Scientific Background Appendix.

This appendix contains a sample of materials prepared by the Science Plan authors to Chapters 2 and 3. This information (mostly, scientific background information) was considered potentially valuable for the readers of the Science Plan and preserved in this appendix.

2. SCIENTIFIC QUESTIONS AND MOTIVATION

Part of Chapter 2 related to Climatic and environmental changes in Northern Eurasia was moved to Scientific Background Appendix

2.6. Physico-geographic description of Northern Eurasia.

The geographic realm of Northern Eurasia spans from the Scandinavian fiords in the west to chains of volcanic islands along the Pacific coast in the east, and from the frozen Arctic tundra in the north to the deserts of the Caspian lowlands and plateaus of Gobi and Takla-Makan in the south. This area serves as a home for most of the earth's biomes including tundra, taiga, leaf forest, steppe and desert. Over vast, flat areas of the East European Plain and Siberian Highlands, the biomes and climatic regions have typical zonal orientation where continentality increases eastward. That is, the further eastward, the less the influence of the warm Atlantic Ocean that moderates to some extent the continental climate. The exceptions to this rule of zonality are the climates of the montane biomes in the Caucasus, Ural, Tian-Shan, and Altai Mountains.

The large landmass of Eurasia causes an extreme range in seasonal temperatures, especially in the central parts of the continent, where the difference between summer and winter reaches a record high in comparison with any other non-mountainous climatic region on the planet. The important climate forming factor of central Siberia is the Arctic Ocean. Cold and dry air masses may form over the Arctic in summer as well as in winter. Siberian rivers, in turn, discharge relatively warm water back to the Arctic Ocean, playing a critical role in the delicate energy and fresh water balances of the oceanic thermohaline circulation. In contrast to the interior of the continent, the moderating influence of the Atlantic Ocean on Northwestern Eurasia leads to much lower seasonal changes and relatively high year-round precipitation. The eastern portion of Northern Eurasia (loosely referred as the Far East) is subject to another maritime influence, the warm Kuroshio of the Pacific Ocean. The heat energy of this current feeds typhoons and other weather systems, causing their deep penetration to eastern parts of the continent.

The flora and fauna of Northern Eurasia is affected by its climatic and geographic variety and is represented by a unique diversity of terrestrial and aquatic species (Vlasova 1976). The following physico-geographic zones with distinctively different biomes are distinguished over Northern Eurasia (Figure 1.2). We use two macro-climatic characteristics: the annual surface radiative balance, R, and the dimensionless Budyko radiative dryness index, (R/Lr), defined as a ratio of R to the energy it takes to evaporate annual precipitation, (where L is latent heat of vaporization, and r is annual precipitation totals; Budyko 1971).

- **Arctic Desert** is characterized by the presence of ice and snow cover, negative air temperature throughout the year, a negative, or close to zero, radiation balance, and R/Lr varies from 0 to 0.2.
- **Tundra Zone** is characterized by a severe, lengthy winter, cool short summer with a long polar day, mean summer surface air temperatures from zero to 10°C with low positive radiation balance and radiative dryness index from 0.2 to 0.4. It has high soil moisture, no forests, moss and lichen cover, with shrubs and grass as the prevailing

landscape. Meadows and bogs are also a common occurrence. Soils are gley and weakly podzolic with widespread permafrost over most of the zone. The vulnerability of tundra nature to different anthropogenic impacts is exceptional, taking into account the degree of sensitivity to impacts on the ground surface. The soil deformation and thermoerosion may occur even after a single movement of caterpillar transport. With permafrost and high air transparency, the tundra environment is more vulnerable to pollution than other areas. Particularly vulnerable to pollution are shrub lichens, which are the main fodder of reindeers.

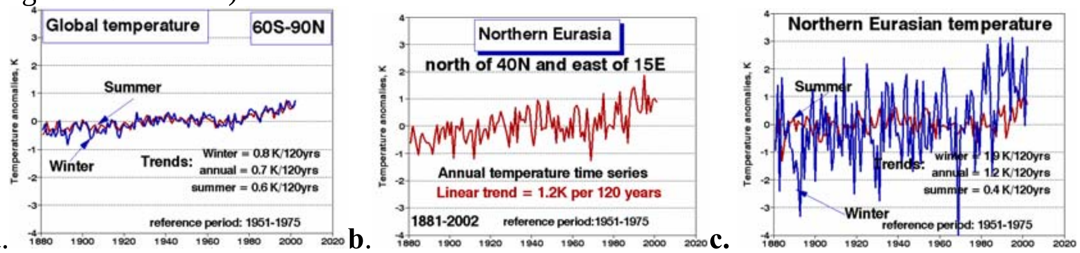
- **Forest-Tundra** is a transitional physico-geographic zone between tundra and forest zones. It is characterized by a combination of forest and tundra elements, as well as thin tundra forests. While referred to as transitional, a substantial area of Eastern Eurasia is occupied by forest-tundra landscape. In Eastern Eurasia, the forest-tundra and up to 75% of forest zone are underlain by permafrost. This makes the zone especially vulnerable to human industrial activity. Gas and oil production, mining, and logging cause catastrophic changes in the habitats of plants and animals. Cutting areas, drilling sites and areas with disturbed vegetation cover do not recover and become boggy. The depth of permafrost seasonal thawing increases, forming thermokarst (sagging deformation of soil surface) and degradation of biomes (3.4, 3.6.1).
- **Boreal Forest Zone** is subdivided into taiga, north, middle and south areas with mixed forest, as well as leaf-bearing (deciduous) forests. This zone is characterized by a snowy winter, a warm summer (with the mean temperature of the warmest month being above 10°C), a positive radiation balance, and a ratio of R/Lr that varies from 0.4 to 1.0. Optimal moistening for the boreal forest occurs when R/Lr is within the 0.8 to 1.0 range. Soil and ground water have low salinity. The major type of soil is podzolic and swampy, coniferous and deciduous forests prevail, and bog moss is widespread. The boreal forest is the largest ecosystem in Northern Eurasia. The area of forested land, however, has steadily decreased during the 20th century, compared to the pre-industrial period (e.g., 16-17th centuries). In West Europe (beyond the Russian boundaries), the forested area has decreased by 68%, from 4.69 10^6.km^2 to 1.52 10^6 km^2, and in Russia by 31%, from 11.75 10^6 km^2 to 8.08 10^6 km^2 (The Last Frontier Forests World Resources Institute - Washington,1997). The major cause for this reduction is the forest clearing for agricultural and developmental needs. A major cause of forest destruction is forest fires, the number of which grows with climate warming and through fault of local population.
- **Forest-Steppe** is a transitional type of landscape that is characterized by a combination of steppe and forest areas. Large forests or groves among steppe areas are widespread on watersheds; there is a considerable amount of precipitation (with high evaporation, greatly varying soil moisture, widespread development of gray podzolized soils and leached chernozem (black soil). Flora and fauna is mixed (i.e., consist of the elements of forest and steppe flora and fauna). This is the most productive agricultural region in Northern Eurasia. Therefore, natural biomes of most of this zone have been replaced by agricultural land. Historical records indicate that natural boundaries of the forest-steppe zone have been highly variable during the past 2-3 millenniums.
- **Steppe** is characterized by a continental climate, a positive radiation balance, a varying radiative dryness index from 1 to 2, lack of forests on watersheds, and a prevalence of grassy vegetation on black and dark nut brown soils.
- **Semi-Deserts** are characterized by a very dry continental climate with R/Lr between 2 and 3, weak development of local hydrographic network, widespread saline soils, and

sparse vegetation consisting of xerophyte grass and shrubs. Semi-deserts are distinguished by natural contrasts (e.g., high temperature ranges in the seasonal and diurnal cycles and presence of oases with very different but regionally restricted ecosystems). They respond rapidly to the disturbances in ecosystem equilibrium. Significant changes took place in these areas in the last decades of the 20th century. The basic cause of these changes was a technogenic factor, i.e. application of modern technology in mining industry, road construction, and mechanization of agriculture on the irrigated lands. When these technical means are used, vegetation is destroyed, fixed sands start moving, and the ground water level becomes lower. Irrigation with excessive watering resulted in salinization of soils, excluding them from land-tenure over a significant part of the zone. The desertification process is going on within the zone. It is determined as a suite of natural and anthropogenic processes leading to destruction of ecosystems in arid areas. It has been established that of 45 factors that identified desertification, 87% are associated with irrational nature utilization by human society and only 13% are caused by natural processes.

- **Deserts** are extremely arid zones with a positive radiation balance and R/Lr greater than 3. Deserts are characterized by a negligible amount of precipitation, a hot summer and high daily and annual air and soil temperature amplitudes. Ephemerals and perennial xerophyte semi-shrubs and shrubs are typical plants. Bare soil prevails. Constant surface water streams are absent. Deserts in Northern Eurasia are extensive (in fact, they are the largest in the extratropics) and are a major source of mineral dust.
- **Subtropics** (dry and wet). The zone is transitional between temperate and tropical belts. There are observed seasons of a year with mild winters. Depending on rainfall amount there are distinguished wet and dry subtropics. Rich vegetation in the wet subtropics is represented by broad-leaved forests (oak, hornbeam, beech) and evergreen shrubs. A very small portion of Northern Eurasia is included into this zone.
- **Glaciers** are a natural accumulation of ice mass mostly self-moving. Section 3.6.1 describes this zone in detail.
- **Mountain regions.** Four types of vertical belts are identified in these regions: Arctic tundra; tundra-taiga; forest-meadow; and subtropical and desert belt. The foothills and mountainous zones with greatest biodiversity (such as the Caucasus, Tyan Shan, and Altai) are the areas where human population pressure may lead to the most pronounced land-use change. Overgrazing, trampling, and nutrient pollution deposition tend to destabilize vegetation, leading to erosion and loss of soil. The high levels of endemism in many montane floras and their inability to migrate upward means that these species are most vulnerable.
- The **coastal zone** in Northern Eurasia is extensive (Figure 2.5). It contains over 40% of the entire population of Northern Eurasia and more than a half of its economic resources. Capitals of several countries of the region (Stockholm, Helsinki, Tallinn, Riga, Baku, and Istanbul) and major industrial centers (St. Petersburg, Odessa, Rostov, Arkhangelsk, Vladivostok, Sapporo, to mention a few) are also located in this zone. In the coastal zone, tendencies of increasing population, economic activity (especially prospecting and exploitation of oil and gas fields), sea level rise, degradation of sea coast due to wave and thermal erosion, denudation, slope processes, and pollution of the coastal bays (especially in the river deltas near large cities) are intensifying.

2.7. Natural variability, anthropogenic impact, environmental and climatic changes in Northern Eurasia

Over the past 5,000 years, the climatic changes in Northern Eurasia were among the largest in the world (Wigley et al. 1981; Lamb 1988; Klige et al. 1998; Selivanov 2000; Jones et al. 2001). Global warming reported by instrumental observations during the past century was also largest in the interior parts of Northern Eurasia [IPCC 2001]. During last few decades mean annual temperature in these regions has increased by 3K, more than anywhere else (Figures 2.2 and 2.7).



a. b. c.

Figure 2.7. Zonal and North Eurasian surface air temperature changes during the past 120 years. (a) global (for zone from 60ºS to 90ºN); and regional surface air temperature area-averaged over Northern Eurasia: (b) annual and (c) seasonal time series. [Data source: CDIAC; Archive of work of Lugina et al. 2003].

Finally, model projections of the future climate changes related to increasing of greenhouse gases in the atmosphere show that this region has the greatest change response (IPCC 2001). Changes in the surface energy balance are accompanied by changes in terrestrial hydrology. In the continental boreal climate of Northern Eurasia, temperature changes directly affect the duration of the frost-free, snow-free, and growing seasons, and thus cause changes in evapotranspiration.

Further, this part of the world is “protected” by mountain ridges from the direct influx of water vapor from the tropics except along the easternmost part of the Pacific coast (Kuznetzova 1978; Shver 1976). Major sources of water vapor in that area include the Atlantic Ocean, the Arctic Ocean, and their coastal seas. Large interior lakes like the Caspian Sea, Baikal, and (up to the recent years) the Aral Sea also contribute. Thus, the advection by extratropical storms is the major means of moisture transport. This makes precipitation conditions of the interior of Northern Eurasia highly variable and very sensitive to circulation changes. Thus, relatively modest changes in the global circulation of the atmosphere and ocean may substantially affect climate and environmental conditions in Northern Eurasia. Historically, small shifts in storm tracks resulted in enormous variations in water balance of interior lakes, in deep ground water circulation systems, and in corresponding shifts of the ecosystem boundaries. Paleoclimatic, archeological, and historical records indicate propagation of forested and steppe areas far southward into the desert and semi-desert areas during “wet” epochs and their retreat and desertification during the prolonged periods of insufficient precipitation. These changes were quite swift (with a time scale of several decades) and were accompanied by prosperity and/or collapse of local agricultural and nomadic civilizations (Wigley et al., 1981; Lamb, 1988; Gumilev, 1990; Kaplin and Selivanov, 1995; Pirazzoli, 1996; Selivanov, 2000; Jones et al., 2001; Kobak et al. 2002; and many others).

Because of the short growing season in the north, most agricultural production in Northern Eurasia is concentrated in the southern part of the region in the forest-steppe and steppe zones. These zones are the regions of increased societal water demand (Vörösmarty et al. 2000). Unfortunately, most of agricultural fields and pasture in these zones are not irrigated and are prone to frequent droughts. Water availability has become a central issue for social and ecological sustainability. Regretfully, conclusions derived from present Global Climate Models are dissimilar when addressing the water cycle changes over the region. The sources of these differences must be carefully assessed and resolved in the future.

During the past century, the anthropogenic impact on the environment has been significant. Deforestation, soil degradation at the agricultural fields, intensive industrial development, conversion of the natural environment into agricultural land and pasture, urban development, water withdrawal, irrigation, and man-induced forest fires have changed landscape and thus impacted regional ecosystems and climate. The state-run centralized economy of the former USSR and other countries of the region significantly enhanced the anthropogenic impact that, in many cases, had unforeseen negative consequences (e.g., Box inserts A2.1 and A2.2).

Box insert A2.1. Figure 2.8 shows one of the many striking effects of human activity on the region. Only forty years ago, the Aral Sea was the world's fourth largest lake and the second largest lake in Central Asia. In 1949, it had a surface area of 66,000 km^2 with an average depth of 16 m and maximum of 68 m. Its waters supplied local fisheries with annual catches of 40,000 tons. The deltas of its major tributaries hosted dozens of smaller lakes and biologically rich marshes and wetlands covering a total of 550,000 ha. Anthropogenic impact in the Aral Sea area began long before the past century. But, during the last fifty years, the Aral Sea has virtually dried up. The water level dropped 14 m, the lake surface decreased to 26,000 km^2, and water salinity reached 25-30 g/L that resulted in the loss of all fish species. Today, the Aral Sea is literally disappearing from the world map. Extensive water withdrawal from the major rivers that feed the lake caused this ecological disaster. If water withdrawal occurs at the present rate, most of the Sea (greenish area in the center) will evaporate in the next 10 years. The exposed seabed consists of vast salt tracts, whose sand and dust, polluted with pesticides, are carried by the wind up to a distance of many hundreds kilometers at an estimated rate of 15 to 75 million tons a year. During dust storms this mixture can cause ecological consequences in regions windward of Northern Eurasia. In Section 3.4, we discuss these issues and other examples of human alteration of major ecosystems in Eurasia in greater detail.

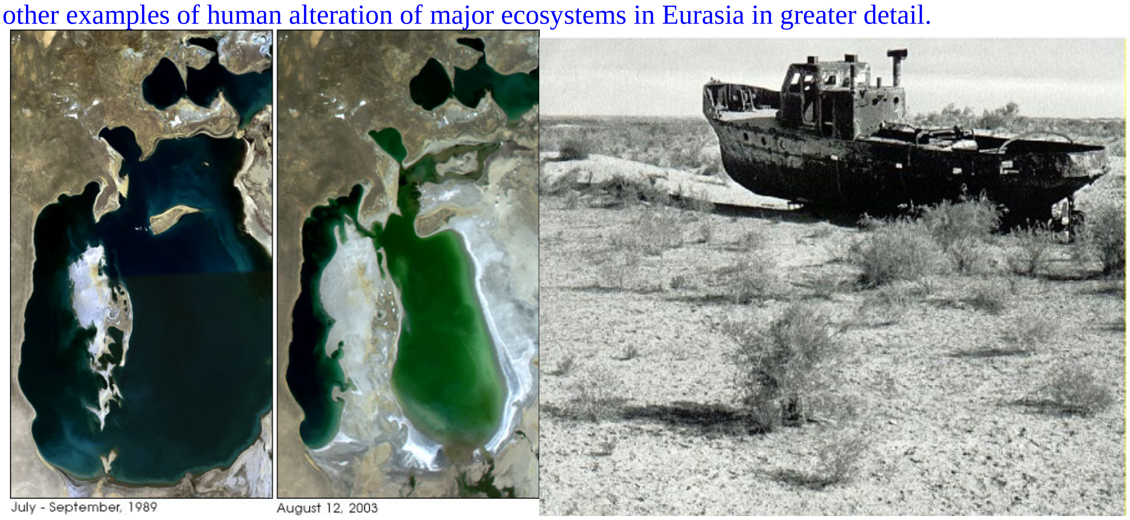


Figure 2.8. Remains of the Aral Sea in 1989 (left) and in 2003 (center). On the satellite images, dark colors represent areas that are still covered by water and white color shows the salt-covered dry bottom that is quite fresh and has not yet been mixed with sand.

Box insert A2.2. The Caspian Sea is the world's largest lake. It does not have outflow and thus is salty. Most of its influx (~80%) comes from the Volga River that has been covered by a set of reservoirs during the 20th century. These reservoirs and water withdrawal for irrigation and other types of water consumption caused a systematic decrease in the River streamflow that affected the Sea level, and thus the coastal zone, fisheries, urban development, and transportation. During the past sixty years, Figure 2.9a shows a relatively stable Sea level up to the late 1970s and then an increase in the Sea level that would have happened without the anthropogenic impact. However during the 1950-1980 period, this natural process had been temporarily reversed by the regional anthropogenic impact misguiding the water managers. The misjudgment caused enormous economic and environmental losses when protective measures "to save the Sea" (the dam construction to separate the Kara-Bogaz-Gol Bay from the Sea) were implemented and finally failed.

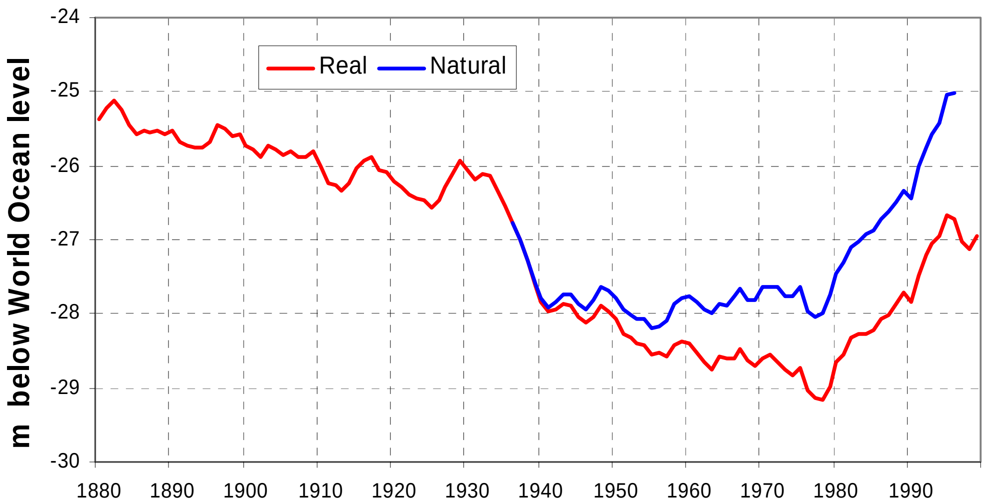


Figure 2.9a. Observed and "natural" changes of the Caspian Sea level (Shiklomanov 1976; Shiklomanov and Georgievsky 2003). "Natural" changes are the changes that would have happened if there were no anthropogenic impacts on the river inflow into the Sea.

Figure 2.9b. Northern part of Kara-Bogaz-Gol Gulf, Turkmenistan. Left on 9 September 1985, Right on 3 June 2000. The total current area of the Gulf is ~12,500 km^2, with an average depth of 10 m. The Gulf is quite shallow, which causes even more dramatic changes in the water level than can be seen along the coast of the Caspian Sea. In 1984, the Gulf was completely dry due to dam building to stop the Caspian Sea level decrease. When the water in the Caspian Sea began to rise again, an aqueduct was built so that the Gulf water level could rise again [Source: CALMIT/LNL].

All global climate models, when used to assess the scenarios of future changes in chemical composition of the atmosphere, predict a significantly and disproportionately high rate of warming over Northern Eurasia. Most of the models also predict an overall precipitation increase in high latitudes, but increasing soil dryness in the interior regions of the continent (already arid) during the summer (IPCC 2001; Mokhov et all. 2003). These changes will shift climatic zones, and have affects on a) the spring onset and duration of the growing season, b) periods of snow cover, and c) periods with GPP. *It is probably too early to speak about shift of climatic zones, but other projected changes are already occurring.* Specifically, during the past century, the regional annual mean temperature has increased by more than 1 K and by ~0.5 K in summer (Figure 2.7); this regional warming was steady and during the past several decades has accelerated (Figure 2.2). During the same century, precipitation over the former USSR territory has increased by ~ 5 to 10% (Groisman 1991; Gruza et al. 1999; Groisman and Rankova 2001). Regionally, a steady precipitation increase was observed in Scandinavia and Eastern Europe, no rainfall increase was observed in Central Asia, and non-linear changes were documented for Eastern Siberia: a notable increase during the first half of the past century was followed by a slight decrease during the past several decades and notable changes in precipitation intensity (Groisman 1991; Gruza et al. 1999; Figure 2.10). Dryer conditions were gradually introduced during the past century in the steppe areas of Western Siberia and Kazakhstan (Figure 2.11). Earlier spring onsets and earlier spring snow cover retreat were documented over Eurasia (Bulygina et al. 2000c; Brown 2000; Groisman et al. 1994; Figure 2.12) and specifically over all mountainous systems of Northern Eurasia (e.g., Figure 2.13). More winter and spring thaws in the eastern half of Northern Eurasia was a result (Groisman et al. 2003a). A significant continental increase of streamflow into the Arctic Ocean and the Caspian Sea was observed (Box insert 2.2; Figures 2.9a, 2.14, and 2.15). Since the second half of the 20^{th} century, a man-induced

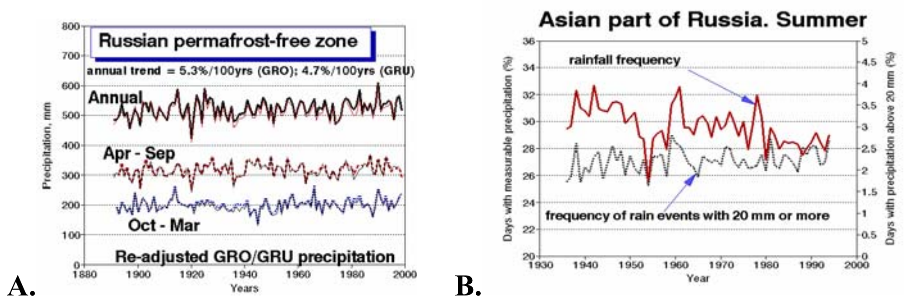


Figure 2.10. Precipitation changes over the major permafrost free zone of the Russian Federation (Groisman and Rankova 2001). (B) Summer frequency of wet days and days with heavy rains over Siberia (Sun and Groisman 2000).

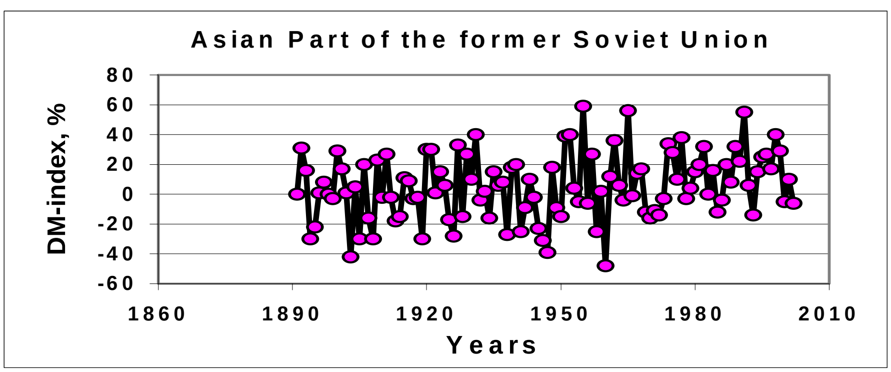


Figure 2.11. Time series of the DM index for May, June, and July over the major cereals-producing region of the Asian part of the former USSR (western Siberia and northern Kazakhstan). Area differences, in percent for the period 1891-2002 are updated from Mestcherskaya and Blazhevich (1997) and characterize the spread of dry conditions over the region. The observed linear trend (16%/100yrs) is statistically significant at the 0.05 level.

degradation of dry lands has increasingly contributed to the desertification process. In several regions of Central Asia, Mongolia, and Northern China, this process is currently under way (Kust 1999; Zolotokrylin 2003; Erdenejav, 2000; 3.6.3). It occurs mostly over arid and semiarid lands, but sometimes also over dry sub-humid lands that have been degraded by human activities. Analyses of the desertification monitoring data during the past two decades using remote sensing tools (NDVI) gave the following results. The northern limit of the area subjected to the desertification process in Central Asia has remained stable. The area expanded southward as a result of draining the Aral Bottom and landscapes of the Amu-Darya and Syr-Darya delta plains. Comparison of the past decade (1992-2001) to the previous decade (1982-1991) revealed a tendency of reduction of the desertification in the Caspian Lowland and its intensification in the areas between the Aral Sea and Lake Balkhash (Zolotokrylin 2003).

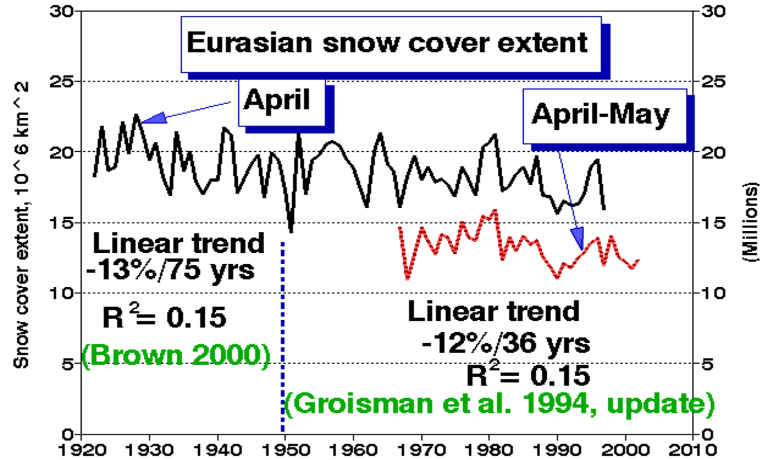


Figure 2.12. Eurasian snow cover extent in late spring (April, April-May) according to reconstruction by Brown (2000) and satellite visual imagery (Robinson et al. 1993; Groisman et al. 1994, updated).

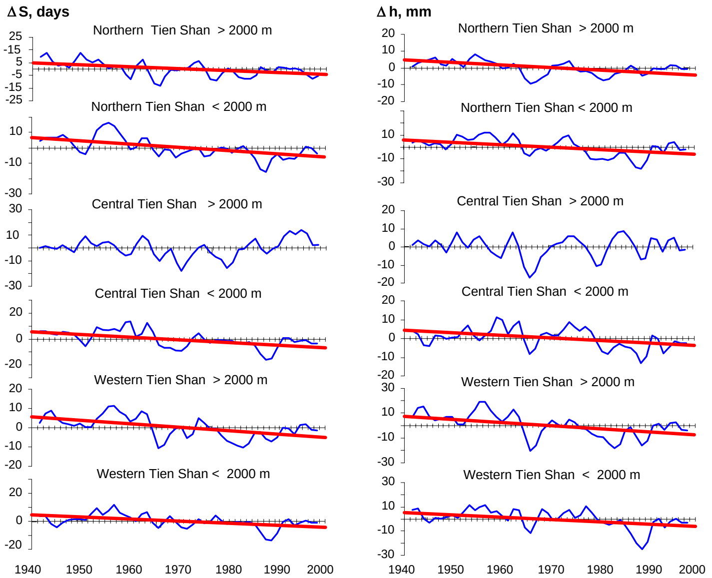


Figure 2.13. The snow duration ΔS and snow thickness Δh changes in Tien Shan (Aizen et al. 1997a).

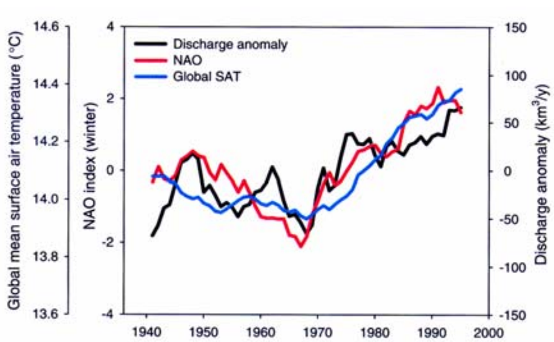


Figure 2.14. Eurasian Arctic river discharge anomalies (Peterson et al. 2002).

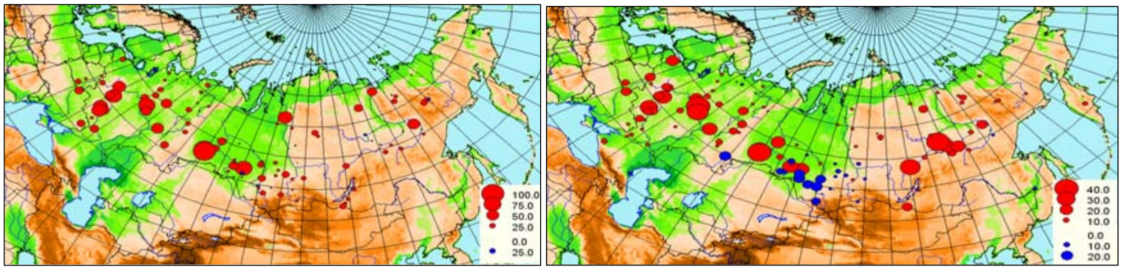


Figure 2.15. Resent changes in North Eurasian streamflow. Deviations (%) of winter (left) and annual (right) runoff for 1978-2000 compared to the long-term mean for ~ previous 55 years. Georgievsky et al. (2003). Note that the scales of changes are different in these two maps.

Besides climatic changes, significant environmental changes have occurred over Northern Eurasia during the past century. Among the most prominent are:

- Lake level changes, including the first and forth largest lakes in the world, Caspian and Aral Seas (Figure 2.16; Box inserts A2.1 and A2.2);

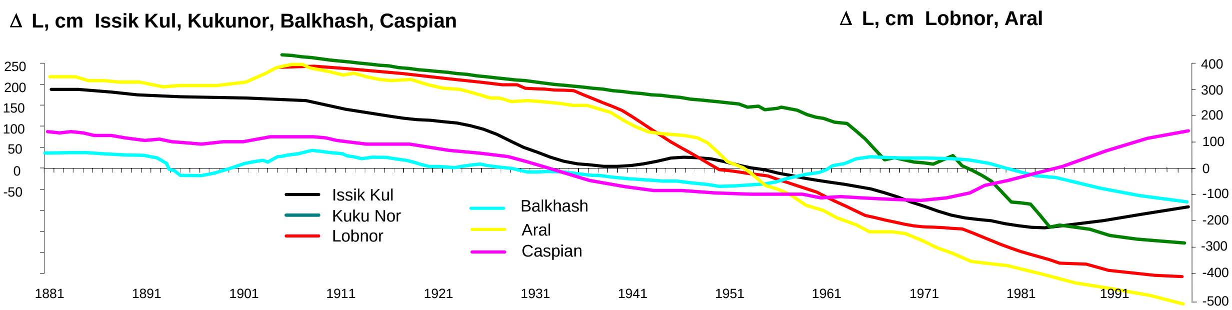


Figure 2.16. The lake level changes in Central Eurasia north of 40°N (instrumental data)

- More frequent droughts and forest fires (Figures 2.11 and 2.17)
- Large scale irrigation projects in Polessie, southern Russia, Ukraine, and Central Asia
- Construction of numerous dams, channels, river regulation, water withdrawal and consumption, streamflow changes, and snow melioration
- Conversion of “virgin lands” (mostly steppe of Kazakhstan, Ukraine, and Russia) in agricultural land (some of them have been gradually abandoned in the past decade);
- Intensive logging, man-caused fires, and fire suppression;
- Large scale reforestation projects in southern Russia and The Ukraine (forest-protection stripes)
- Land withdrawal for urban and industrial development
- Changes of air, soil, and water quality in the areas around industrial centers as well as far downstream (and downwind), especially in the regions affected by the air transport from industrial centers of Western Europe
- Acid rains
- Inadvertent (or ill-conceived) negative anthropogenic changes: soil erosion; degradation of fallow fields overgrown with shrubs; drainage of bogs and bogged forests in attempt to increase the forest productivity; removal of the upper soil layer in tundra and the permafrost zone for road and pipeline constructions; logging in the water-protection forest areas; woody debris remains after logging, along the rivers’ and lakes’ banks and sea shores (which are potential CO_2 source and disturb flood regimes and runoff); dams and reservoirs that lead to bogging the adjacent territories; introduction of agro-mono-cultures (e.g., cotton in Central Asia); overloading soils with chemical fertilizers; livestock waste infiltration into ground waters and rivers; deflation after pasture overloading; etc.

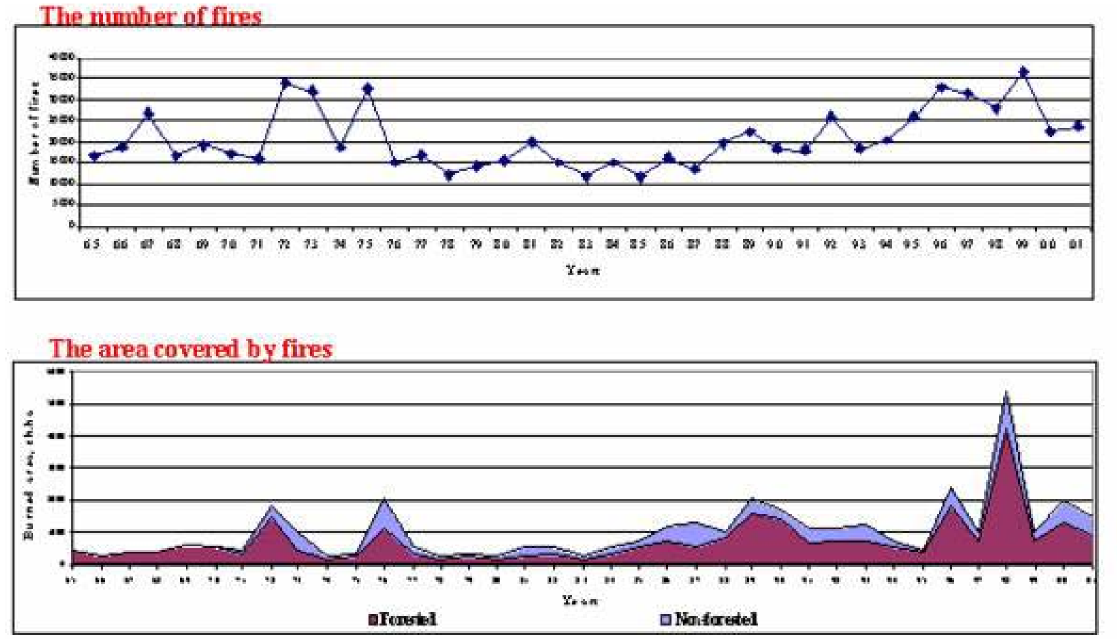


Figure 2.17. Dynamic of fire numbers (top) and the area covered by fire (bottom) in Russia during the 1965-2001 period.

Most of the above listed changes have been caused, at least in part, by HA and thus, are *forced* changes. To reveal the climatic component in these changes is not a trivial task (see however, Box inserts A2.2 and 3.6.1). However, each of these environmental changes did occur. They interacted with climate, influenced, and were influenced by it. **The future regional models (blocks of the global change models) that seek a realistic description of the past changes in Northern Eurasia and their global feedbacks must, therefore, include a changing external forcing and internal feedbacks that characterize these environmental changes**. A vague name for these changes is a *land cover change forcing*, although not all of them affect the land cover itself (IPCC 2001; Pielke 2002).

Historical vegetation changes were more dynamic in southern regions with an earlier beginning of agricultural activities: in the forest-steppe and steppe zone in East Europe (Dinesman 1977; Serebryannaya, 1982), in the foothills of the Caucasus, and in south of Mongolia (Dinesman and Savinetsky 1997; Savinetsky 2000), in Central Asia (Klige et al. 1993, 1996), on continental dunes in the interior of Poland (Jaskovski, 2002), and generally over the interior of Eurasia (Selivanov 1994, 1996, 2000). In other words, natural changes in these regions were grossly enhanced by anthropogenic impacts much earlier than it could be anticipated. The above-mentioned regional models should, therefore, account for the HA impact even when used to reproduce the pre-industrial epoch in these regions. For example, one of the most famous environmental changes in the history of Medieval Central Asia (diversion of the Amu-Darya streamflow from the Caspian Sea to the Aral Sea) was made by the Mongol army during the siege of Khoresm City in the 13th Century.

To complete the story, it should be emphasized that significant environmental changes occurred over Northern Eurasia during the past 6K years, when the most vivid impact of the last glaciation was mostly gone and the global climate did not vary too much. Nevertheless, in Northern Eurasia shifts of climatic zones by several hundred km, intra-area changes in species composition, substantial variation in lake levels and the areas and humidity conditions of arid, semi-arid, and steppe zones were documented. These last zones seem to be the most volatile in the past millennia (Kobak et al. 2002; Zubakov and Borzenkova 1983;

Khotinsky 1977, 1984; Selivanov 2000; Kozharinov and Puzachenko 2004; Table 2.1; Figure 2.18).

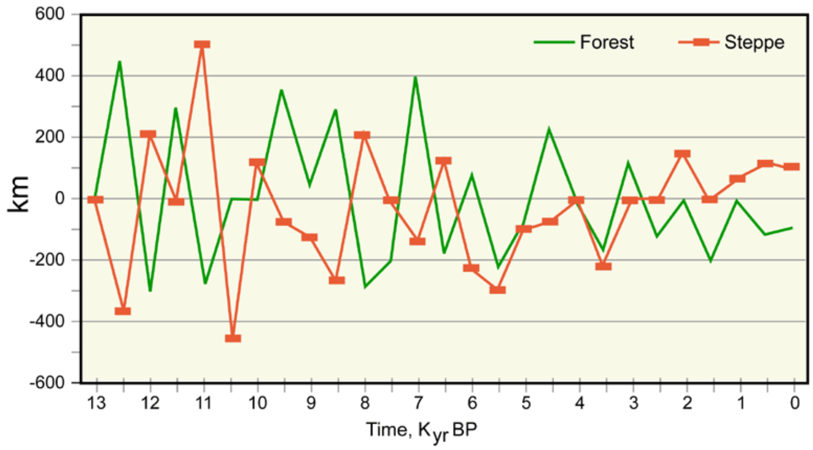


Figure 2.18. Changes of the northern boundaries of forest and steppe zones along the 39°E during the past 13 thousand years (Kozharinov and Puzachenko 2004).

Table 2.1. Phytomass and Net Primary Productivity (NPP) of Siberian vegetation in the mid-Holocene and in contemporary climate (Monserud et al. 1995).

Vegetation Type	Areas, Mha		Phytomass, Pg		NPP, Pg yr^{-1}	
	mid-Holocene	Present	mid-Holocene	Present	mid-Holocene	Present
Tundra and Mountain tundra	67.2	142.2	1.29	2.73	0.23	0.48
Forest-Tundra (spruce, larch)	23.8	18.4	1.02	0.79	0.09	0.07
Forest-Tundra (larch)	39.9	16.5	1.73	0.72	0.19	0.07
Dark north taiga (spruce, larch)	132.1	56.6	14.14	6.06	0.87	0.37
Light north taiga (larch)	35.5	118.3	1.89	6.3	0.19	0.63
Dark middle taiga (cedar, spruce)	167.1	56.4	31.39	10.6	1.32	0.45
Light middle taiga (larch, pine with spruce)	124.1	189.5	17.13	26.16	0.81	1.24
Dark south taiga (Fir, spruce, pine)	86.9	76.6	17.84	15.73	0.68	0.6
Dark mountain forest	36.4	44.0	4.36	5.27	0.24	0.29
Birch sub-taiga	18.8	19.6	3.45	3.59	0.24	0.26
Birch with broad-leaf species	14.1	0.00	2.63	0.00	0.15	0.00
Light subtaiga (larch, pine with linden and steppe)	26.7	20.3	4.39	3.34	0.22	0.17
Birch forest-steppe	16.3	48.2	0.96	2.83	0.14	0.42
Forest-steppe (birch, pine)	11.0	3.6	1.14	0.37	0.04	0.1
Mixed grass mesophytic steppe	91.8	76.6	1.57	1.31	1.57	1.31
Semidesert and desert	4.6	9.5	0.04	0.07	0.03	0.06
Total	896.3	896.3	104.97	85.87	7.01	6.43

Some dominant species of the modern boreal forest existed in their territories during the Late Pleistocene and Holocene (Vygodskaya et al., 1995; Kozharinov and Puzachenko, 2002). For example, a dominant species of the modern European dark-leaf taiga *Picea abies* formed forests with co-dominant species across East Europe during the last 15 000 years. There were some changes within the communities, though. The main determining environmental factor of the spruce forest dynamics during the last 7 000 years was the heat and water supply (Kozharinov and Puzachenko 2002). Thus, *Pine sylvestris* forests in Poland preserved during a part of the Subboreal period were climatically unstable in the Subatlantic then, as well as now (Jaskovski, 2002). These, and similar "within the biome" changes occurring over large areas affect the large-scale biogeophysical and biogeochemical properties of the biome and thus, generate appropriate feedbacks.

By the mid-Holocene (4,500-6000 before present, BP), the main vegetation pattern in Northern Eurasia looked like the present (Khotinsky 1984; Monserud et al. 1998), although quantitative differences were noticeable (Table 2.1). During that period, the climate was milder and wetter (reconstructed January temperature were higher by ~ 3.7 ^{o}C, July temperature by ~ 0.7 ^{o}C, and annual precipitation was higher by 95 mm; note that the temperature changes are already close to those observed during the past century!). The forest border moved far northwards and some European warm-loving tree species, like linden and elm, advanced into West Siberia from the Ural. A distinct feature of vegetation cover in Siberia was more developed dark taiga on the east bank of the Yenisei River.

By the Late Holocene, 2,500-3,000 BP though, a Siberian tundra-forest border moved southwards. Larch and pine dominated the forests east of the Yenisei River and cedar dominated the forests west of the river. In the southern mountains, the dominating role of cedar and sometimes spruce in the upper belts increased; fir and spruce outcompeted light species like pine and larch in the middle belts. Both events were related to a moister climate (Nastchekin, 1975). It can be concluded that climate became more severe and caused these changes.