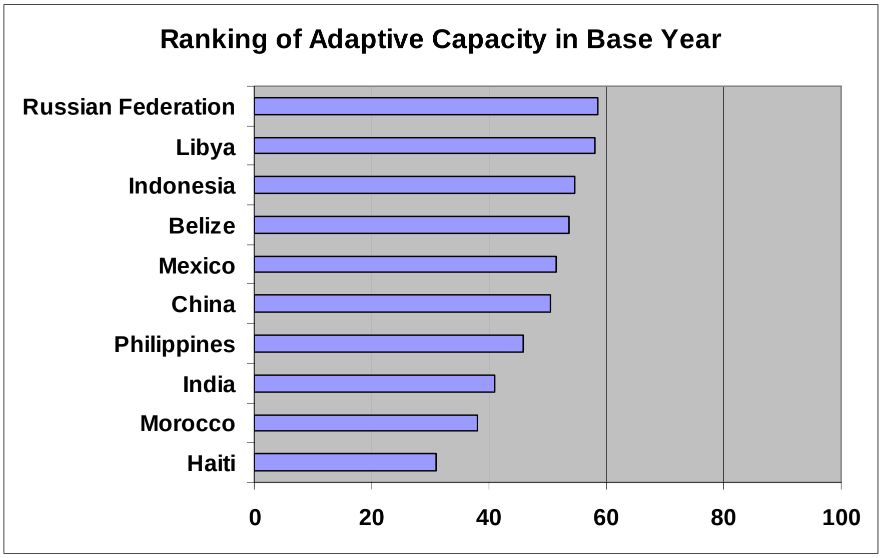

Figure 6. Sample of 10 countries' rankings of adaptive capacity (2005).

Figure 7 shows the contribution of each variable to the overall ranking (slight differences occurring because of the methodology [see box]). In current adaptive capacity, Russia ranks first among the 10 countries shown in Figure 6. Russia's comparatively high literacy levels (indicating higher human capital), low greenhouse gas emissions, and low population density (indicating a less of a burden on the environment) more than compensate for low GDP per capita. This corresponds roughly with the pattern that one

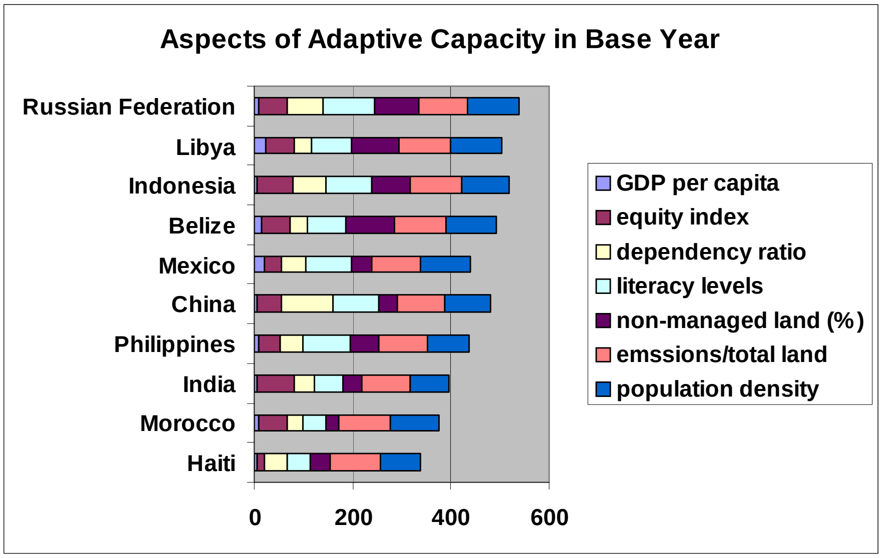

Figure 7. Variables' contributions to adaptive capacity rankings.

would expect for Russia. Russia has some significant areas of vulnerability, but it also stands to see some beneficial impacts from climate change. It has a well-educated populace, an economy that has some diversification but not a great deal, and a socioeconomic picture in which there is a small middle class, a small cluster of people with great wealth, and many who have only limited means.

Figure 8 shows projected adaptive capacity growth over time for the 10-country sample. Projections are made for two scenarios; rates of growth are based on the IPCC's A1 scenario in its *Special Report on Emissions Scenarios*.[cxvi] VRIM simulates two different hypothetical development tracks out to the year 2065 (well beyond the timescale of the present study) with intermediate results at 15-year time steps. These alternative development tracks are not intended to be predictive; they are scenarios.

Both scenarios feature moderate population growth and a tendency toward convergence in affluence (with market-based solutions, rapid technological progress, and improving human welfare). The scenarios used in this study differ in the rate of economic growth, one modeling high-and-fast economic growth, the other delayed growth.

Over time, a low-growth scenario widens the gap among the 10 countries—and the high-growth scenario widens the gap even more (Figure 8). In both scenarios, China's high economic growth (indicated by GDP per capita), favorable dependency ratio, and literacy rate allow that country to overtake Russia by 2050. In both scenarios, the strengths and weaknesses of current Russian adaptive capacity persist, with slow economic growth being a notable weakness.

Looking forward, Russia's ability to cope with climate change impacts to 2030 and beyond will obviously depend on both the nature and extent of the impacts and the extent to which Russia's adaptive capacities develop over time. This in turn depends on the nature and extent of Russia's socioeconomic and sociopolitical development over the coming years.

In the delayed-growth scenario, Russia's position is much less influenced by wealth accumulation (adaptive capacity) and much more heavily influenced by water availability, the production of cereal grains, and the use of fertilizer (included in impacts/sensitivity rather than in adaptive capacity). In this scenario, Russia's adaptive capacity still improves over time, but its progress, like that of other countries, is much more modest than in the high-growth scenario.

The high-growth scenario could, in the case of Russia, be consistent with robust early-period revenues from hydrocarbons and other commodity production, leading to significant wealth accumulation in the country and, over time, greater economic diversification of the sort that has been advocated in the last year by President Dmitriy Medvedev. (The elements and implications of this high-growth scenario are outwardly consistent with the track that Russia appeared to be on until the collapse of energy prices in the past six months.) In this scenario, Russia's adaptive capacity grows significantly over time, with Russia ending the period second only to China.

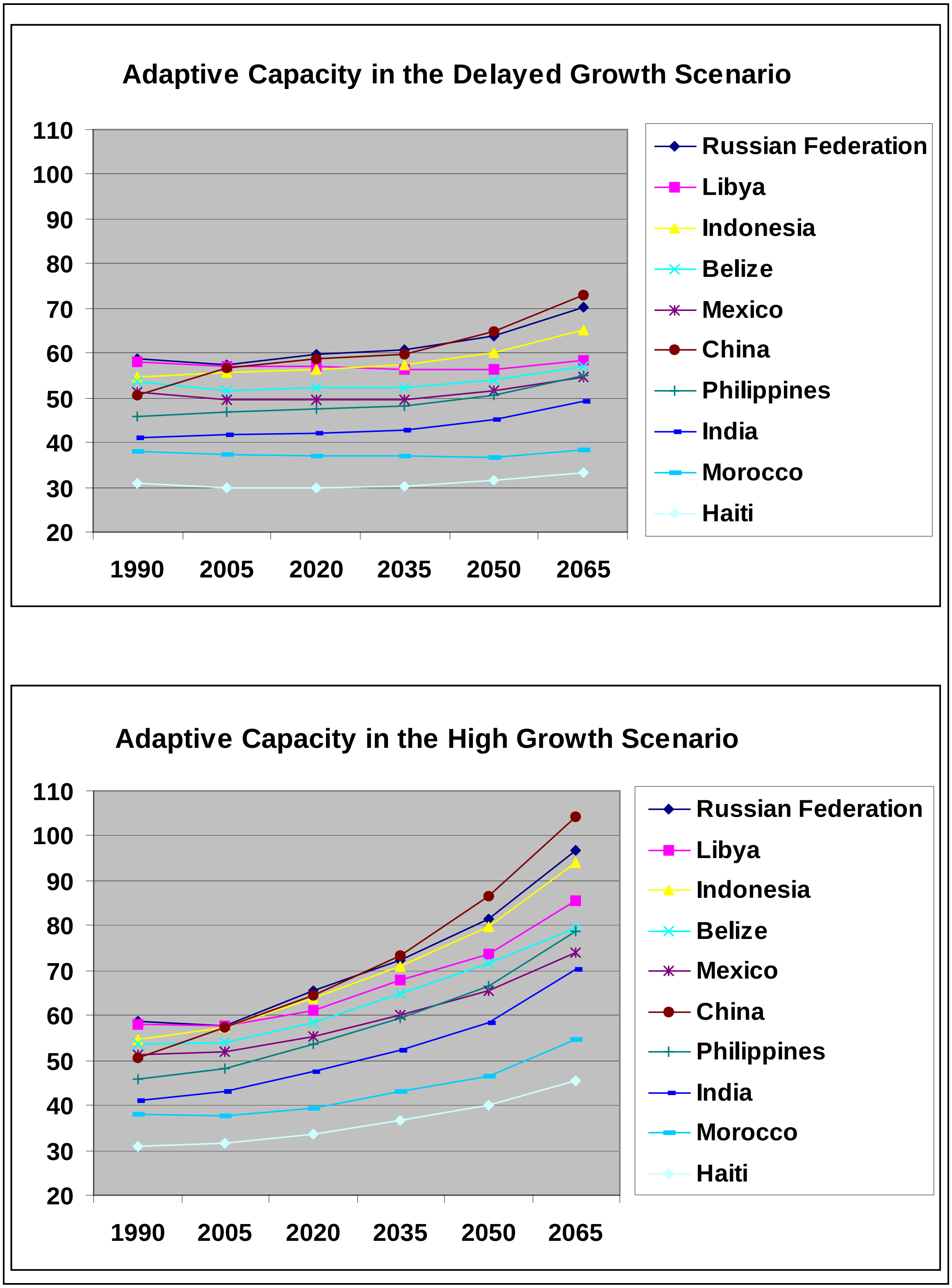

Figure 8. Projections of adaptive capacity for 10 countries.

In the real world, a variety of factors will play into the overall calculus of Russia's adaptive capacity. Evolving socioeconomic conditions will be one key factor. To highlight this fact, one can compare the adaptation of the Russian oil industry to the adaption of its gas industry in the period since the breakup of the USSR. In the late 1990s and the first years of the current decade, the Russian oil industry experienced rapid innovation that reflected new ownership forms, new managerial techniques, and the introduction of international technology. Production skyrocketed, especially after the 1998 financial crash, while environmental impacts for the oil industry as a whole (spills, emissions, and accidents) dropped. By comparison, the relatively traditionalist Russian gas industry, where there was substantially less commercial, managerial, and technological change, evolved less dramatically.

In the area of Russian agriculture, socioeconomic forms and institutions most likely will be significant in determining the efficacy of the sector's adaptation to climate change.[cxvii] One particular shortcoming will be the relative weakness of agricultural education and training, akin to the extension service programs operated by the US Department of Agriculture. Russia's rural population is generally the country's most conservative social grouping; adapting to changing climatic conditions will require innovation that has historically been alien to much of rural Russian society.

Strengths/Weaknesses in Adaptive Capacity Assessments

Even comparative measures of adaptive capacity only allow analysts to ask better focused questions about area or local conditions that contribute to or reduce resilience. It is likely, for instance, that for particular places in Russia important variables or domains are not included. For agricultural regions, this might include the extent of irrigation; for urban areas, better measures of education could be important. The measure of unmanaged land does not account for the potential usefulness of that land.

However, comparative measures such as these can be an important first step toward determining where to direct resources—for further analysis or additional factors.

Conclusions: High Risk Impacts

Energy. Russia's current and foreseeable future economic health depends extremely heavily on Russia's ability to produce and export oil and natural gas. The oil and gas infrastructure that exists today was not designed with an eye to vulnerability stemming from a changing climate—such as structural subsidence, pipeline crossings at surging rivers, and sea-level rise. Therefore, current production will be increasingly at risk in the coming years. Moreover, as production from traditional Russian gas supply provinces declines, Russia must develop replacement sources. The Yamal Peninsula and Barents Sea (including the Shtokman field) are absolute priorities, and the Russian Far East is a secondary priority. The impacts of a changing climate may delay significantly (or significantly raise the cost of) efforts to bring these new production areas on-line, which could affect Russia's fiscal position and balance of payments.

Agriculture. By 2030, Russia will begin to experience significant changes in agriculture. The critical question will be whether the positive impacts – longer growing season, new land that can be put under the plow, and the possibility of introducing new varieties and new crops—will outweigh the significant negative impacts. In this latter regard, the reduction in precipitation in parts of Russia's traditional agricultural belts and the projected reduction in yields for traditional grain crops are significant considerations. Also significant is the projected increasing reliance on irrigation and chemical additives to deter pests and enrich soils. Rural Russia historically has been a very traditionalist part of the country, and to date Russia has not developed widespread systems to educate farmers, particularly to help them anticipate and adapt to changes in their growing conditions stemming from climate change. There are risks that rural Russia simply will not adapt itself in a timely manner to the agricultural realities of a changing climate. Russia's food supply could be under stress.

Migration. Many of Russia's southern neighbors face a drier, hotter future in which economic prospects may become increasingly dire. If these neighbors are unable to adapt themselves in a timely manner and provide for their populations, Russia may experience significant new migration pressures, which could plausibly be associated with greater instability and ethnic strife in affected Russian cities and towns.

Accentuated Socio-Economic and Socio-Political Stresses. Russia is a massive country with a pronounced continental climate, thus extreme weather is not entirely unfamiliar. Nor is hardship unfamiliar to the people of Russia. Nonetheless, the significant increase in dangerous weather events over the last two decades, and the prospect of a continuing trend in this regard, make clear that extreme weather may be the sword of Damocles hanging over Russia's future. Heat waves, wind storms, droughts, and severe flooding may result in considerable damage to infrastructure, impacts on livelihoods, and even significant loss of life. These threats, in turn, may place even greater socio-economic and socio-political stress on parts of the country where the relationship between the government and governed is already tense. Areas such as the North Caucasus have already seen political tensions and instability that are unrelated to climate change. By 2030, however, climate change could significantly exacerbate such areas of stress.

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Annex A: Accuracy of Regional Models

This is an excerpt from IPCC (2007), Chapter 11, Regional models; see IPCC 2007 for references.[4]

11.4.2 Skill of Models in Simulating Present Climate

Regional mean temperature and precipitation in the MMD models show biases when compared with observed climate (Table 2). The multi-model mean shows a cold and wet bias in all regions and in most seasons, and the bias of the annual average temperature ranges from –2.5°C over the Tibetan Plateau (TIB) to –1.4°C over South Asia (SAS). For most regions, there is a 6°C to 7°C range in the biases from individual models with a reduced bias range in Southeast Asia (SEA) of 3.6°C. The median bias in precipitation is small (less than 10 percent) in Southeast Asia, South Asia, and Central Asia (CAS), larger in northern Asia and East Asia (NAS and EAS, around +23 percent), and very large in the Tibetan Plateau (+110 percent). Annual biases in individual models are in the range of –50 to +60 percent across all regions except the Tibetan Plateau, where some models simulate annual precipitation 2.5 times that observed and even larger seasonal biases occur in winter and spring. These global models clearly have significant problems over Tibet, due to the difficulty in simulating the effects of the dramatic topographic relief, as well as the distorted albedo feedbacks due to extensive snow cover. However, with only limited observations available, predominantly in valleys, large errors in temperature and significant underestimates of precipitation are likely.

South Asia

Over South Asia, the summer is dominated by the southwest monsoon, which spans the four months from June to September and dominates the seasonal cycles of the climatic parameters. While most models simulate the general migration of seasonal tropical rain, the observed maximum rainfall during the monsoon season along the west coast of India, the north Bay of Bengal and adjoining northeast India is poorly simulated by many models (Lal and Harasawa, 2001; Rupa Kumar and Ashrit, 2001; Rupa Kumar et al., 2002, 2003). This is likely linked to the coarse resolution of the models, as the heavy rainfall over these regions is generally associated with the steep orography. However, the simulated annual cycles in South Asian mean precipitation and surface air temperature are reasonably close to the observed. The MMD models capture the general regional features of the monsoon, such as the low rainfall amounts coupled with high variability over northwest India. However, there has not yet been sufficient analysis of whether finer details of regional significance are simulated more adequately in the MMD models.

Recent work indicates that time-slice experiments using an AGCM with prescribed SSTs, as opposed to a fully coupled system, are not able to accurately capture the South Asian monsoon response (Douville, 2005). Thus, neglecting the short-term SST feedback and variability seems to have a significant impact on the projected monsoon response to global warming, complicating the regional downscaling problem. However, May (2004a) notes that the high-resolution (about 1.5 degrees) European Centre-Hamburg (ECHAM4) GCM simulates the variability and extremes of daily rainfall (intensity as

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[4] Some references in this section have been changed to be internally consistent with this document and other references have been removed to avoid confusion.

well as frequency of wet days) in good agreement with the observations (Global Precipitation Climatology Project, Huffman et al., 2001).

Three-member ensembles of baseline simulations (1961–1990) from an RCM (PRECIS) at 50-kilometer resolution have confirmed that significant improvements in the representation of regional processes over South Asia can be achieved (Rupa Kumar et al., 2006). For example, the steep gradients in monsoon precipitation with a maximum along the western coast of India are well represented in PRECIS.

East Asia

Simulated temperatures in most MMD models are too low in all seasons over East Asia; the mean cold bias is largest in winter and smallest in summer. Zhou and Yu (2006) show that over China, the models perform reasonably in simulating the dominant variations of the mean temperature over China, but not the spatial distributions. The annual precipitation over East Asia exceeds the observed estimates in almost all models and the rain band in the mid-latitudes is shifted northward in seasons other than summer. This bias in the placement of the rains in central China also occurred in earlier models (e.g., Zhou and Li, 2002; Gao et al., 2004). In winter, the area-mean precipitation is overestimated by more than 50 percent on average due to strengthening of the rain band associated with extratropical systems over South China. The bias and inter-model differences in precipitation are smallest in summer but the northward shift of this rain band results in large discrepancies in summer rainfall distribution over Korea, Japan and adjacent seas.

Kusunoki et al. (2006) find that the simulation of the Meiyu-Changma-Baiu rains in the East Asian monsoon is improved substantially with increasing horizontal resolution. Confirming the importance of resolution, RCMs simulate more realistic climatic characteristics over East Asia than AOGCMs, whether driven by re-analyses or by AOGCMs (e.g., Ding et al., 2003; Oh et al., 2004; Fu et al., 2005; Zhang et al., 2005a, Ding et al., 2006; Sasaki et al., 2006b). Several studies reproduce the fine-scale climatology of small areas using a multiply nested RCM (Im et al., 2006) and a very-high resolution (5 kilometers) RCM (Yasunaga et al., 2006). Gao et al. (2006b) report that simulated East Asia large-scale precipitation patterns are significantly affected by resolution, particularly during the mid- to late-monsoon months, when smaller-scale convective processes dominate.

Southeast Asia

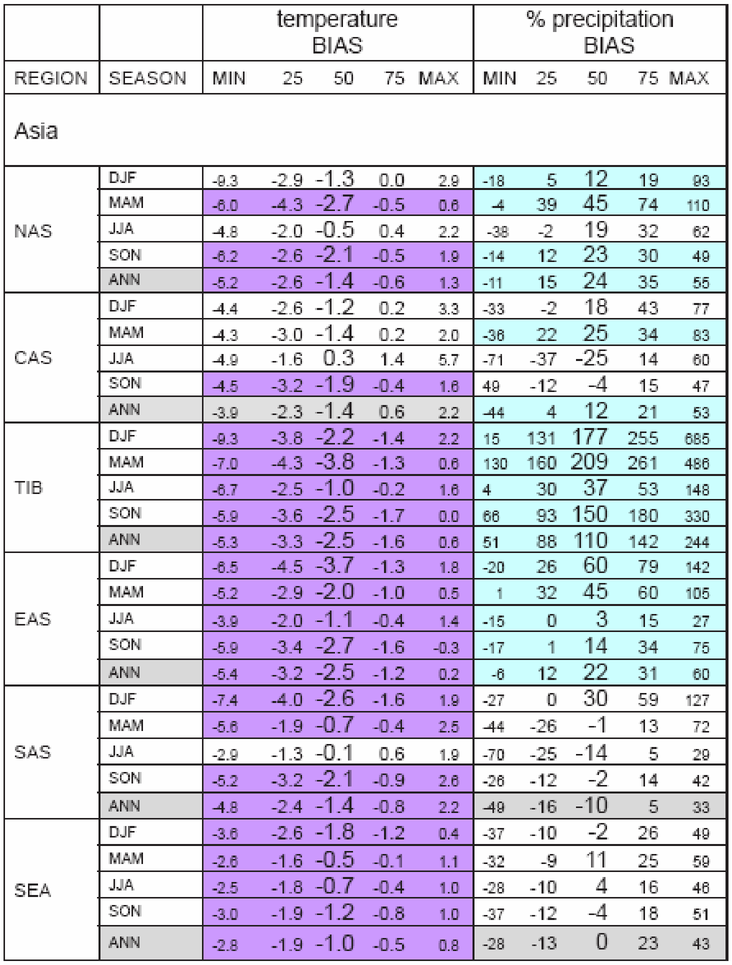
The broad-scale spatial distribution of temperature and precipitation in DJF and JJA averaged across the MMD models compares well with observations. Rajendran et al. (2004) examine the simulation of current climate in the MRI coupled model. Large-scale features were well simulated, but errors in the timing of peak rainfall over Indochina were considered a major shortcoming. Collier et al. (2004) assess the performance of the CCSM3 model in simulating tropical precipitation forced by observed SST. Simulation was good over the Maritime continent compared to the simulation for other tropical regions. B. Wang et al. (2004) assess the ability of 11 AGCMs in the Asian-Australian monsoon region simulation forced with observed SST variations. They found that the models' ability to simulate observed interannual rainfall variations was poorest in the Southeast Asian portion of the domain. Since current AOGCMs continue to have some significant shortcomings in representing ENSO variability, the difficulty of projecting changes in ENSO-related rainfall in this region is compounded.

Rainfall simulation across the region at finer scales has been examined in some studies. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) stretched-grid Conformal-Cubic Atmospheric Model (CCAM) at 80-kilometer resolution shows reasonable precipitation simulation in JJA, although Indochina tended to be drier than in the observations (McGregor and Nguyen, 2003). Aldrian et al. (2004a) conducted a number of simulations with the Max-Planck Institute (MPI) regional model for an Indonesian domain, forced by reanalyses and by the ECHAM4 GCM. The model was able to represent the spatial pattern of seasonal rainfall. It was found that a resolution of at least 50 kilometers was required to simulate rainfall seasonality correctly over Sulawesi. The formulation of a coupled regional model improves regional rainfall simulation over the oceans (Aldrian et al., 2004b). Arakawa and Kitoh (2005) demonstrate an accurate simulation of the diurnal cycle of rainfall over Indonesia with an AGCM of 20-kilometer horizontal resolution.

Central Asia and Tibet

Due to the complex topography and the associated mesoscale weather systems of the high-altitude and arid areas, GCMs typically perform poorly over the region. Importantly, the GCMs, and to a lesser extent RCMs, tend to overestimate the precipitation over arid and semi-arid areas in the north (e.g., Small et al., 1999; Gao et al., 2001; Elguindi and Giorgi, 2006).

Over Tibet, the few available RCM simulations generally exhibit improved performance in the simulation of present-day climate compared to GCMs (e.g., Gao et al., 2003a,b; Zhang et al., 2005b). For example, the GCM simulation of Gao et al. (2003a) overestimated the precipitation over the north-western Tibetan Plateau by a factor of five to six, while in an RCM nested in this model, the overestimate was less than a factor of two.



		temperature BIAS					% precipitation BIAS				
REGION	SEASON	MIN	25	50	75	MAX	MIN	25	50	75	MAX
Asia											
NAS	DJF	-9.3	-2.9	-1.3	0.0	2.9	-18	5	12	19	93
	MAM	-6.0	-4.3	-2.7	-0.5	0.6	-4	39	45	74	110
	JJA	-4.8	-2.0	-0.5	0.4	2.2	-38	-2	19	32	62
	SON	-6.2	-2.6	-2.1	-0.5	1.9	-14	12	23	30	49
	ANN	-5.2	-2.6	-1.4	-0.6	1.3	-11	15	24	35	56
CAS	DJF	-4.4	-2.6	-1.2	0.2	3.3	-33	-2	18	43	77
	MAM	-4.3	-3.0	-1.4	0.2	2.0	-36	22	25	34	83
	JJA	-4.9	-1.6	0.3	1.4	5.7	-71	-37	-25	14	60
	SON	-4.5	-3.2	-1.9	-0.4	1.6	49	-12	-4	15	47
	ANN	-3.9	-2.3	-1.4	0.6	2.2	-44	4	12	21	53
TIB	DJF	-9.3	-3.8	-2.2	-1.4	2.2	15	131	177	255	685
	MAM	-7.0	-4.3	-3.8	-1.3	0.6	130	160	209	261	486
	JJA	-6.7	-2.5	-1.0	-0.2	1.6	4	30	37	53	148
	SON	-5.9	-3.6	-2.5	-1.7	0.0	66	93	150	180	330
	ANN	-5.3	-3.3	-2.5	-1.6	0.6	51	88	110	142	244
EAS	DJF	-6.5	-4.5	-3.7	-1.3	1.8	-20	26	60	79	142
	MAM	-5.2	-2.9	-2.0	-1.0	0.5	1	32	45	60	105
	JJA	-3.9	-2.0	-1.1	-0.4	1.4	-15	0	3	15	27
	SON	-5.9	-3.4	-2.7	-1.6	-0.3	-17	1	14	34	75
	ANN	-5.4	-3.2	-2.5	-1.2	0.2	-6	12	22	31	60
SAS	DJF	-7.4	-4.0	-2.6	-1.6	1.9	-27	0	30	59	127
	MAM	-5.6	-1.9	-0.7	-0.4	2.5	-44	-26	-1	13	72
	JJA	-2.9	-1.3	-0.1	0.6	1.9	-70	-25	-14	5	29
	SON	-5.2	-3.2	-2.1	-0.9	2.6	-26	-12	-2	14	42
	ANN	-4.8	-2.4	-1.4	-0.8	2.2	-49	-16	-10	5	33
SEA	DJF	-3.6	-2.6	-1.8	-1.2	0.4	-37	-10	-2	26	49
	MAM	-2.6	-1.6	-0.5	-0.1	1.1	-32	-9	11	25	59
	JJA	-2.5	-1.8	-0.7	-0.4	1.0	-28	-10	4	16	46
	SON	-3.0	-1.9	-1.2	-0.8	1.0	-37	-12	-4	18	51
	ANN	-2.8	-1.9	-1.0	-0.5	0.8	-28	-13	0	23	43

Table 2. Biases in present-day (1980-1999) surface air temperature and precipitation in the MMD simulations. The simulated temperatures are compared with the HadCRUT2v (Jones, et al., 2001) data set and precipitation with the CMAP (update of Xie and Arkin, 1997) data set. Temperature biases are in °C and precipitation biases in per cent. Shown are the minimum, median (50%) and maximum biases among the models, as well as the first (25%) and third (75%) quartile values. Colors indicate regions/seasons for which at least 75% of the models have the same sign of bias, with orange indicating positive and light violet negative temperature biases and light blue positive and light brown negative precipitation biases.

Annex B: Knowledge Deficiencies that Preclude a Full Evaluation of Climate Change Impacts on Russia and Russia's Adaptive Capacity

In order to increase the likelihood that this evaluation represents a reasonable assessment of Russia's projected climate changes and their impacts, and the country's adaptive capacity, the following gaps would need to be addressed:

- In physical science research, regional analyses will continue to be limited by the inability to model regional climates satisfactorily, including complexities arising from the interaction of global, regional, and local processes. One gap of particular interest is the lack of medium-term (20-30 years) projections that could be relied upon for planning purposes. Similarly, scientific projections of water supply and agricultural productivity are limited by inadequate understanding of various climate and physical factors affecting both areas. Research agendas in these areas can be found in, for instance, the synthesis and assessment reports of the US Climate Change Science Program (http://www.climatescience.gov) and the National Academy of Sciences (e.g., http://books.nap.edu/catalog.php?record_id=11175#toc). Similar types of issues exist for the biological and ecological systems that are affected.
- In social science research, scientists and analysts have only partial understandings of the important factors in vulnerability, resilience, and adaptive capacity—much less their interactions and evolution. Again, research agendas on vulnerability, adaptation, and decision-making abound (e.g., (http://books.nap.edu/catalog.php?record_id=12545).
- Important factors are unaccounted for in research; scientists know what some of them are, but there are likely factors whose influence will be surprising. An example from earlier research on the carbon cycle illustrates this situation. The first carbon cycle models did not include carbon exchanges involving the terrestrial domain. Modelers assumed that the exchange was about equal, and the only factor modeled was deforestation. This assumption, of course, made the models inadequate for their purposes. In another example, ecosystems research models are only beginning to account for changes in pests, e.g., the pine bark beetle.
- Social models or parts of models in climate research have been developed to simulate consumption (with the assumption of well-functioning markets and rational actor behavior) and mitigation/adaptation policies (but without attention to the social feasibility of enacting or implementing such policies). As anthropogenic climate change is the result of human decisions, the lack of knowledge about motivation, intent, and behavior is a serious lack.

Overall, research about climate change impacts on Russia has been undertaken piecemeal: discipline by discipline, sector by sector, with political implications separately considered from physical effects. This knowledge gap can be remedied by integrated research into energy-economic-environmental-political conditions and possibilities.

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