Scientific Background Appendix. Chapter 3

3.1. Terrestrial Ecosystem Dynamics .

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3.1.2 Ecosystem pattern and key features

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3.1.2.1 Tundra

The tundra biome occupies the Northern limit of the Eurasia. In Russia, the tundra biome occupies near 280 10^6 ha or 16% of total country area. The structure and functioning of tundra ecosystems are strongly governed by climate gradients and local geomorphology (Chapin et al., 2000), leading to complex mosaic of landscape types and intrazonal elements (Figure 3.5). Main landscape types in Russian tundra biome (Zamolodchikov, Karelin, 2001) presented by arctic deserts and arctic tundra (25% of total biome area), typical tundra (27%), south sub-arctic tundra (16%), forest-tundra (17%) and different variants of mountain tundra (16%). The vegetation cover is presented by different combination of dwarf shrubs, grasses, mosses and lichens. The canopy height is low usually not exceeding 30-50 cm. The aboveground biomass of specific plant groups is close correspondent to projective cover. This situation allows the two-dimensional view on production processes and facilitates the using of remote sensing techniques (Oechel at al., 2000a). The structure and functioning of tundra ecosystems are strongly affected by the presence of the perennially frozen ground. Physical, chemical and biological processes are strongly slowed down within the permafrost body under low temperatures. Warm seasons melt of a thin uppermost ground layer (called an "active layer") on the atmosphere/lithosphere boundary results in multifold increase and acceleration of these processes. A dynamics of active layer strongly depend on soil temperature behaviour, which is mostly driven by air temperature, solar radiation, albedo, heat conductivity of vegetative and soil cover, soil moisture, ground water mobility, snowpack thickness, etc. Particular combinations of these controls in different permafrost landscapes are rather variable, which makes it difficult to predict a permafrost dynamics at regional and global scale.

3.1.2.2 Forests

Forests are a significant global reservoir of the organic matter and a powerful regulator of water and energy exchange and biogeochemical cycle. A single country in Northern Eurasia, Russia, has 22 % of the global forest resources and 38% of the Eurasian forest resource (FAO 2001). The magnitude of the forest area suggests its role in the global climate system, as potential sink or source of atmospheric carbon (Stocks et al. 2002). It is difficult to overestimate role of forests as source of many goods of vital importance for human society, as a habitat for wild animals of taiga, as a natural habitat for indigenous population of the North. Distribution of forests over territory of the Northern Eurasia as well as forest composition and productivity are determined by temperature and humidity gradients, continentality and also by soil forming rocks and relief. About 75 % of forests are growing on permafrost, including regions of Central and East Siberia, as well as Far East. Significant part (41 %) of Russian forests is categorized as mountain forests therefore altitude is also important factor of forest distribution in Northern Eurasia.

The boreal coniferous forests are the dominant biome in the Northern Eurasia, and six tree genera mainly form forest stands: 16.0% of Russian forest area is covered by pine (*Pinus* sp.), 10.6 %- by spruce (*Picea* sp.), 36.6% - by larch (*Larix* sp.), 2% -by fir (*Abies* sp.), 12.9 %- by birch (*Betula* sp.), and 2.8% -by aspen (*Populus tremula*). In European part pine, spruce, birch and aspen are most representative. Ural and Western Siberia forests are dominated by *Picea obovata, Pinus sibirica*, and also by *Abies* sp. Eastward pine forests are widely distributed. In the Asian part of Russia, larch covers 38% out of total area in forest. Significant areas of birch- and aspen-dominated secondary forests are the result of extensive forest exploitation, mainly during 20^{th} century.

In Russia, most of forests (76%) falls within the southern (128 millions ha) and middle (461millions ha) taiga (Utkin and Zukert, 2003). The southern boreal zone has a dominance of conifers and scattered occurrences of the broad-leaved trees. A contribution of herbs and shrubs into the vegetation composition is relatively high. Both the middle and northern boreal zone have conifer dominance, with Birch spp. as the main deciduous trees. Herbs are mainly restricted to nutrient-rich sites. The northern boreal zone deviates from the middle boreal zone by the addition of a number of northern vascular plants and an abundance of willow Salix spp thickets as well as by higher abundance of bryophytes and lichens (Esseen et al, 1997).

Southward of zonal tundra, forest-tundra and sparse north taiga forests occupy large area (143 million ha) (Utkin and Zukert, 2003). In European part of Russia, Western Siberia and Krasnoyarsk region, southward of taiga, temperate forest (mixed and deciduous) are located and they transit to forest-steppe. Area of these forest is insignificant (3- 4% out of total forest area). Forests of steppe zone, semi-desert and desert amount to 1 -1.5% out of forest area. These south forests are dominated by oak on west and by birch and aspen on east.

The main source of information on geographical distribution of the forest over Northern Eurasia and its structure is national inventories. Accuracy and availability of these data significantly differ from one country to another. E.g. in Russia by 1998 the forest area inventoried with use of high resolution air photographs and selective field observation was 61%; about 24% were inventoried only by using of false-colour satellite photographs and 15% were inventoried by air visual survey at the 1950-60^{th} of 20^{th} century (mainly in remote unmanaged forests situated in forest tundra and sparse taiga zones). As the accurate and up-to-date data on forests is important input for number of the NEESPI research and development the creation of uniform and comprehensive database on forest cover for entire Northern Eurasia is considering among other priorities. The appropriate methods to derive qualitative and quantitative characteristics of the forests with use of earth Observation data combined with available in-situ information have to be developed to ensure data accuracy and reliability.

3.1.2.3 Grasslands and associated arid ecosystems

Grasslands, semi-arid and arid ecosystems, constitute a significant portion of total land area in Northern Eurasia and act as a "food basket" for the global population being the main area for agricultural production. These systems have experienced dramatic land-use changes over the last several decades. Over the last decade, these changes have accelerated due to policy reforms. The scale and magnitude of these land-use dynamics are relatively unknown (Desertification and Soil Degradation, Moscow, 1999).

Grasslands and arid ecosystems of Northern Eurasia are quite different and include the following biomes (from north to south) (Dobrovolskiy, Urusevskaya, 1984):

- Plots of grasslands inside broad-leaf forest and forest-steppe subzones with high annual grass productivity (5-8 t/ha), annual precipitation of 400-500 mm and evaporation ratio of 1.0-1.2;
- Steppe grasslands with extremely high annual grass productivity (12-15 t/ha), annual precipitation of 350-450 mm and evaporation ratio of about 0.8-1.0;
- So-called "true" or "real" steppes with very high annual grass productivity (8-12 t/ha), annual precipitation of 300-400 mm and evaporation ratio of about 0.6-0.8;
- Dry steppes with high annual grass productivity (5-8 t/ha), locally alkaline soils, annual precipitation of 250-350 mm and evaporation ratio of about 0.3-0.6;
- Semi-desert grasses and semi-sub-shrubs with weak annual productivity (3-5 t/ha), big areas of alkaline and saline soils, annual precipitation of 150-250 mm and evaporation ratio of about 0.2-0.3;
- Desert ecosystems with extremely weak annual productivity (<3 t/ha), areas of saline soils, annual precipitation of 50-150 mm and less and evaporation ratio below 0.2.

Besides these belt-like zones and subzones of grasslands and arid ecosystems, the specific biomes of grasslands, semi-arid and arid ecosystems are located to the pre-mountains regions of Altai, Sayan. Tyan-Shan, Pamir, Kopetdag, Caucasus, Ural and other mountains areas. The specificity of these biomes depends on the climatic conditions (prevailing winds, macro- and micro-climate), altitude, and soil-forming rocks.

In addition to the mentioned biomes it is necessary to withdraw that despite of the similarity of ecosystems in the belts, they differ also from the west to the east with the formation of so-called "facies changes" that occur as the result of the increase of climatic continentality and of the growth of the contrast between warm and cold year seasons.

The total annual productivity of grasslands ecosystems in Northern Eurasia is the highest among other ecosystems of the area. Also it characterized by the relatively high content of living biomass in the topsoil. The content of the dead organic matter (soil humus) is also very high in chernozem soils of the steppe regions (up to 900-1200 t/ha) and decreases to 50-100 t/ha in arid conditions. Despite of these features, the accumulation of dead organic matter in steppe area is much less than in forests and reach zero in deserts.

Another common feature of these ecosystems is the lack of water that increase from north to the south and limits the potential productivity. But in the regions of rivers deltas and other flood-lands or under the irrigation the annual production is large. Thus, these areas and the relatively northern grasslands are intensively used for agricultural purposes. Due to aridity, some regions, peculiarity, closed river basins, represent globally important geochemical accumulations of alkaline and neutral salts (Kust, 1999).

3.1.2.4. Peatlands are characterized by the unique ability to accumulate and store dead plant material originating from mosses, sedges, reeds, shrubs, and trees as peat, under waterlogged conditions. Peatlands have extremes of high water and low oxygen content and vary from low to high availability of nutrients. Peatlands are the most widespread of all wetland types in Northern Eurasia, representing up to 70% and even more of their area. Mire is a peatland on which peat is currently forming and accumulating. It is difficult to determine whether a mire/peatland ecosystem works as a sink or source of carbon at a given moment. This source/sink function can change from year to year with long- or short-term climatic changes working as a triggering mechanism. Paludified lands and forests having thin peat layer (<30 cm) are especially sensitive to such functional changes.

The Russian Federation possesses vast areas of peatlands (peat >30 cm) and paludified lands (peat <30 cm) estimated over 370 million ha, which make up over 20% of its territory (Vompersky et al., 1994; 1996). Peatlands cover 139 million ha (Vompersky et al., 1994; 1996) of the Russian Federation, which corresponds to 8,2% of the country given by State Land Inventory (Peatlands of Russia…, 2001). During two last centuries up to 0,85–1,5 million ha was disturbed by peat extraction, not less then 4 million ha drained for forestry, and up to 5 million ha (including over-moistened mineral lands) – for agriculture (Peatlands of Russia …, 2001). Comparatively not large to whole country territory these lands are concentrated in certain regions arising in some cases serious environmental problems. Nowadays many of them are not used, not restored and re-cultivated, thus have additional specific impact on the environment.

Peatlands of Northern Eurasia are extremely diverse and include a wide variety of peatland types, from tundra palsa and polygon mires to aapa mires, raised bogs, fens and swamps within boreal zone. They exist from the marine Baltic Sea cost throughout severe continental region in East Siberia and to monsoon Far East. They can be treeless or keep tree cover with commercial wood stock exceeds 150-200 $m^3 ha^{-1}$.

The basic data on Northern Eurasia's peatlands (area, geographical distribution etc.) is not yet sufficiently identified. Comparison and gap analysis of existing information on basic characteristics like peat covered area, peatlands type, peat depth and storage is still a key question for the problem strongly announced on the scientific level (Vompersky, 1994; 1999) and stated on the official one (Peatlands Action Plan …, 2003). There is a strong need to improve data on the peat covered area over Northern Eurasia considering nature diversity of the regions, peatland/mire typology and peat depth. Remote sensing data could make a valuable contribution to peatlands inventory and for hard-to-reach northern and eastern regions could have no alternative.

Peatlands provide a wide range of wildlife habitats supporting important biological diversity. They play an important role in maintaining freshwater quality and hydrological integrity, carbon stores and sequestration. Peatlands contain one-third of the world's soil carbon and 10 % of the global freshwater volume (Wise …, 2002). Only in Russia peatlands could store from 113.5 (Vompersky et al., 1996) to 210 Gt C (from the data for the USSR obtained by Botch et al., 1995), which make up 20–50 % of the world peatland carbon. Peatlands present high variety of natural conditions thus have quite different peat accumulation rate, contribution to the other components of the carbon balance, GHG emission etc. (Vompersky et al., 1998; Vasiliev, Titlyanova, Velichko, 1999; etc.). The accurate data on carbon and water storage, carbon accumulation rate, GHG emission for Russian peatlands must developed using adequate methodological approach to be worked out.

From a conservation point of view, it is important that most of the peatlands are relatively intact and offer a rare opportunity for conserving areas large enough to allow natural hydrological and ecological processes to occur. World largest peatland territories are West Siberian mire massif and Polistovo–Lovatsky mires are biggest in Europe. Russian peatlands support globally significant biodiversity, and provide a variety of hydrological and biogeochemical functions valuable to people throughout Eurasia.

3.1.2.5 Fresh water systems

Fresh water systems of Northern Eurasia consist of water objects of different rank (temporary watercourses, rivers, lakes, ponds, water reservoirs and underground aquifers) and connecting them in the process of water flows cycle together with abiotic elements and biota. On the territory of the former USSR only there are about 3 million rivers (Domanitsky et al., 1971) with total length exceeds 9.6 million km. The largest rivers are – Yenisei (average annual runoff 572 km^3), Lena (537 km^3), Ob (405 km^3), Amur (306 km^3). Among lakes small ones with areas of less than 1 km^2 also prevail. The Baikal Lake is the world largest fresh water body has 23 thousand km^3 of water volume. Fresh water systems are in close connection with different components of the environment (climate, geological structure of territory, relief, soil and biota) and human activity, which is the factor of formation and functioning of fresh water systems and water user. Important role in functioning and dynamics of fresh water systems belongs to their catchments.

Boundaries and state of Fresh water systems vary within broad limits depending on climatic conditions and impact of other factors, first of all anthropogenic ones.

Besides socio-economic functions Fresh water systems (rivers, interior lakes, and reservoirs) play very important role as factor of environmental sustainability as well as important link of global and regional cycles of carbon and other biogenic elements (chapter 3.2).

On vast and low populated territories of Northern Eurasia fresh water systems remain practically in the natural state and fulfil functions of biosphere sustaining. At the same time in the most populated regions the natural environment is to a great extend transformed by man, and problems of providing acceptable state of fresh water systems are very acute there.

In the natural state the majority of fresh water systems of Northern Eurasia belong to hydrocarbonate class with water mineralization of 200-400 mg/l. In the most populated regions hydrochemical composition of water is dramatically changed. As a result of discharge of sewage water and other waste of economic activity into rivers and water bodies almost all of them are polluted. Among the contaminants there are petroleum products, phenols, biogenic elements, salts of heavy metals. Because of low temperatures in the water the processes of self-purification in the majority of rivers and water bodies of Northern Eurasia go on slowly, that is why the fresh water systems are especially vulnerable. Biotic component of fresh water systems is also very vulnerable to external impacts including anthropogenic ones. At the same time it fulfils extremely important functions of regulation of fresh water systems state, their self-purification and self-recovering. In the best way fresh water systems fulfil their regulating, and to a considerable degree, resource functions as well when values of their parameters are close to the natural ones. The important task is identification of optimum between economic demands in water and biological resources of fresh water systems and their possibilities for restoration and keeping of medium formation functions by them.

The important index of fresh water ecosystem change is degree of transformation of structure and metabolism of biocoenosis or their ecological modifications (Izrael, Abakumov, 1991). In populated regions of Northern Eurasia many rivers and water bodies are in the state of anthropogenic ecological tension, ecological and metabolic regress by hydrobiological indices.

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3.1.3. Soils

No less important than plants are the soils' and soil cover. Soil climatic zonality is caused by changes in temperature-precipitation ratio from north to south. This results in gradual changes of major natural zones. In polar desert, the soil development is very limited due to the extremely severe environment. Cryozems and shallow weakly-developed soils characterize the zone. The tundra zone mainly is occupied by a diversity of soils, in which gleyzems prevail. It is important to note that deep peat soils are very limited in this zone, but gleyzems with shallow peat horizons (within 30-50 cm) extend widely. This illustrates that the tundra zone is too cold for deep peat formation. The share of gleyzems decreases due to better drainage conditions compared with the tundra zone. However, at the same time, the proportion of deep peat soils considerably increases following improvements in thermal conditions. The middle taiga contains a great portion of Al-Fe-humic and metamorphic soils. It is important to note that this zone favours conditions for the formation of sod organic horizons in soils and supports the development of deep peat. The southern taiga is widely occupied by texture-differentiated and peat soils. The temperate forest zone is dominated by texture-differentiated and metamorphic soils. This zone presents a mosaic of forest and meadow-steppe vegetation and is also characterized by the expansion of humic-accumulative soils. The steppe zone is occupied by humic-accumulative soils, and the semi-arid dry-steppe condition also favours them. Lastly, low-humic accumulative calcareous soils and a range of salt-affected soils, such as alkaline clay differentiated and halomorphic, occupy deserts (Stolbovoi, 2002. Soils; In: Stolbovoi V. and I. McCallum, 2002). As a result of heterogeneity of parent rocks, relief, vegetation and land use the variety of soils in each zone is much higher than the general picture of the climatic zonality described above.

Soils act as a reservoir for carbon in the form of soil humus. In this case any type of soil degradation as a rule leads to disengage of soil carbon to the atmosphere and the lack of such data provides mistakes in the modelling of global carbon cycle and global climate. Second point is that soils are the living place for more than 80% of terrestrial animals and act in this case as the necessary element for biodiversity conservation issues. And at last, soils act as a "shield" for litho- and hydro- spheres preventing their destruction and pollution and providing the sustainability of their chemical composition (Dobrovolskiy, Kust, 2003). Unfortunately, the new understanding of the role of soils in the biosphere is very young scientific concept and there are almost no data on soils on this issue. The most of soils data have been collected only for the agricultural and (much less) for forestry purposes; they were presented in the forms of land cadastre and not renewed for past 20 years. Moreover, these data are disintegrated, most of them were not published and are stored in "hard copies" in the storages of different organizations (Kust, Kutuzova, 2003). The conclusion can be made is that *there is a lack of present uniform soil data available to use for the adequate assessment of the real role of soil cover in the environmental changes of Northern Eurasia*

The rigorous continental climate over significant part of Northern Eurasia is the reason for permafrost formation, which occupies an area greater than 10 million square kilometers. In the European part, permafrost occurs only in the tundra and the forest-tundra zone. In Siberia and Far East to the east of the Yenisei the permafrost is spread almost everywhere, except for south Kamchatka, Sakhalin Island, and Primorjie. The following types of permafrost are distinguished on the basis of how they are propagated (Kotlyakov and Khromova, 2002. Permafrost; In: Stolbovoi V. and I. McCallum, 2002):

Continuous permafrost is distributed throughout the northern part of the Bolshezemelskaya tundra; on the Polar Urals; in the tundra of West Siberia; in the northern part of the Middle-Siberia tableland, on Taimyr Peninsula, Severnaya Zemlya, Novosibirskie Islands, Yano-Indigirka and Kolyma lowlands; in the mouth of the river Lena; on the plain of Central Yakutiya and on Prilenskoe plateau; on the Verkhoyanskii, Cherskii, Kolymskii, and Anadyrskii ranges, on the Yukagirskii tableland, and on Anadyrskaya plain. The thickness of perennially frozen layers is around 300–500 m and greater; a maximal thickness of 1,500 m was recorded in the basin of the river Markhi, which is one of tributaries of the Vilyui River. As a rule, the rock temperature varies from –2 down to –10°C, but sometimes it can be lower.

Discontinuous or sporadic permafrost occurs in the Bolshezemelskaya and Malozemelskaya tundras; on the Middle-Siberian tableland between the rivers Nizhnyaya and Podkamennaya Tunguskas; in the south part of the Near-Lena plateau, and in Zabaikaljie. The thickness of the layers here varies from 10 to 150 m, but sometimes reaches 250–300 m. The temperatures are usually from –2 up to 0°C.

Insular permafrost occurs on the Kola Peninsula; on the Kanin Peninsula; and in the Pechora River basin; in the taiga zone of West Siberia; on the south of the Middle-Siberian tableland, along the coast of the Sea of Okhotsk; and on Kamchatka. The thickness of the layers is from several meters to several tens of meters, and the temperatures are close to 0°C. Insular permafrost occurs in the mountains, frequently along the periphery of regions of contemporary glaciations.

3.1.4 Driving forces of the large-scale ecosystem dynamics

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***Tundra ecosystem*.** The dynamic of tundra ecosystem caused by climate change, considerably varying between different Arctic regions (Serrese et al., 2000) and resulting in both positive and negative feedbacks in "permafrost – active-layer – vegetation – atmosphere – climate" interactions (Chapin et al, 2000). As an example, tundra landscapes in Alaska (USA), North-European Russia and East Siberia under local warming converted to source of carbon dioxide to atmosphere (Oechel et al., 1993, 1995; Zimov et al., 1996; Zamolodchikov et al., 2000) and presented the positive feedbacks to Global Changes. Far-East tundra increased the carbon sink activity and provided the negative feedbacks (Zamolodchikov et al., 2003). *The described situation stresses the necessity of the development of adequate methodological base to generalize known effects on permafrost area of Northern Eurasia.*

The system of climate-tundra feedbacks includes not only the carbon dioxide balance. The lakes and overhumidified tundra soils are important sources of methane fluxes (Zimov et al., 1997). The climate changes can lead to increase of unfrozen periods and stimulate the methane emissions. On the contrary, the drying of climate results in restricting of tundra wetlands and correspondent decreasing of methane emissions. Additional problems in prediction of tundra biome dynamics are created by changes of feedbacks hierarchy under long-term climate influence with stimulation of negative feedbacks (Camill and Clark, 2000; Oechel et al., 2000b). *To improve conclusions of climate change effects on tundra ecosystems, it is necessary to have more observations on the system functioning in different regimes over long-term scales.*

The specific question is the current destruction of shores of Arctic seas. In Siberian Arctic the ground of coast and islands contain considerable amount of ice. During the summer melting of the ground ice the coast is destroying very quickly. The speed of coast destruction can reach 10-20 m per year with preliminary estimation of average level 6 m per year (Semiletov, 2001; 3.6.2). During this process the terrestrial substances enter the seawater, affecting the biogeochemical cycles in marine ecosystems. *The scales of coast destruction and ecosystem effects need to be investigated.*

The frequency of tundra fires was expected to increase during global warming (Oechel, 1993). The recent catastrophic fire events in Far-East part of Eurasian tundra confirm above prediction. Tundra fires often lead to complete destroying of aboveground vegetation cover and up to 15 cm of top organic soil horizons. The direct CO_2 emissions from tundra fires constitute up to 50 tC ha^{-1}. The most of tundra territories in Russia are not fire protected, which is leading to absence of data on fire events and burnt areas. The period of post fire regeneration of carbon pool in vegetation is near 10 years, in soil near 100 years (Zamolodchikov et al., 1998). *The up to date and accurate data on tundra fires, including burned area and fire severity have to be collected on the regular basics.*

The important part of tundra ecosystem is reindeer populations as major consumer of net primary production. The reindeer husbandry presents the base of life for many native people, among them Nenets, Evenks, Chukchi and others. At present the reindeer husbandry in Russia is in deep depression, the total population of domestic reindeers decreased from 2.5 to 1.5 millions during last ten years (Jernsletten, Klokov, 2002). The reasons are both natural and social. *The system approach to studies of tundra biome demands the consideration of reindeer population dynamics as possible object for optimization* (3.4).

The industrial influence on tundra biome is expressed mainly in resource exploration and pollutions (3.4). The total tundra area damaged by anthropogenic factors, extending from the Kola Peninsula to Chukotka, is about 470 000- 500 000 km^2 (Kryuchkov, 1990). The damages are frequently associated with acidifying pollutants, heavy metals, other toxic substances, and with land disturbance (AMAP Assessment report, 2002). Large-scale dispersion of heavy metals has been observed on tundra areas. The metals most concern about effects in the Arctic are mercury, cadmium. They are present at high levels for a region remote from most anthropogenic sources. The processes of industrial exploration present essential threats to ecosystem structure and functioning (Forbes et al., 2001). The exploitation of gas in Yamal, oil in South Chukotka and coal in Vorkuta region (Virtanen et al., 2002) are among major examples. Any types of building and transport activity in tundra lead to disturbances of vegetation cover and hydrological regimes, by this way changing of soil heat conductivity and permafrost degradation. The analogical processes are observed in polluted zones in Cola peninsula and southern part of Taymyr peninsula. *The remote sensing technique is considered as most appropriate to estimate the impact of human caused disturbances on regional scale* (Virtanen et al., 2002).

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Forest ecosystem. The current pattern of forest vegetation reflects the combined effects of anthropogenic and natural disturbances over a range of time scales. Nowadays the growth of forest trees and the functioning of the forest ecosystems are affected by multiple stresses as a combination of climate change and disturbances. Forest ecosystems of northern Eurasia are subjected to climate changes that may result in changes in length of growing period and snow cover, production and vegetation carbon storage enhancement, replacement of tundra with boreal forest, warming permafrost and fire frequency increase. But, recently an increasing number of studies have been revealing advances in the onset of phenological spring phases from 1 to 3 days per decade that are related to air temperature (Menzel and Fabian, 1999; Bradley et al., 1999; Menzel, 2000; Chmielewski and Rötzer, 2000; Rötzer et al., 2000; Menzel , 2003**).** Changes of the length of the growing season for the northern hemisphere which have been derived from CO2 records (Keeling et al., 1996) and satellite data at relatively coarse spatial resolution (Myneni et al., 1997) generally confirm analyses of phenological data. However, the data which demonstrate opposite trends also exist (Kozhevnikov,1996; Kullman,1996; Minin,2000; Hogda et al, 2001; Kozlov, Berlina, 2002). some observations in Northern regions were already said to contradict the general predictions on global warming (Normile, 1995; Polyakov et al. 2003)

Thus, there still exist major uncertainties in predicting of the length of the growing season changes. The accuracy of predictions can be increased by the coordinated investigations of past changes in both biotic and abiotic environment (Houghton et al, 1996) taking into account regional variations.

Analyses based on satellite data suggest that both production and vegetation carbon storage have generally been enhanced across the boreal forests in recent decades (Myneni et al, 1997; 2001; Randerson et al, 1999; Zhou et al, 2001), an observation that is consistent with climate warming. One hypothesis for the mechanism of increased production is that warming increases decomposition of soil organic matter to release nitrogen in forms that can be taken up by plants. Since production is often limited by plant nitrogen supply in boreal forests (Van Cleve and Zasada, 1976; Van Cleve et al., 1981; Chapin et al., 1986; Vitousek and Howarth, 1991), an increase in nitrogen availability to plants should increase production. Several boreal warming experiments and modeling studies have provided support for this mechanism (Van Cleve et al., 1990; Bonan and Van Cleve, 1992; Bergh et al., 1998; Stromgrem and Linder, 2002; Clein et al., 2002). Increased N deposition, management changes, increased CO_2 are also possible explanations for these records (Erisman and de Vries, 2000). Increased accumulation of soil organic matter in European forests has also been observed. One of hypothesis is that increased N deposition causes an increased rate of soil organic matter accumulation due to an increased biomass of assimilative organs and litter production and a reduced decomposition of organic matter (Berg and Matzner, 1997).

The hypotheses explaining production and carbon storage enhancement across the boreal forests in recent decades have not been critically evaluated for ecosystems in northern Eurasia.

The replacement of tundra with boreal forest occurred in earlier warm periods of Holocene in northern Eurasia (MacDonald et al., 2000). Over the last half century, treeline advances into tundra have been documented in Alaska (Cooper, 1986; Suarez et al., 1999; Lloyd et al., 2003; Lloyd and Fastie, 2003), Canada (Morin and Payette, 1984; Scott et al., 1987; Lavoie and Payette, 1994). There are also some evidences of this phenomenon in Russia (Gorchakovsky and Shiyatov, 1978). Because significant part (41 %) of Russian forests is categorized as mountain forests investigations of tree line variations in mountains is of great importance.

Permafrost maintains a perched water table that keeps moisture in the root zone and maintains forest cover. Loss of permafrost is expected to increase soil drainage and may result in aridization in these areas and loss of forest cover. There are some indications that this process may have started already as river run-off to the Arctic Ocean increased during the last decades occurred even though the amount of precipitation remained the same or slightly decreased (Peterson et al. 2002). Additional processes, such as thermokarst may further impact the functioning of forests. The areas where permafrost has recently thawed, boreal forests have been replaced by grasslands and wetlands. (3.6.1).

While treeline advance and warming permafrost may effect on climate change, investigations of temporal and spatial variations of these phenomena are challenging.

Vegetation type and distribution have large impacts on regional and global climate through effects on terrestrial carbon storage (Smith and Shugart, 1993) and on water and energy exchange (Charney et al., 1977; Shukla et al., 1990; Bonan et al., 1992). Forest ecosystems through water/energy and radioactively active gases exchange with the atmosphere may respond to climate change in ways that tend to enhance warming (positive feedbacks) and through effects that tend to mitigate warming (negative feedbacks) (3.5; Smith and Shugart, 1993; McGuire and Hobbie, 1997; etc.). Increase in fire frequency has the potential to quickly release large amounts of carbon (Goulden et al, 1998; McGuire et al, 2003) (positive feedbacks), and these responses may more than offset increases in carbon storage that might arise from the slow expansion of boreal forests into tundra regions (negative feedbacks) (McGuire and Hobbie, 1997). On the other hand, fire may result in replacement of coniferous forests with deciduous forests with higher albedo. A longer growing season and reduced snow cover would decrease albedo and result in atmosphere heating (positive feedbacks). On the other hand, longer growing season in ecosystems of Northern Eurasia should enhance terrestrial carbon storage (Frolking et al, 1996). An expansion of temperate forests into regions now occupied by boreal conifers could also lead to negative feedbacks. On the contrary, replacement of tundra with boreal forest would decrease albedo and result in atmosphere heating. Climate change can generate both positive and negative feedbacks in "permafrost – active-layer – vegetation – atmosphere – climate" interactions (Chapin et al, 2000).

The present and future role of Northern Eurasia cannot be adequately understood without better knowledge of response of forest ecosystems to climate change. Of particular concern is the likelihood of amplifying feedback loop that can cause a further warming

Important changes in forest cover of the Northern Eurasia that may affect climate include changes associated with disturbances, such as fire, insect outbreaks, timber harvest, agricultural establishment and abandonment and air pollution. Human influences on the disturbance regime include both direct effects, such as harvesting or inducing and/or suppressing natural disturbances (fires, insects, flooding, etc.), and indirect influences from altering the forest environment. Indirect influences include both climate change and atmospheric pollution, and their effects on tree health and survival. Because of natural and human- induced disturbances forest area in Northern Eurasia is a gigantic mosaic of successions (Smirnova, 2004). The area of pristine forests dramatically decreased. European-Ural area, Russian cradle of slash-and-burn farming, metallurgy and timber harvest, is characterized by the most large-scale changes. In last three centuries land use and cuttings have resulted in elimination of more productive forests on the area of 70 million ha in European part of Russia (Utkin and Zukert, 2003).

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Periodically Northern Eurasia forests are subject to massive <u>insect infestations</u> that occur on millions of hectares causing forest dieback or damage. The outbreak of Siberian gypsy moth *Dendrolimus sibiricus superans* was identified mostly in taiga regions on areas from 8 to 10 million ha in 2001-2002, which is much higher than long-term averages (Isaev 1997, FSFMR 1998, Shvidenko and Goldammer 2001, GFMC 2003). These outbreaks are induced by a combination of favourable weather conditions (optimal temperature, low levels of precipitation and humidity) and occur with a periodicity of 15 to 25 years. Harsh climatic conditions have, thus far, limited the outbreaks to areas below 60^{o} north latitude. However, with increased warming, outbreaks may occur in the forests north of this line since desirable food species are available. *Adequate detection and mapping of insect outbreaks is essential for understanding of their impacts and the assessment of potential for northward expansion*.

The forests of northern Eurasia represent a wood resource of global significance. Forests are heavily managed for wood production and harvest resulting in losses of the organic matter and nutrients. In general, <u>forest harvest and management</u> results in lower vegetation and soil carbon stocks than equivalent unmanaged forests. For example, forests in Fennoscandia are so heavily managed for wood production and harvest that both vegetation and soil carbon are lower in comparison with other areas of the boreal forest (McGuire et al., 2002). Wood harvest could reduce carbon storage in Siberia's boreal forest (Rosencranz and Scott, 1992) and may have already done so in far eastern Siberia where illegal logging has apparently been increasing over the past decade. However, carbon loss from this activity, which results in the export of wood to China and other Asian countries, may be offset by the drop in legal commercial logging associated with the breakup of the Soviet Union. Legal timber harvest in boreal Eurasia has changed substantially since 1993 with all regions experiencing substantially lower harvest. The decline, as reflected in official statistics, has varied among regions between 40% and 60% of pre-1990 harvest rates.

Agricultural activities in northern Eurasia have also been changing rapidly over the last decade. According to official statistics 29 million ha of arable lands were lost in Russia from 1990 to 1999 (Russian Statistical Yearbook, M., Goscomstat RF, 642 pp). Ongoing analyses of satellite data indicate that most of the abandoned agricultural land is converted to young forest regrowth (Bergen and Zhao, 2003; Utkin and Zukert, 2003). While the abandonment of agricultural lands is likely increasing carbon storage in northern Eurasia, the increase has not been well quantified. *Because of the changing dynamics of logging and agriculture in northern Eurasia, it is important to understand how these disturbance regimes are changing throughout northern Eurasia to better understand net changes in carbon storage associated with these activities.*

Nowadays air pollution is important driving factor of forest dynamics. Accordingly modern hypotheses the growth of forest trees and the functioning of the forest ecosystems are effected by multiple stress as a combination of direct air pollution, indirect soil-mediated acidifying impacts of S , N deposition and eutrophication, and changes in weather conditions, either acting directly via drought or indirectly via pest infestation or fungi attack (Erisman and de Vries, 2000).

Currently in Europe S and NO_3 deposition has decreased strongly but the deposition of NH_4 stayed relatively constant in the past decades. (Erisman and de Vries, 2000). Although there has been a 50 % decline in industrial activity in Russia since 1992, pollution decreased by only 25 % and their impacts are still a severe problem. At the north end of the Siberian transect there exists the world's largest pollution induced forest decline caused by Noril'sk smelters. The most powerful in Northern Europe sources of atmospheric pollution, "Severonikel' and "Pechenganikel" smelters, are located in the Kola Peninsula. There are about 230 million ha of forested area at risk from sulphur and nitrogen deposition in Russia (Nilsson and Shvidenko, 1999).

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The different types of disturbances are often linked. For example, in some forest types the probability and intensity of fire may increase following insect outbreaks because of increases in available fuel. In other cases salvage logging (recovering the usable timber following a disturbance) can reduce the total area of living forest that is disturbed in a given year by all agents combined. It is common to try to replace natural disturbances (such as wildfires) with commercial harvesting, using a combination of protection and scheduled logging. In Sweden and Finland, for example, logging has become the main disturbance type; and large-scale natural disturbances resulting from wildfire, insect outbreaks, or storms have been almost non-existent for half a century (Lähde et al., 1999). The interactive effects of disturbances and climate change need to be studied.

Up to date large-scale dynamic processes in forests of Northern Eurasia have not been adequately explored. Forest ecosystem dynamics caused by multiple stresses as a combination of climate change and disturbances may result in changes of surface albedo, evapotranspiration, hydrological regime, carbon sequestration, and integrally in global climatic change.

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Fresh Water Systems. Climatic short-term and long-term dynamics is a one of the main forces of hydrological changes that are characterized by rhythms of different duration and amplitude (Belyaev, Georgiadi, 1992; Klige et al., 1998). From the beginning of 20th century and especially since 30th the increasing role begins to play the anthropogenic factor, which is imposed on natural variability.

Intensity of anthropogenic impact in river channels and in water bodies as well as on their catchments was constantly increasing during the whole 20th century till the 1980-1990th (Koronkevich, 1990). The fresh water systems of central and southern parts of Russian plain, southern part of Siberia and Western Siberia were characterized by extraordinarily high intensity of river runoff resources use. (Voronkov, 1970; L'vovich, 1974; Water Resources…, 1987; Shiklomaniov, 1989; 2002; Koronkevich, 1990, etc.). The state of fresh water systems was to a high degree determined by intensity and distribution of anthropogenic load in the watersheds. Expansion of arable lands, especially irrigated ones, increased use of fertilizers, the total number of cattle live-stock, etc., increase in industrial production accompanied with increased withdrawal of water from rivers and underground waters, return of waste waters, including not well purified, into rivers resulted in the fact that by the end of the 1980s the norm of annual runoff had decreased in different regions on 20-30 % (Shiklomanov, Georgievsky, 1995), and quality of water had noticeably deteriorated.

Consequences of socio-economic changes in the 1990s were of a completely different character. On the one hand, reduction of industrial and agricultural production with considerable changes of structure of land use reduced the anthropogenic load upon waters. For example, under decrease of industrial and agricultural production by the end of the 1990s up to two-three times as compared with threshold of the 1980-90s use of water in Russia decreased by 25-30% on the average (Koronkevich, Zaitseva, 2003). On the other hand reduction of nature protection, including water protection, activities and change of the structure of anthropogenic impacts upon water brought opposite results.

These changes were occurring against the background of climate dynamics, which were linked to the beginning of the global climate changes, resulting from the anthropogenic emission of greenhouse gases to atmosphere.

Available estimations of consequences of probable climate warming for Fresh water system, which methods of calculation still more not extremely enough, show, that, for example, conditions of river runoff formation, water regime of Fresh water systems can be changed essentially (chapter 3.3). Thus character of changes will be non-uniform over territory of Northern Eurasia. In boreal zone and, especially, in Siberia the river runoff will be increased, in a forest-steppe and steppe zone it can be decreased. Respective alterations will take place and with a water regime of fresh-water bodies and surrounding seas, and also with riverine export of organic and mineral substances. Additional inflow of fresh waters to Arctic Ocean can lead to regional climatic changes (chapter 3.3).

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3.2. Biogeochemical Cycles

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3.2.1.3. Responses of Biogeochemical Cycles in Northern Eurasia to Global Change

The biogeochemical cycles of terrestrial ecosystems in Northern Eurasia may respond to global change in ways that tend to enhance warming (positive feedbacks) and through effects that tend to mitigate warming (negative feedbacks) (Smith and Shugart, 1993; McGuire and Hobbie, 1997; McGuire et al. 2000a; Chapin et al. 2000; Clein et al. 2002). The net effect will depend on the balance between the two and positive feedbacks to warming are of imminent concern. For example, increases in fire frequency and soil warming have the potential to quickly release large amounts of carbon (McGuire et al. 2003b,c; Goulden et al. 1998), and these responses may more than offset increases in carbon storage that might arise from the slow expansion of boreal forest into tundra regions (e.g., McGuire and Hobbie, 1997) or increased productivity due to increasing CO_2 (McGuire et al. 1997) or N fertilization associated with N deposition (Kauppi et al. 1992; Berg and Matzner, 1997). Similarly, if permafrost thawing results in the expansion of lakes and wetlands, then releases of CH_4 and carbon storage in the form of peat are both likely to be enhanced (Reeburgh and Whalen, 1992; Zimov et al. 1997), but it may take up to 500 years until the enhanced storage of carbon in the wetlands offsets the enhanced radiative forcing associated with CH_4 emissions (Roulet, 2000). Responses of CH_4 emissions to warming in northern wetlands may be quite rapid. During a warm year Dlugokencky et al. (2001) has estimated CH_4 emissions from northern wetlands were enhanced by ~11 Tg above the 1982-1993 mean emissions (1998). High levels of N deposition may also have negative consequences on ecosystem function, as negatively charged nitrates leach from the soil and carry away important cations such as potassium, calcium, and magnesium (Aber, 1992). To predict the effects of climate and land cover change on the future dynamics of CO_2 and CH_4 exchange in northern Eurasia, it is important to understand the processes involved and their spatial and temporal dynamics. Predicting the long-term influence of elevated CO_2 concentrations on the carbon stocks of forest ecosystems remains a research challenge (Bolin et al. 2000; Prentice et al. 2001, Arneth et al. 2002). Ecosystems that initially absorb C in response to higher atmospheric CO_2 will become 'saturated' or even later release CO_2 if increasing temperatures lead to enhanced decomposition and respiration (Cao and Woodward, 1998; Scholes et al. 1999). Fires and other disturbances could increase in frequency and intensity if temperatures increase and precipitation patterns change. The net impact of these, and other global changes, is an area of active research (e.g., Woodwell et al. 1998). Changes in land use also affect the biogeochemical cycles in forest, grassland, and other ecosystems. Land use changes in the Eurasian region are associated with dramatic social and economic transitions occurring in the past decade. For example, the reorganization of the former Soviet Union and the increased globalization of commodity markets have resulted in marked changes in land-use during the last decade: large tracts of croplands have been abandoned (~ 30 million ha in Russia from 1988-2000, Kljujev et al. 2001); some degraded rangelands have been rehabilitated; timber harvest initially declined and currently is about one third of the level it was in 1990; peatland drainage has virtually ceased; and fire control has declined. The dynamics of land use, which are driven by different socio-economic factors in China, Mongolia, Russia and the other former Soviet Union Republics, have implications for biogeochemistry. In addition, significant expansion of the extraction of natural resources (oil, gas, etc.) has started in a number of regions (West Siberia, Taymyr, others) and has been accompanied by an influx of people and development of infrastructure in extremely fragile landscapes. There is evidence that the stability of permafrost has been affected in areas disturbed by resource extraction activities; Ivanov 2003, which has consequences for the dynamics of biogeochemical cycles. However, how these changes have affected biogeochemical cycles in not well documented and is not well understood. The future trends of land use are uncertain and will likely affect the future storage of carbon and the dynamics of other biogeochemical cycles in the region.

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3.2.3. Patterns and Variability

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These atmospheric analyses are consistent with analyses based on forest inventory data, which indicate that Russia was responsible for a carbon sink of 0.3 to 0.4 Pg C per year in the early to mid-1990s (Liski and Kauppi, 2000; Myneni et al. 2001 Figure 1.2a and Zhou et al. 2003, Fig 1.2b; Shvidenko and Nilsson, 2003). One analysis for Russia based on forest inventory data from 1961 to 1998 estimates that Russian forests have been a net C sink of 0.32±0.06 Pg C yr^{-1} over the entire period with inter-annual variation of between 0.17 to 0.45 Pg C yr^{-1} (Shvidenko and Nilsson, 2003). When changes in land use are considered, the C stocks in Russian forest lands are estimated to have increased by 0.43 Pg C yr^{-1} over the period from 1961 to 1998, with non-forested lands contributing an additional 0.09 Pg C yr^{-1} over the same period (Shvidenko and Nilsson, 2003). The uncertainty of these estimates is large and the future of this carbon sink depends on a complex interaction of climatic variation and human activities.

Most methane emission scenarios expect continuing growth of the methane emissions (Nakecenovic et al. 2000) in near future. Estimates of CH_4-C exchange between Russian soils and the atmosphere suggest that Russia is a source of methane of between 5 to 100 Tg C yr^{-1} (Zavarzin and Vasilieva 1998). A recent (1999-2003), puzzling decline of the atmospheric methane growth rate (Dlugokencky et al. 2003), after previous drop in 1990s, has called for more attention to understand the basic mechanisms responsible for climate controls and anthropogenic impacts on methane emissions. This recent drop is correlated with reduced fossil fuel emissions from the former Soviet Union (Olivier and Berdowski, 2001), but can not be fully explained by it. Large wetland areas of Scandinavia and Northern Russia are likely to feel the heat of the warming climate, possibly resulting in changing methane emissions and carbon accumulation rates. In North Eurasia, West Siberia can be designated as a key area for understanding changes in methane emissions, because it serves as both a major wetland area and natural gas exploration and transportation region. Long term observations of the seasonal and interannual dynamics of wetland methane exchange are conducted in Canada and Scandinavia, but only fragmentary data exist for West Siberia, because those observations require well maintained automated systems deployed in the field. Current understanding of the spatial variability of methane emissions is based on spatial and temporal extrapolation of the observations using process-based models (e.g., Walter et al., 2001 and Cao et al., 1998), that incorporate surface heat balance and hydrology to simulate the variations of the water table and temperature, which are the major environmental factors controlling the dynamics of methane production and emission in anaerobic peat mass environment. Spatial representation of the wetlands in those models follow existing maps of the wetland typology (Matthews, Fung, 1987) which can be refined in North Eurasia only at regional level where some detailed maps of wetlands are available. The future dynamics of methane in Northern Eurasia are highly uncertain, as methane emissions could decrease if the increasing aridity that has been observed continues, while increased fire severity has the potential to release substantial amounts of methane from burning peatlands as methane released from such fires is on the order of 1 - 2% or more of consumed carbon. The release of methane associated with fire emissions has substantial the potential to affect radiative forcing of the climate (Kajii et al. 2002).

Currently, the global anthropogenic emissions of NO and SO_2 into the atmosphere exceed natural rates from terrestrial ecosystems by about 8 and 4 times, respectively (Galloway, 2001). In Europe, NO_3 and S deposition has decreased substantially in recent decades, but the deposition of NH_4 has stayed relatively constant (Erisman and de Vries, 2000). Forests in Europe currently receive inorganic nitrogen deposition (wet and dry) ranging from less than 1 kg ha^{-1} yr^{-1} in Northern Norway and Finland to more than 60 kg ha^{-1} yr^{-1} in the Netherlands and Czech Republic (Macdonald et al. 2002). The deposition of N and S over the area of the Former Soviet Union ranged from 5 to 30 kg ha^{-1} yr^{-1} and from 8 to 35 kg ha^{-1} yr^{-1}, respectively, in the latter half of the 20th Century (Vasilenko, 1991). For the period 1990-2001, the emissions of NO_x and S decreased in Russia in association with decreased economic activity, but it is expected that these emissions will again increase and reach levels comparable to 1990 values by 2020 (Annuary….., 2001). The deposition of heavy metals in Europe was also substantial during the latter half of the 20th Century. Since reaching a peak during the 1960's, the deposition of heavy metals in Europe has decreased markedly as a result of improved emission controls, closure of polluting industries, and phasing out of lead in gasoline (Johansson et al. 2001). While it is well known that there are substantial sources of heavy metal pollution located in Russia (for instance, Cu-Ni smelters in Norilsk, in the Kola peninsula, and elsewhere), the absence of a national monitoring program means that the patterns and variability of heavy metal pollution has not been well quantified. While the levels of pollution have not been well quantified, their effects on terrestrial biogeochemical cycles are clearly evident. For example, approximately 3 million ha of forest tundra around the largest smelter in the world in Norilsk (which emits about 2 million tons of sulfur oxide emissions per year in addition to heavy metals) has been completely destroyed with no vegetation growth possible because of the levels of soil contamination associated with the deposition of heavy metals.

3.3. Surface Energy and Water Cycles.

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Introduction

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In the diagnostic mode of weather modeling (the re-analysis mode) any erroneous parameterizations or misinterpretations of the processes that define the behavior of the system are corrected by the data. There is no such helping hand when we are trying to project future climate and state of environment or assess their vulnerability. All basic processes must be described as accurately and completely as possible within the model because the quality[60] ….

3.3.2. Processes that directly feed back to the Global Earth System

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- **Changes in surface albedo related to vegetation changes, shift of ecological zones, and land use changes**

These changes directly affect the surface heat and water balance and are discussed in 3.4 and 3.5 in detail. While it is possible to reconstruct some of these changes over time[61], large-scale environmental monitoring became a reality only in the era of remote sensing. During the last two decades, the area of forested land, green vegetation (NDVI), forest fire scares, agricultural fields, and their changes with time are objectively monitored and documented from satellites[62]. The period of this monitoring is still too short to permit confident conclusions about a shift of ecological zones, but pilot estimates (e.g., Figure 2.1) have already indicated large-scale changes in the biogeochemical cycle over Northern Eurasia with global implications (3.2). Off-line land surface models convert the observed changes in vegetation into the direct climate feedback estimates related to albedo, evapotranspiration, and sensible heat flux changes[63]. For example, there is substantial spatial variability in winter albedo within the boreal forest due to the spatial mosaic of coniferous forests, deciduous forests, and non-forested wetlands and burn scars. The latter have a higher albedo of ~ 0.6 in the cold season when the short-statured vegetation is snow covered. Thus, it is important to know the proportion of the landscape occupied by short-statured ecosystems within boreal forest. During summer, the albedo of deciduous stands and boreal non-forested wetlands is higher than the albedo of coniferous forests (Rauner 1972; Chapin et al. 2000a). Therefore, changes in the land cover composition directly affect surface heat balance.

- **Thawing of permafrost**.

Degradation of permafrost and changes in the soil carbon cycle in Northern Eurasia have the potential to noticeably affect the atmospheric CO_2 and CH_4 concentrations and, therefore, global climate. About half of the Northern Eurasian terrain has permafrost (Figure 2.3). Section 3.6.1

[60] To achieve this quality, the models' output is compared with the observational evidence and the behavior of the underlying processes described in the model is tested in specially designed field and laboratory experiments. The best approach to develop valid projections of the future is to strive for a comprehensive model that accurately simulates past and present climates and states of environment and apply it for future projections or, at least, assess the predictability of the modeled system (Pielke 1998; IPCC 2001; Chase et al. 2004; Real et al. 2004).

[61] e.g., the lake levels, changes in the area of agricultural land (3.4; Golubev et al. 2003), and reports of the forest harvest and inventories (Shvidenko and Nilsson 2002).

[62] 4.1; Tucker 1979; Vygodskaya and Gorshkova 1987; Vygodskaya et al. 1997; Conard et al. 2002; Wagner et al. 2003; Zolotokrylin 2003.

[63]Nakaegawa et al. 2000; Stewart et al. 1998; McGuire and Hobbie 1997; McGuire et al. 2000a, b.

describes the increasing trends of the near-surface permafrost temperature over Northern Eurasia. The increase in permafrost temperatures may change many of its physical properties that can have negative effects on infrastructure but the *dominant non-linearity* occurs when permafrost starts to thaw near the surface. At that time, many processes (some of them very destructive) will be triggered or intensified. The most significant impacts on ecosystems, infrastructure, carbon cycle, and hydrology will be observed in areas where the permafrost contains a considerable amount of ground ice (Nelson et al. 2001, 2002). As a result, dramatic changes in vegetation, surface and subsurface hydrology, and in the carbon cycle should be expected. Section 3.6.1 specifically addresses all issues related to this process.

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- **Ongoing aridization of the continental interior and dust storms.**

Temperature rise without appreciable changes in precipitation (or even its decrease) can lead to aridization in steppe, semi-arid and arid climatic zones of Northern and Central Eurasia. Additional causes for aridization could be of anthropogenic origin (water withdrawal and/or intense agricultural use) and glaciers and permafrost degradation. Whatever the causes may be, an increase of the dust load in the troposphere may be a result. Mineral aerosols, or dust, are a dominant component of the total atmospheric aerosol burden. Most dust particles are lofted into the atmosphere by aeolian (wind) erosion of arid and semi-arid lands, which cover approximately 33% of the global land area. Current estimates of the global annual mean dust burden range from 1000 to 5000 Tg/yr. With an average transport time of up to several weeks, mineral particles can be transported great distances downwind from the source, causing diverse effects on health, environment, and climate (Figure 3.3.3). *Once lifted into the atmosphere, both anthropogenic and natural components of mineral aerosols play an important role in air quality, atmospheric chemistry, ecology, biogeochemical cycles, cloud formation, rainfall, agriculture, Earth's radiation budget, and, hence, climate change.* Since Central and East Asia is the second largest source of atmospheric dust in the world, a quantitative understanding of Eurasian dust sources, transport routes, and effects on the climate system on regional and global scales is urgently needed. Section 3.6.3 addresses these issues in detail.

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3.3.3. Processes of major societal importance

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The following two processes are only partly a function of SEWC, but directly and substantially affect society and human health and thus are included below.

- ***Impact on agricultural production***

  An artificially controlled environment of arable lands is less flexible than a natural environment, unless it is irrigated and there is no water shortage. It is controlled for a purpose, being managed for maximum harvest. But, the biodiversity on the agricultural lands is suppressed and natural soil resources are exploited and gradually depleted. Therefore, societal changes and climatic changes are affecting the agricultural environment (that was previously adjusted for maximum productivity of a specialized harvest) greatly and making it highly sensitive to external forcing. Scale and frequency of droughts in agricultural regions and changes in irrigation norms and water consumption in Northern Eurasia due to the global warming are the major areas of concern (Menzhulin et al. 1995, 1996; 3.4).

- ***Atmospheric/water pollution***

  Quality of human health and life conditions, negative effects on land, riverine, and coastal zone ecosystems are direct effects of pollution (3.4, 3.6.3). Its indirect effects include modification of surface radiation balance by atmospheric aerosols and the water cycle by impact on cloud formation (by providing additional condensation nuclei).

3.3.4. Surface Energy and Water Balance: Quantifying the Components and their Interactions

3.3.4.1. Climatology

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Atmospheric transport of water vapor

A relatively dense spatially distributed network of aerological stations has allowed for early estimation of major characteristics of the water vapor distribution in the atmosphere and its transport over most of Northern Eurasia within the former Soviet Union boundaries (Kuznetsova 1978, 1983; IWP 1984). These studies were based on the aerological data from the 1960s when the network was already well established and observations were frequently made four times per day at 156 aerological stations. Kuznetsova (1983) assessed the total amount of water vapor transferred annually and its fraction that finally ends as runoff over the former USSR territory. It appears, that while the atmosphere over the western half of Northern Eurasia is more humid, most of the water vapor (~88%) passes over it (or recirculates) and the "utilization" of the water vapor in Siberia is more effective. About half of the water vapor is converted to soil moisture and eventually streamflow. One of the semi-closed branches of the water cycle originates in the Northern Atlantic: evaporation from the ocean, atmospheric moisture transfer to Eurasia by westerlies, precipitation, runoff into the Arctic Ocean, and return to the Northern Atlantic via oceanic currents. *At present, there is no clear understanding of the characteristics of these highly variable processes that control the energy and water budgets of Northern Eurasia. This problem can be addressed with a focused regional modeling effort and a multi-facet observational program.* Modern estimates based on satellite observations (Randel et al. 1996) show similar results for total water content of the atmosphere (Figure 3.3.6), but it is not yet possible to assess the differences as an indication of climatic changes of the water content in the atmosphere due to very different methodologies used to determine these estimates. Observations of the near-surface atmospheric humidity indicate that the water vapor content in the atmosphere has been increasing during the past century (Sun and Groisman 2000). This is consistent with the increasing atmospheric water vapor holding capacity with regional warming.

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3.4. Land Use Interactions: Societal-Ecosystem Linkages

Four expanded contributions to the Chapter (while partially used in the Chapter) are presented here in their entirety

***Contribution to 3.4* "Managed Land, Terrestrial Carbon Cycle and Climate Feedbacks Over Northern Eurasia: Building Interactive Hierarchies of Data and Models of Agricultural Land-Use for NEESPI' by Cynthia Rosenzweig and Francesco N. Tubiello, NASA-Goddard Institute for Space Studies and Columbia University, New York, NY USA and Gunther Fischer International Institute for Applied Systems Analysis, Austria**

Recent assessments have identified the contribution of agriculture and forestry practices as responsible for roughly two-thirds of the total carbon sink into Northern Hemisphere land. Yet a great deal of spatial and temporal refinement is necessary to document current distributions of land dynamics, their inter-annual variability, and their future changes. Research work is needed to improve the description and quantification of the impacts of climate variability and change on of agricultural and forestry productivity, as well as to describe how management and land use changes feed back on the regional climate and carbon cycle. The fundamental scientific questions are as follows: What are the effects, over the next decades, of land-cover and land management of large-scale agricultural systems on the regional carbon cycle in Northern Eurasia? What are the important feedbacks among current and future climate variability and change, water use, crop production systems, land management, and the related land-based carbon fluxes? Specifically, NEESPI-LULUC would focus on research that will result in a modeling network hierarchy over Eurasia that covers three orders of scales and processes: 1) Expansion of agricultural sites network database and point dynamic crop modeling, extending methodologies from work already developed for previous national and international assessment work (e.g., US National Assessment; EPA Country Study Programs, including several countries in the former Soviet Union); 2) detailed 5X5 km grid land use database and dynamic agro-ecological zone model (AEZ); and 3) Further development of interactive agricultural-land use modules for a general circulation model (GCM).

At the basis of this network is the recognition that assessing carbon fluxes from land requires a multi-scale approach in space and time, as well as an interdisciplinary one. The site network that we propose to be at the core of NEESPI-LULUC provides ground-truth for the overlying levels (process model and data development, calibration and validation based on local agricultural practices and contact with local agronomists; and satellite observation); the fine-grid AEZ model provides the needed land coverage and a dynamic modeling capacity to allow for resolving inter-annual changes in land management, as well as providing the proper framework to compute effects connected to future climate change; finally, the third level (GCM) provides the ability to "extract" to very large spatial scales (2.0° x 2.5° Lat. x Long.) the underlying carbon flux signals, properly validated at the lower scales, and to investigate the feedbacks between current and future land use change and climate itself, and how these in turn may affect the fluxes computed at the underlying scales. A vigorous plan for use of county and regional land use data (field, statistical, satellites) is strongly needed in order to strengthen the assessment and linkages among the proposed hierarchical levels.

Background

We know that over the last 20 years land-based carbon emissions from land have been progressively masked by increased land uptake (IPCC, 2001). Atmospheric measurements, inversion methods, land-based modeling and data estimates all suggest that there are two large terrestrial carbon sinks at work in today's earth system: one is extra-tropical, divided between North America and Northern Eurasia, while the other is tropical (Schimel et al., 2001). While both terrestrial sinks seem to have the same uptake strength, or roughly 1-2 Gt C yr^{-1}, deforestation in the tropics tends to counterbalance uptake so that net carbon emissions from the tropics are about zero (Watson et al., 2001). In the Northern Hemisphere however, net effects from land use are small --possibly because forest regrowth and woody encroachments nearly equal fluxes from agriculture (McGuire et al., 2001) –so that a net carbon flux is "seen" from the atmosphere into the Northern Hemisphere (Pacala et al., 2001).

Much uncertainty remains with regards to the exact *biophysical mechanisms* responsible for current land carbon uptake, as well as in the estimation of *land use emissions* to the atmosphere. In terms of ecosystem dynamics: climate change, climate variability, rising CO_2 concentrations, and N deposition have all been identified and tentatively quantified as collectively responsible for the apparent land sink (Schimel et al., 2001). In terms of land use activity, rather simplified accounting methods, prescribing carbon loss from soils and plant stocks following deforestation and land conversion, have been employed to estimate land-use related carbon emissions (Houghton, 2000). Uncertanties in biophysical mechanisms and land use emissions clearly limit our ability to answer two relevant scientific questions: What has happened to the anthropogenic carbon emitted in the past? What atmospheric CO_2 trajectory will result from future carbon emissions? In order to improve our predictive ability around such questions, the U.S. Carbon Science Plan (Sarmiento et al., 1999) has listed four goals related to land-based carbon cycle science, namely: 1) Quantify and understand Northern Hemispheric uptake; 2) Analyze past and future land-use impacts; 3) Improve linkages between carbon and climate models; and 4) Develop linkages between physical and socio-economic modeling.

Within such efforts, it is necessary to improve current biophysical descriptions of agricultural and managed forestry systems within existing ecosystem models, focusing on plant growth and yield as a function not only of climate, but also as a function of genetic and management factors such as crop and cultivar characteristics, irrigation and fertilization schedules, rotation types, soil management, etc. (McGuire et al., 2001).Yet, there has been a deficit in closing the gap among site-level crop modeling studies, land use dynamic, and terrestrial carbon modeling, including critical linkages with climate modeling. We propose that NEESPI-LULUC develops strong interdisciplinary collaborations among researchers with expertise covering crop, ecosystem modeling and carbon cycle, as well as climate change impacts land and water resources, adaptation and management strategies, and vegetation-climate interactions within regional and general circulation models. Such expertise should include ground-truthing of data, models, and scenarios using field, statistical, and satellite data. Integration of research and education at the local to international level needs to be an essential component of this effort.

NEESPI-LCLUC: Science questions and work plan

Previous efforts in terrestrial carbon cycle research have focused on projecting carbon emissions from managed land using both simple accounting methods and terrestrial ecosystem models modified to include crops (e.g., Ramakutty and Foley, 1998; McGuire et al., 2001). Others have focused on using detailed crop modeling studies in order to understand, at farm to regional levels, the impacts of projected climate change on future productivity and land use, including the effects of adaptation and mitigation (e.g., Reilly et al., 2001; Fischer et al., 2001a; Tubiello et al., 2002). Others still have concentrated on modeling land-use dynamics as a function of both climate and socio-economics (e.g., Lambin et al., 1999). NEESPI-LULUC expertise needs to cover research and education components in the areas of crop, ecosystem and carbon cycle modeling (e.g., McGuire et al., 2001; Tubiello et al., 2002), climate change impacts land and water resources, adaptation and management strategies (e.g., Rosenzweig and Parry, 1994; Reilly et al., 2001; Fischer et al., 2001a), and vegetation-climate interactions within general circulation models (Tubiello and Rosenzweig, 1998). For example, we implemented a series of land evaluation steps widely know as the agro-forestry ecological zones model (GAEZ), and applied this methodology to the territory of the former Soviet Union, Mongolia, and China (see figures below; Fischer et al., 2001b). GAEZ has also been applied on a global level to investigate agricultural productivity and risk as a function of historical climate variability and future climate change (e.g., Fischer et al, 2001a). For Eurasia, the model operates on a resolution of 5X5 kilometer, including 148 crop 52 forest and 6 grassland land use types.

NEESPI-LULUC proposes to focus on improving the assessment of future carbon emissions arising from regional land use and productivity. During a proposed research period of three-five years, NEESPI needs to implement a general modeling framework linking crop, land use and ecosystem models, and climate, to investigate key research questions within regional case studies, specifically Northern Eurasia. *Focus on this region is justified by a need to better resolve spatial and inter-annual distributions of Northern Hemispheric carbon fluxes, considering that Northern Eurasia is responsible for a sizeable portion of the carbon sink at northern extra-tropical latitudes. At the same time, pronounced observed and projected patterns of warming in the Eurasian region over the coming decades may be associated with high impacts on ecosystems, land use and management, greatly affecting carbon cycle dynamics*. An integral part of these activities, we aim to generate a set of educational activities for students, educators, and the general public. <u>The scientific questions that need investigation are as follows: What happens to carbon emissions from land-use changes in Northern Eurasia under climate change, over the next 30-50 years? How does climate change interact with regional impacts of likely regional adaptation and mitigation strategies during this period</u>? Proposed research activities focus on three phases:

i) Global linkages among field, statistical, and satellite data, dynamic ecosystem and land use models, and a climate model;
ii) Regionalized simulations and link to global climate;
iii) Workshops and educational activities involving students, faculty, and stakeholders.

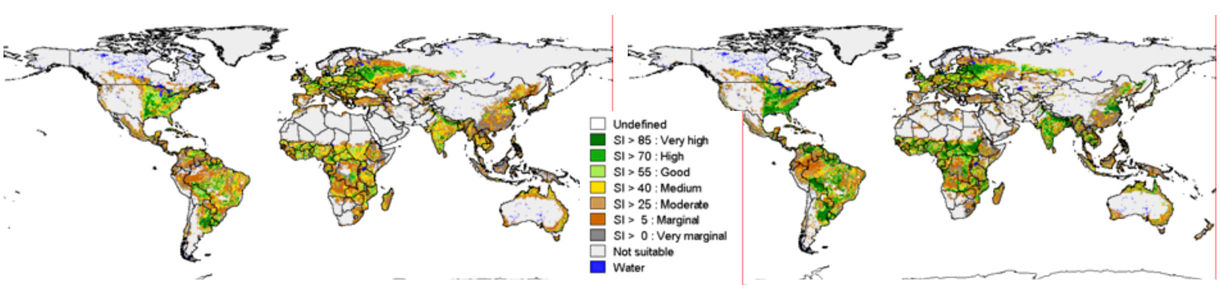
The ability to predict carbon emissions and sequestration due to land-use activity depends on a correct representation of crop-management dynamics and the proper scaling to regional levels. This multiple tasks can only be achieved by merging existing modeling approaches in a meaningful manner. Dynamic crop models excel in describing the local interactions between management, genetics, environment and plant growth, including effects of elevated CO_2 and their interactions with water and N regimes (Tubiello et al., 1999; Tubiello and Ewert, 2002). These models have been extensively validated locally, though this characteristic has severe limitations with respect to spatial scaling (Ewert et al., 2001). On the other hand, land use models are very well-suited for larger scale agro-ecosystem computations, focusing on dynamic management adaptation, including under climate change, but are in general poorly calibrated against reported data. Finally, terrestrial ecosystem models are the proper tool for calculating large-scale natural ecosystem carbon and N fluxes (Xiao et., 1997). However, they have non-dynamic land use components and poor agricultural crop simulation capacity. Clearly all three approaches must be considered in order to improve projections of land-based carbon emissions, including the effects of climate change. Finally, climate models must be modified to interactively simulate these effects as climate changes through time.

In brief, site, county and regional-level data (field and satellite), together with site-level dynamic crop model simulations, must be used to calibrate and validate increasingly larger scale resolutions for land use (0. 1°X0.1°) and ecosystem (0.5°X0.5°) models, up to GCM grid scale (2.5X2.5 and 4X5), both under current and future climates, up to the period 2050. Once a consistent set of data and modeling results has been achieved (validation), changes in land-use and management—computed with a agro-ecological zone model--can then be translated into carbon emissions using an ecosystem model. Finally, feedbacks between land-use, carbon cycling and regional climate can be assessed within GCM coupling. Adaptation to climate change in the form of likely management practices (planting dates, cultivar, crop, irrigation and/or fertilization changes) need also be evaluated, first at the site level—where management decisions are actually implemented—and then scaled regionally in terms of land use and carbon cycle dynamics.

Finally, the proposed LULUC NEESPI plan further seeks to analyze sets of scenario simulations, with current climate as well as under climate change conditions, with and without adaptation/mitigation. Comparisons of ensemble runs will help us assess the strength of the interactions between climate change, land use and carbon emissions.

Model Integration: Land use and carbon dynamics

Computations with an agro-ecological zone model (AEZ) evaluate the suitability of a particular land unit for crop production, including factors such as the quality of the soil, the local climate conditions, and the possibilities of using different types of inputs such as fertilizers, pesticides, machinery, etc. The model then evaluates various mixes of crops that are possible under the specific conditions of a plot using bio-physically-base computations of crop growth and yield. The figure on this page is an overview of the flow and integration of information implemented in the IIASA AEZ. Biophysical calculations of attainable yields in a land unit start with estimating site-specific maximum biomass and yield potentials as possible under prevailing climatic conditions. Then, agro-climatic constraints, soil constraints, and terrain limitations are assessed against crop requirements to derive attainable yields. The procedure takes into account yield losses occurring due to temperature limitations, moisture stress, pests and diseases, and workability constraints. Production is estimated for different levels of management and inputs. Following the crop suitability assessment, the productivity assessment also considers



Predicted rainfed cereal suitability *Predicted irrigated cereal suitability*

Figure 3.4.2. Predicted cereal suitability

(a) production increases resulting from multiple cropping; and (b) fallow requirements to maintain soil fertility and structure. Land utilization types (LUT) are then defined from the coupling of the resulting agronomic, forestry, and technical specifications. *GAEZ distinguishes 148 crop LUTs, 52 forest LUTs, and 6 generalized grassland land use types*. Assessment of alternative LUTs is typically performed by superimposing various thematic maps including different attributes of land such as climate, soil, altitude, landform, terrain slope, present land cover/use, and administrative boundaries. For Eurasia, the model operates on a resolution of 5X5 kilometer. The work we have developed to date has resulted in a database containing extended information on all feasible land utilization types for each grid cell. It can be used to tabulate or map potential arable land by crop or zone. The database contains also the geo-referenced agronomic data for district, regional, and national land-use planning scenarios. Linkages between GAEZ and an carbon-ecosystem model (CEM) will provide a powerful tool that can be used to analyze carbon emissions from land as a function of: 1) land management dynamics; and 2) agro-ecosystem production and dynamics.

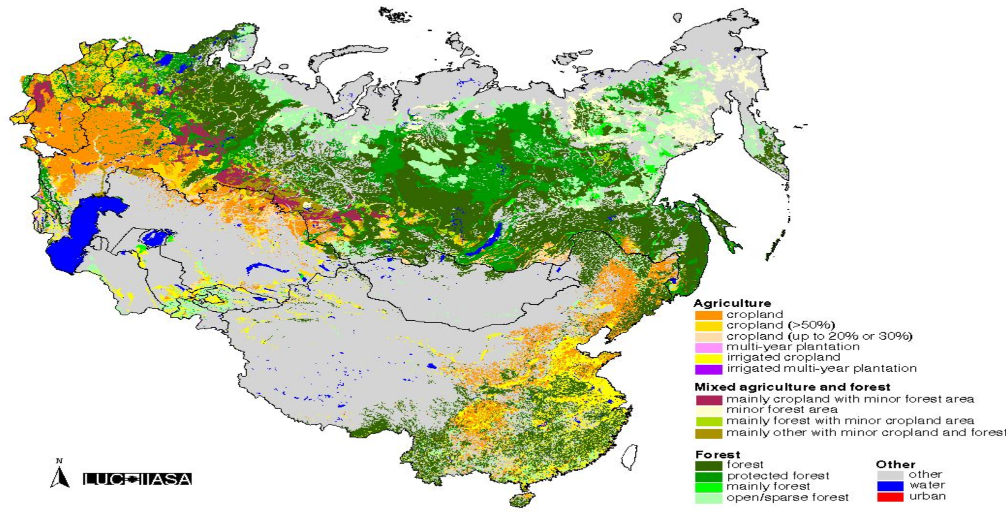


Figure 3.4.3. Agricultural and forested land

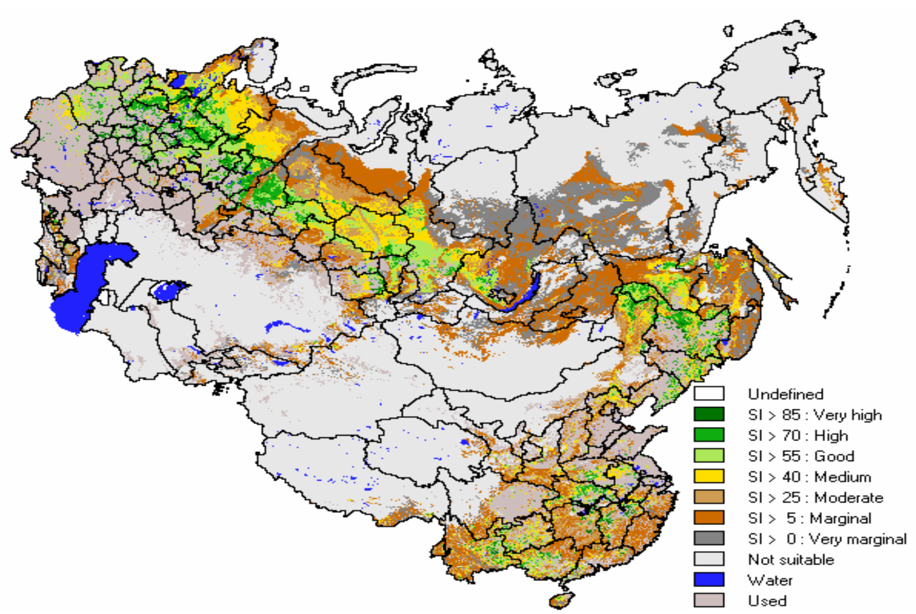


Figure 3.4.4. Suitability for conservation forestry (excluding cultivated and urban areas).

Sensitivity studies: management versus climatic effects. The linked GAEZ-CEM models can further be used to investigate, within current climatic conditions, key dynamics affecting inter-annual variability of carbon emissions. These have at least two interacting components: one

related to climate variability; the second related to crop management. Existing models with simple
agronomic approaches can only resolve the first of these two factors, while we will be capable of analyzing both. To this end, daily time series of biomass growth during growing periods, including leaf area index development, must be generated under varying management.

Climate change impacts, adaptation and mitigation

Climate change and elevated CO_2 will affect agro-forestry systems productivity, altering local food and fiber supply, thus affecting the magnitude of land carbon fluxes and their spatial distributions. Impacts will depend on the severity of climate change as well as on the adaptation capacity of regional systems. GISS has already compiled a set of over 100 agricultural sites for dynamic crop model simulations under current conditions and climate change. These will be used in evaluating/developing the AEZ simulations over the NEESPI region. Using such modeling tools, NEESPI LULUC focus will be on analysis of plausible sets of adaptation/mitigation responses in terms of consequences for carbon emissions. *Specifically, it is generally projected that the impacts of climate change on agriculture can be quite small where large adaptation capacity exists, in terms of changes in crop management (water and/or fertilizer), crop adoption, and land conversion (e.g., Reilly et al., 2001). However, little attention has been given so far to consequences of those adaptation adjustments in terms of their potential for either carbon emissions or sequestration*. For example, if agricultural production in Eurasia does move north, as the currently projected increases in temperatures and growing seasons suggest (see figure), how much more carbon will be lost to the atmosphere from land conversion? What happens to regional soil carbon stocks when additional irrigation is applied, for example to counteract drier, hotter summer in continental interiors?

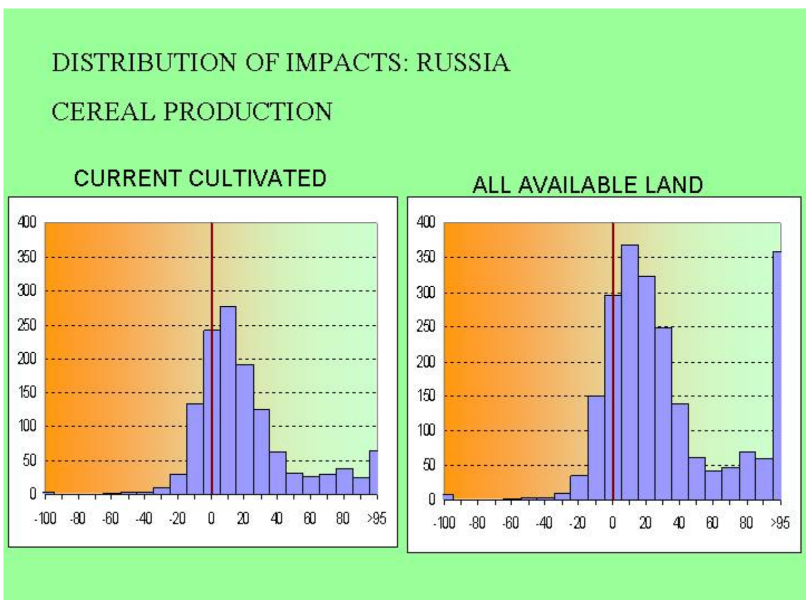


Figure 3.4.5. Projected impact on cereal production in Russia.

As argued elsewhere (e.g., Reilly et al., 2001; Tubiello et al., 2002), it is important to consider contrasting projections of future climate change if system vulnerability and/or dynamics are to be assessed. In addition to GCM projections, it would be wise to compile sensitivity tables of agriculture and forestry production in Eurasia in response to ranges of temperature and precipitation change. Such table can often be of great use in quickly assessing impacts of additional GCM projections over a region.

GCM land surface model: interactions of land use, carbon and climate

In addition to the climate change simulations using fixed climate scenarios as described above, NEESPI-LULUC proposed to focus on a full- coupling of land use, carbon and climate models. Under work funded by NSF and NOAA, for example, we are already modifying the GCM "cultivated" category to include multiple descriptors of crop type and management, with testing for the U.S. Midwest and agricultural China; the current 4X5 version of the GISS-GCM covers the US central plains and China with about 8 grid-boxes each. Similar simulations at GCM resolutions are proposed under NEESPI similarly to the research examples below. Specific regions for Northern Eurasia will include major crop production areas such as the Ukrainian wheat belt as well as seimi-arid marginal production areas in Central Asia. Specific study areas will be selected at GISS and IIASA in collaboration with local agronomists and land managers from participating NEESPI countries.

Example. Case study under current funding: interannual variation of agricultural yield, leaf area coverage, water and carbon fluxes in the continental US and China. *We have accumulated a detailed dataset of crop yield data at the county level, covering wheat and maize yields and planted/harvested areas from 1950 to date. We also have developed methods for aggregating such data at the regional level, covering regions that can be spanned within the coarse GCM resolution. The regions we propose for detailed analysis are: Northern mid-west plains (North and South Dakota, Nebraska, Kansas); southern mid-west plains (Oklahoma, Texas); northwest US and Canada (Montana, Saskatchewan); and Northeast, Central, and South China. The simulations are as follows:*

- Baseline simulations 1950-2000, *with GCM running with observed sea-surface temperatures predicting leaf-area index development, fraction of vegetation (i.e., planted versus base soil) over time, and crop yields. Available satellite data for the US and China over this period, as well as crop yield datasets are being used to assess the goodness of GCM simulations. Model sensitivity to management studied by simulating an "all rainfed" case versus an "all irrigated" one.*
- Climate change scenario without adaptation.
- Climate change scenario with adaptation**.**

All stages of proposed activities under NEESPI-LULUC will be integrated by education at the undergraduate, graduate and post-doc level. Analysis of land use and land use change within NEESPI propose to integrate climate, agro-ecological zone and cropping systems, and carbon cycle-cycle modeling, in order to capture the key interactions between climate impacts, adaptation and mitigation responses.

3.4.6. Biodiversity. Expanded version of Sub-section

Contribution by Kathleen Bergen and Mykola Zalogin

Potential Effect of Land-Use and Climate Change on Biodiversity in Northern Eurasia

Global biodiversity is under particular risk from global climate change. Already hemmed in by habitat loss, pollution and over-exploitation, species and natural systems are now faced with the need to adapt to new regimes of temperature, precipitation and other climatic extremes. Biodiversity science and management have increasingly difficult challenges to face in the new millennium.

At the simplest level, changing patterns of climate will change the natural distribution limits for species or communities. In the absence of barriers it may be possible for species or communities to migrate in response to changing conditions. Vegetation zones may move towards higher latitudes or higher altitudes following shifts in average temperatures. Movements will be more pronounced at higher latitudes where temperatures are expected to rise more than near the equator. In most cases natural or man-made barriers will impact the natural movement of species or communities. Arctic tundra and alpine meadows may become squeezed by the natural configuration of the landscape, while these and many other natural systems may be further confined by human land-use patterns (Figure 3.4.6). Many national parks and protected areas are now surrounded by urban and agricultural landscapes which will prevent the simple migration of species beyond their boundaries.

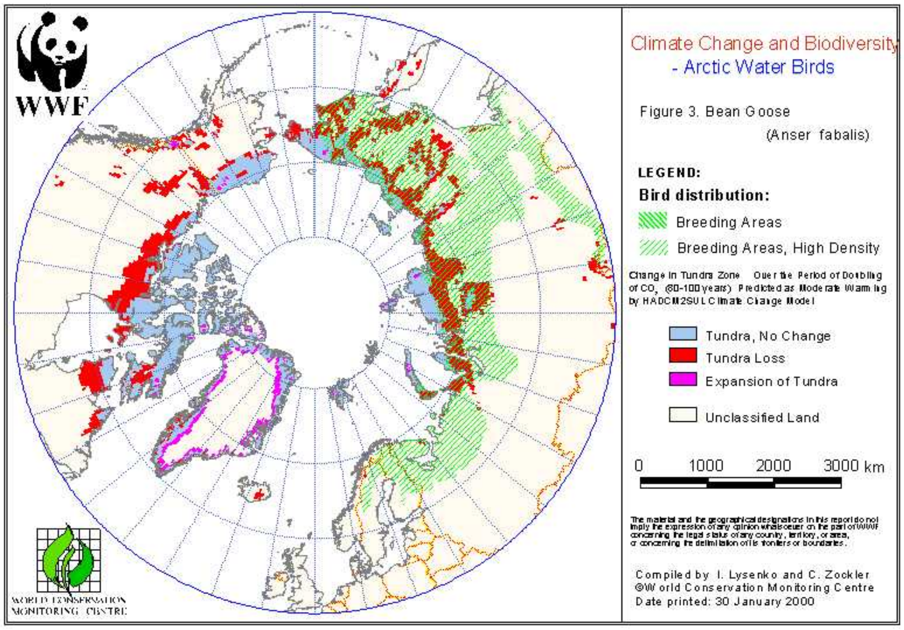


Figure 3.4.6. Change of arctic water birds distribution area. (Source: Biodiversity and Climate Change Programme, UNEP World Conservation Monitoring Centre).

Perturbations to rainfall and drought patterns will also be of critical importance. Increased flooding would have implications for large areas, especially riverine and valley ecosystems. On the relatively narrow habitats of the coastal margins, especially where these are backed by areas of intense human use, rising sea levels may lead to the squeezing out of important coastal habitats. Rising sea temperatures will further affect the distribution and survival of particular marine resources. Studies have shown dramatic changes in the distribution and survival of the Pacific salmon in the late 1990s (citation?). In addition to causing a warming effect, increased concentrations of atmospheric carbon dioxide are known increase rates of photosynthesis in many plants, as well as improving water use efficiency. In this way the climate changes may increase growth rates in some natural and agricultural communities.

Characterizing of Biodiversity

Biodiversity is characterized at several scales – species, community, ecosystem – and includes both plant and animal diversity. Northern Eurasia has significant diversity of ecosystems. Using World Wildlife Fund categories (WWF), Northern Eurasia is comprised primarily of the following diversity of ecosystems: Tundra, Boreal Forest-Taiga, Temperate Broadleaf and Mixed Forests, Temperate Coniferous Forests, Steppe Grasslands, Flooded Grasslands, Montane Grasslands, Desert and Xeric Shrubland. These ecosystems in turn have variability in the levels of biodiversity within them and in their degree of present intactness. Ecosystem diversity if often studied and described in terms of intactness or fragmentation. “Hot spots” is a term currently popular for describing regions with high levels of biological endemism of individual species of plants and animals and under threat of loss of that diversity.

Biodiversity in Boreal Russia

Russia alone has been cited as having "one-fifth of the worlds forests, the longest coastline of any nation, and a host of rare, endemic and highly charismatic species, including Amur tigers, Siberian Cranes, Baikal seals, and the Saiga antelope (Dinerstein et al, 1994)." The status of entire Russian ecosystems in terms of their intactness is important in responding to land-use and climate change with more or less resilience. While limited to European Russia, an important study completed in 2001 assessed forest ecosystem intactness by use of remote sensing and GIS methods. Last Intact Forest Landscapes of Northern European Russia was published jointly by Global Forest Watch and Greenpeace Russia. They found that forest landscapes that are still intact make up only about 14% of the total forest area of European Russia and stress that "conservation of large intact landscapes is a robust and cost-effective way to conserve biological diversity (Yaroshenko et al., 2001)". Other scientific studies have identified geographic regions of Russia known in general for high species richness and endemism. These include 1) the Caucasus Mountains, the Altai and Sayan mountains of southern Siberia, the south of the Russian Far East and the Lake Baikal watershed (Olson and Dinerstein, 1998). A similar study determined that mountainous territories on Russia's southern borders were the greatest centers of endangered species diversity: Maritime state, Krasnodar state, Dagestan republic, Sakhalin province and the Jewish province (Griffen, 1999). Biodiversity conservation in the Russian Federation and former Soviet Union relied upon a nature reserve system of Zapovedniki. Currently approximately 85 zapovedniks (16 of which are biosphere reserves) remain along with 26 national nature parks. These are currently facing staffing and financial hardships but form a basis for biodiversity science and conservation (Colwell et al, 1997; Dinerstein et al, 1994. Species are well documented and listed in Russia's Red Data Book (Eliseev et al., 1985).

Biodiversity in Caucasus and Semi-Arid Regions

According to Conservation International, a group that has identified a select number of global scale "hot spots", the location in Northern Eurasia that has attained "hot spot" status is the Caucasus Mountains in southwestern Northern Eurasia. Both the topography and the vegetation of the Caucasus is very diverse including significant areas of grassland steppes, semidesert, desert, swamp forests, arid woodlands ecosystems. Scattered throughout the hotspot are broadleaf forests, montane coniferous forests, and shrublands. Today, only about 50,000 square kilometers, 10 percent of the hotspot's original area, remains pristine (http://www.biodiversityhotspots.org/xp/Hotspots/caucasus/). The Caucasus region contains 1600 endemic plant species (of 6300 species) and 59 endemic vertebrate species (of 632), 10 threatened species and 3 critically endangered species.

Biodiversity in Europe and the Ukraine

In many European countries, half of the known vertebrate species are threatened. More than one-third of Europe's bird species are in decline, mainly due to damage to their habitats by land-use changes and increasing pressure from agriculture and forestry (Tucker and Heath 1994; Tucker and Evans 1997). In Europe and Central Asia, about 300 wetland sites are protected under the Ramsar Convention, in addition to some 70 world natural heritage sites and biosphere reserves, also important for wildlife preservation (EEA 1995). There is need to incorporate biodiversity considerations into other policy areas. The all- European strategy of biological and landscape diversity preservation is an innovative approach to stopping and turning back the degradation of biological and landscape diversity in Europe, because it strives to unite all of the initiatives and different projects in a European framework. One of the main elements of the strategy's philosophy is the principle that the preservation efforts will be successful only then, when socio-economic factors will be taken into account.

Data obtained by Ukrainian researchers and outcomes of international projects give evidence that the main factors contributing to a decrease of biodiversity sustainability in Ukraine are 1) fragmentation of landscapes, 2) complete tilling of soil and chemical pollution reaching 75-85% in some oblasts, and 3) nearly complete shift in water yield and chemical composition of water in surface water reservoirs. Similar examples are observed on the European scale. The application of advanced information technologies, such as remote sensing (RS) and geographical information system (GIS), is very efficient tools for investigation of such factors. Also, the government policy on nature conservation remains reluctant to drastic changes in state of biodiversity. Moreover, the current legislation on protected areas is not consistent with today challenges and sometimes is worst than at the beginning of 20th century (Figure 3.4.7).

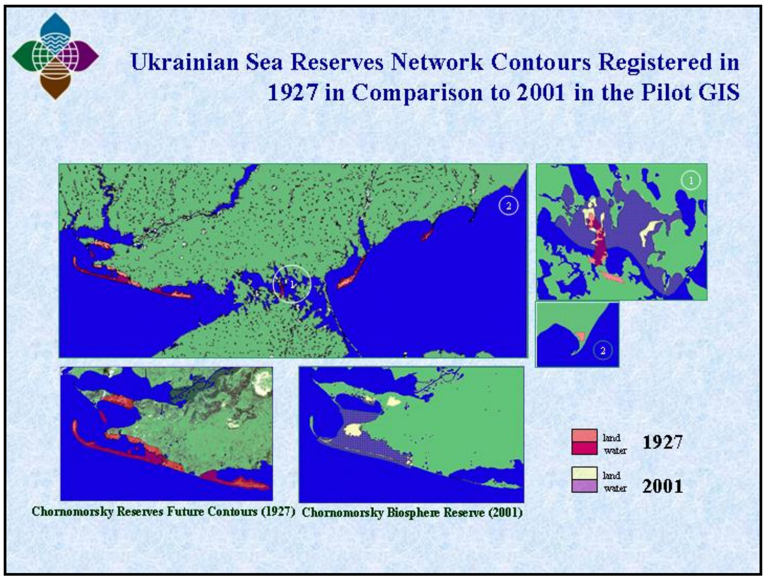


Figure 3.4.7. Ukrainian Sea Reserves Network Contours Registered in 1927 in Comparison to 2001 in the Pilot GIS. (Source: Ukrainian Land and Resource Management Center, ULRMC).

According to the data of 1996-2003, the number of endangered species of mammals increased both in the Eastern and in the Western parts of Europe. In terms of practical actions, reasonably anthropocentric approach was recommended or completion of red lists, combined with urgent designing of quasi-natural ecosystems and protection of functionally steady aggregations rather than species as such (Zagorodniuk, 2000). In scope of this and other approaches following priorities could be proposed:

- enhance the application of IT (RS, GIS and Internet);
- migratory species monitoring and conservation;
- zoning of the protected territories the most threatened by global climate changes;
- Management of transboundary protected areas and territories, development of Northern Eurasian Protected Areas network;
- biodiversity and sustainable agriculture.

The NEESPI could contribute to the updating the global biodiversity model (GLOBIO) as well as to the improving scenarios “2010” and “2100” related to biodiversity. NEESPI should consider supporting projects that seek to use remote sensing, GIS/ geospatial technologies, and modeling to better understand and quantify the relationship between biodiversity and land-cover/use change and climate change and their interactions in Northern Eurasia. There are a number of national and international groups that NEESPI should investigate coordinating with. NEESPI should seek to coordinate with the Biodiversity Program within NASA on this topic as well as World Resources Institute, Conservation International, World Wildlife Fund, Greenpeace Russia, and other groups in United States, Northern Eurasia, and Europe. Within Northern Eurasia there are a number of regional and local conservation groups and science efforts underway.

Box insert 3.4.3. Atmospheric pollution and health issues. Contribution by Eugene L. Genikhovich.

The atmospheric pollution in Northern Eurasia seems to be an important socioeconomic factor, especially, in Siberia and Ural regions. In many cities there the level of pollution is extremely high, and it is reflected there in high levels of morbidity and mortality. The actual information about the levels of air pollution is collected on the local, regional, national, and, in certain instances, international levels and the results of processing of corresponding data are usually published on the regular basis. In particular, the monitoring data obtained in the framework of the EMEP program in 1978 - 1998 are analyzed by Barrett et al. (2000). The most resent information about air pollution in Russia was presented in the national report published by Izrael et al. (2002, 2003). Table 2.4.3 taken from this report lists the most polluted Russian cities where short-term (20 min averaged) concentrations of one of the pollutants, monitored in 2001, were at least once higher than the tenfold value of the corresponding Maximum Permissible Concentration (the Russian National Ambient Air Quality Standard). The values of MPC (usually both, short- and long-term ones) are established in Russia for more than 2000 species.

Table 3.4.3 shows that in 2002 short-term averaged concentrations higher than 10 MPC were observed in 48 Russian cities. In relation to annually averaged concentration, the cities were sorted using the Air Pollution Index (API) that is the sum of five highest partial indices (for each pollutant, the partial API is determined as the ratio of its mean annual concentration to corresponding MPC raised to the power 0.85, 1.0, 1.3 or 1.5 depending on the toxicity group the pollutant considered belongs to, which is identified in the official list of MPCs). In 2002 the list of the most polluted Russian cities based on this API sorting included 31 cities with the total population over 15 million people. The environmental situation did not improve in 2002 (see Izrael et al., 2003). That year 35 Russian cities with the total population over 20 million people were included in the list of the most polluted cities. Among those, 20 cities were located in Eastern Siberia and Far East regions.

Table 3.4.3. Russian cities with highest in 2001 short-term concentrations exceeding 10 MPC (Izrael et al., 2002)

City	Pollutant (Cmax/MPC)
Arkhangelsk	Methylmercaptan[1] (1360 μg/m^3)
Achinsk	Benzo(a)perene (12.2)
Barnaul	Nitrogen dioxide (10.6), phenol (10.7), particulate matter (10.4), hydrogen sulfate (10.9)
Berezniki	Ethylbenzene[2] (10.8)
Bratsk	Benzo(a)perene (22.2)
Vladivostok	Formaldehyde (12.0)
Vologda	Benzo(a)perene (12.1)
Volgograd	Hydrochloride (12.7)
Gubakha	Ethylbenzene[2] (15.6)

Ekaterinburg	Ethylbenzene[2] (30.2)
Zima	Benzo(a)perene (26.5)
Kansk	Benzo(a)perene (21.8)
Kemerovo	Hydrochloride (17.2)
Korsakov	Particulate matter[3] (27.3)
Krasnoyarsk	Benzene (19.5), toluene (13.0), benzo(a)perene (20.1)
Kurgan	Benzo(a)perene (20.0)
Kyzyl	Benzo(a)perene (10.1)
Magadan	Benzo(a)perene (12.2)
Magnitogorsk	Ethylbenzene[2] (19.0), nitrogen dioxide (11.4), benzo(a)perene (15.0)
Minusinsk	Benzo(a)perene (13.8)
Mirnyi	Hydrogen sulfate (22.4)
NizhniTagil	Ethylbenzene[2] (13.5)
Novoaleksandrovsk	Soot (10.3)
Novodvinsk	Methylmercaptan[1] (6078 $\mu g/m^3$)
Novokuibyshev	Xylene (18.5)
Novokuznetsk	Phenol(14.0)
Novorossijsk	Nitrogen dioxide (12.6)
Omsk	Ethylbenzene[2] (16.0), phenol (14.8), hydrogen chloride (10.5), acetaldehyde (103.6)
Orenburg	Nitrogen dioxide (14.9)
Partizansk	Benzo(a)perene (10.7)
Pervouralsk	Hydrofluoride (18.2)
Perm	Hydrochloride (19.0), nitrogen dioxide (10.5), ethylbenzene[2] (22.6), formaldehyde (12.1)
Samara	Benzo(a)perene (10.8)
St. Petersburg	Nitrogen dioxide (13.2)
Selenginsk	Benzo(a)perene (11.9)
Solikams	Ethylbenzene[2] (10.3)
Sterlitamak	Benzo(a)perene (10.0), hydrochloride ((12.5)
Taganrog	Nitrogen dioxide (13.3)
Ulan-Ude	Benzo(a)perene (34.8)
Usolie-Sibirskoe	Benzo(a)perene (15.2)
Ussurijsk	Benzo(a)perene (15.9)

Ufa	Nitrogen dioxide (24.0), benzo(a)perene (13.8), carbon monoxide (13.0)
Khabarovsk	Benzo(a)perene (14.6)
Chelyabinsk	Ethylbenzene[2] (16.4)
Chita	Benzo(a)perene (38.0)
Shakhty	Nitrogen dioxide (11.5)
Shelekhov	Benzo(a)perene (28.7)
Yuzhno-Sakhalinsk	Benzo(a)perene (14.6), soot (17.7), particulate matter [3] (11.3), nitrogen dioxide (10.5)
[1] – Cmax is given without normalizing with MPC. [2] – Daily averaged concentrations are normalized with the short-term MPC. [3] - Daily averaged concentrations are normalized with the long-term MPC.	

Correlations between the air pollution and adverse health effects in Russia were studied in numerous publications. For example, Bezuglaya and Zavadskaya (1998) were using data on the number of cases of first-time found malignant tumors in 47 Russian cities during 1986 – 1990 (these data were collected in the information system "AGIS – Health" run by the Russian Ministry of Public Health). They found, in particular, that the annual coefficients of correlation between these numbers and API in the cities considered were varying for different years between 0.42 and 0.69 and, for the whole sample, this coefficient of correlation was equal to 0.60; thus, from 20% to 50% of this morbidity could be associated with the air pollution. Accordingly to these authors, about 11% to 16% of respiratory diseases in Russia were also related to the air pollution. Ozkaynak et al. (1998) linked concentrations of TSP (Total Suspended Particles) in Yekaterinburg and Nizhni Tagil with acute respiratory and cardiovascular mortality (ARM and ACM, correspondingly). Their findings were as follows: 11% to 16% of ARM in Yekaterinburg was associated with previous day's TSP; 5% to 9% of ARM in Nizhni Tagil was associated with same day's TSP; 2% of ACM in Nizhni Tagil was associated with previous day's TSP. The impact of high levels of pollution on human health is also illustrated with the following results of spectral analyses of lung tissue samples from lung cancer patients in Magnitogorsk, the city that hosts one of the largest Russian steel works (Table 3.4.4).

Table 3.4.4. Spectral analysis of lung tissues in Magnitogorsk, 1997 (after Koshkina, 1998)

Chemical	Concentration		
	Background level	Magnitogorsk	
		Healthy tissue	Malignant tissue
Ag	0.0007	6.77	0.72
Zr	2	9.13	8.05
Ca	-	-	222
Co	0.02	0.69	1.46
Ni	0.047	1.79	0.44
Mo	0.03	no	12.23
Sr	-	no	0.22
Si	-	53.33	793.6

Sb	0.06	203.3	153.2
Au	0.063	no	1.63
Cr	0.092	2.8	4.95
Be	0.007	0.16	0.22
Zn	11	61.39	47.53
Cd	0.35	3.11	7.25
P	780	5091	3649
Pb	0.39	6.53	1.14
Cu	1.2	3.06	1.32
Fe	3600	no	125.5
K	1900	558.11	466
Na	1800	1855	1572

The regional effects of atmospheric pollutants depend on the strength of the emission sources and on meteorological and climatic conditions, each of these factors being varied in space and time. One of the principal questions still to be addressed is how this complex picture of atmospheric pollution and its impacts on the human health and environment could be influenced by the projected climatic changes and what are corresponding possible climatic feedbacks and socioeconomic impacts.

Box insert 3.4.4. Consequences of Chornobyl Disaster. Contribution by M. Zalogin.

The April 26, 1986, explosion of the fourth reactor at the Chornobyl Nuclear Power Plant (CNPP) is considered to be one of the worst man-made accidents of the 20th century, leading to wide-scale radionuclide contamination in the region (Figure 3.4.8). The "Chornobyl Exclusion Zone (CEZ)" is an established and largely secured area around and including the nuclear power plant, located approximately 80 kilometers from Kyiv, and extending northward to the border with Belarus. More than 160,000 people have been resettled from the CEZ since 1986 to mitigate health impacts of the catastrophe.

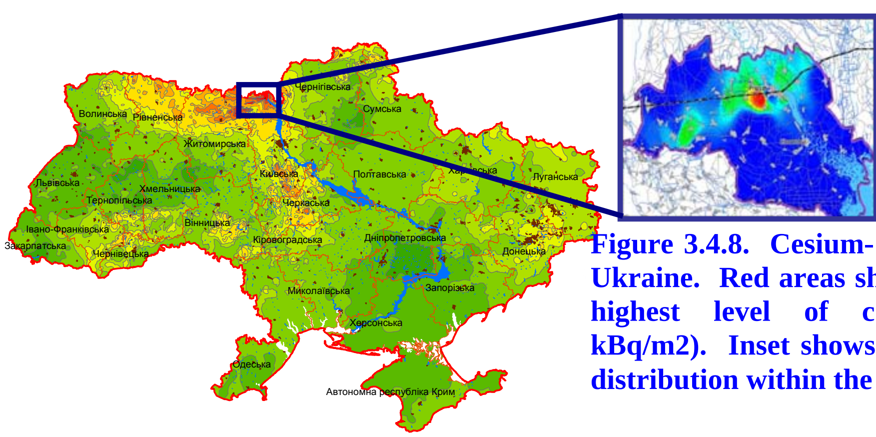


Figure 3.4.8. Cesium-137 Contamination of Ukraine. Red areas show locations with the highest level of contamination (3,700 kBq/m2). Inset shows overall radionuclide distribution within the CEZ.

Permanent and temporary waste depositories were created in 1986 and 1987 as part of the first priority operations designed to decontaminate the territory within a 10 km zone immediately surrounding the CNPP. According to expert assessments, the radioactivity concentrated in these radioactive waste depositories equals $13 * 10^{15}$ Bq . Radioactive contamination in the CEZ continues to spread through natural processes outside of the larger 30 km exclusion zone. Estimates are that 90% of radionuclide dispersion is related to water transport into the Prypyat River by various mechanisms (Derevetz et al, 2003).

About 20 km south of the CNPP, the Prypyat River converges with the larger Dnipro River in a reservoir known as the "Sea of Kyiv." The Dnipro River provides water for approximately 33 million residents, or two-thirds of the population of Ukraine, of which 10 million are living directly adjacent to the waterway downstream from Chornobyl.

Approximately 10% of radionuclide dispersion is due to vegetation fires within the CEZ (Caletnik, 2003) with the potential to release airborne radionuclides to the greater Trans-Polissya region of northern Ukraine and neighboring countries such as Belarus, Russia, Poland and the Baltics. CEZ forests act as a protective shield slowing the spread of radioactive contamination by absorbing radionuclides. In 1992, "Chornobyl Forest," a state-owned, specialized industrial forestry complex, started its activities within the CEZ. This enterprise aims to protect the CEZ's forests from fires and poachers, protects vegetation from pests and diseases, and also plants young trees to sequester radionuclides in the biological chain. Forest planting in contaminated territories is one of highest priorities in the entire program to remediate the consequences of the Chornobyl disaster. Forests around Chornobyl continue to play an important role, decreasing levels of radionuclides migration and further nuclear contamination by more than 50% (Caletnik, 2003).

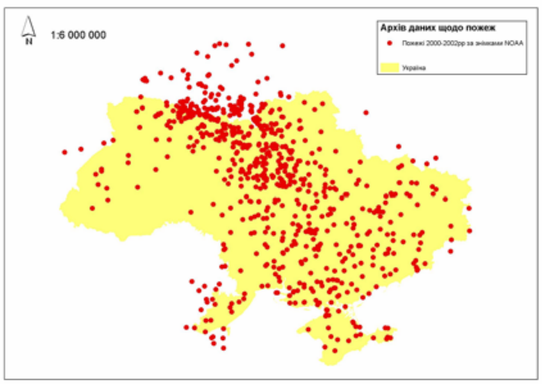


Figure 3.4.9. Fires Identified Between 2000 and 2002 Based on Analysis of NOAA AVHRR Imagery Acquired by ULRMC.

On the other hand, the fires in highly contaminated forest area around the CEZ dramatically affect a nature European region and health of population. The problems of transbondary radionuclides transportation caused by forest fires is very critical for this region which is associated with high density of fires (Figure 3.4.9).

Administrative regulations for the CEZ require that the duration of forest fires be limited in burn time to a maximum of three hours. The implementation of this regulation requires substantial human and financial resources in order to fight vegetation cover fires within the CEZ (Figure 3.4.10). Accordingly, improvements in the ability to predict climatic conditions that may lead to increased forest fire threats are greatly needed and can support the planning, response and deployment processes of the Administration of the CEZ.

Figure 3.4.10. Firefighters in the CEZ.

Chapter 3.5. Ecosystems and climate interactions.

Three extended references (in green) were removed from the chapter but are preserved below

Introduction. The climate system and terrestrial ecosystems interact as they change. The interactions enhance and/or moderate the changes making these changes non-lineary[64] There are theoretical indications that the particular state of the ecosystem may make the history of the global climatic changes intransitive[65]. Gradually, Human Activity (HA) has become a part of these interactions by affecting the atmosphere, hydrosphere, cryosphere, and biosphere[66]. ……

…

3.5.1.1 Major feedbacks

…..

Biogeophysical feedbacks. …. Vegetation provides shade, affects surface energy balance (Figure 3.5.2), controls evaporation, runoff, soil moisture, snowmelt, and a partition between sensible and latent heat losses[67]. …

….

The entire section presented below (3.5.2) was moved from Chapter 3.5 to the Scientific Background Appendix

3.5.2. Observed impacts of *changes* in ecosystems and climate on each other

3.5.2.1.Climatic changes that have most directly affected the biosphere and society

[64] Budyko 1971; Graetz, 1991; Bonan et al., 1992; Botkin and Nisbert, 1992; Field et al., 1992; Prentice et al., 1992; Raich et al., 1992; Shugart et al. 1992; Mooney et al., 1999; Rosema et al., 1993; Denning et al., 1995; Vygodkaya et al., 1995b; Keeling et al., 1996; Melillo et al., 1993, 1996; Braswell et al., 1997; Margolis and Ryan, 1997; Ryan et al., 1997; Cao and Woodward, 1998; Churkina and Running, 1998; Galloway and Melillo, 1998; Houghton et al., 1998; Pielke et al., 1993, 1998; Liski et al., 1999; Schulze et al. 1999, 2001; Valentini et al., 2000; Eastman et al. 2001; Pielke 2001; Kabat et al. 2004

[65] I.e., a possibility of the multiple long-term equilibriums of the Global Earth System exists under the same external conditions (Pielke 1998). One of the regions of the possible intransitivity is in the Central East Asia desert area (Claussen 1998). Another example is in the boreal forest zone of Northern Eurasia, where a millennium-scale process of paludification, i.e., gradual moss coverage of the surface and mire development could be an autogenous process (Pajula 2000). For example, the surface air temperature and precipitation conditions ~10,000 years ago may be approximately the same as the present at certain locations. But, now we have there a well developed moss cover that insulates the ground while10 to 6,000 years ago the moss cover was absent (or undeveloped) and the entire regional ecosystem (first of all, the soil temperature regime) was different.

[66] E.g., Kirikov, 1979; Osipov and Gavrilova, 1983; Schulze et al., 1989a;1989b; Vitoussek and Howard, 1991; Berendse at al., 1993; Godbold and Huterman, 1994; Houghton, 1995; Santer et al., 1995; Sirotenko et al., 1995; Melillo, 1996; Aber and Driscoll, 1997; Foster et al., 1997; Sokolov, 1997; Lloyd, 1999; Vitoussek and Field, 2001.

[67] Molchanov 1961; Rauner 1972; Ross 1875; Pavlov 1975; Monteith 1975, 1976; Skatveit et al., 1975; Fedorov, 1977; Bihele et al., 1980; Varlagin and Vygodskaya, 1993; Vygodskaya 1981; Abrazhko 1992; Vygodskaya et al., 1995a, 2004; Chapin et al. 1996, 2000; Pielke 2001; Molchanov, 2000; Pielke 2000; Baldocchi et al. 2000; Sellen, 2001; Oltchev et al. 2002; Tchebakova et al., 2002; Lynch et al. 2003; Avissar et al.2004; Kelliher et al., 1993a,b, 2001, 2004; Kurbatova et al., 2002.

While changes in surface air temperature and precipitation are most commonly addressed in the literature, changes in their derived variables (variables of economic, social and ecological interest based upon daily temperatures and precipitation) have received less attention. The list (incomplete) of these variables (indices) includes: frequency of extremes in precipitation and temperature, frequency of thaws, heating degree days, spring onset dates, growing season duration, sum of temperatures above/below a given threshold, days without frost, day-to-day temperature variability, precipitation frequency, precipitation type fraction, frequency of rain-on-snow events, characteristics of potential forest fire danger, and many similar characteristics of the thermal and hydrological regimes**.** In practice, these and other indices are often used instead of "raw" temperature and precipitation values for numerous applications. These include modeling of crop-yields, prediction and planning for pest management, plant-species development (e.g., Table 3.5.1), greenhouse operations, food-processing, heating oil consumption in remote locations, electricity sales, heating system design, power plant construction, energy distribution, reservoir operations, floods, and forest fires. These indices provide a measurement for the analysis of changes that might impact agriculture, energy, and ecological aspects of terrestrial and aquatic systems of Northern Eurasia. Figures 2.11, 3.5.4, and 3.5.5 and Tables 3.5.2 and 3.5.3 provide estimates for changes in some of these indices for Northern Eurasia during the 20th century.

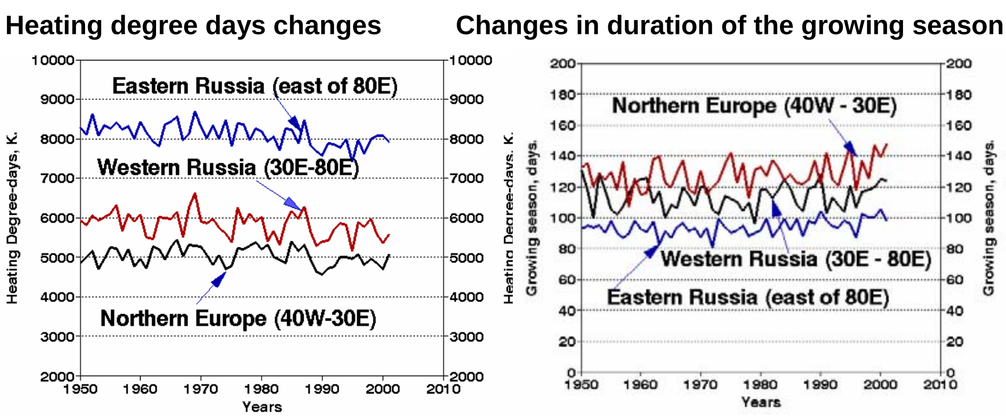


Figure 3.5.4. Example of changes in temperature regime over Eurasia north of 50º N that affect heating costs and agriculture production (Groisman et al. 2003a).

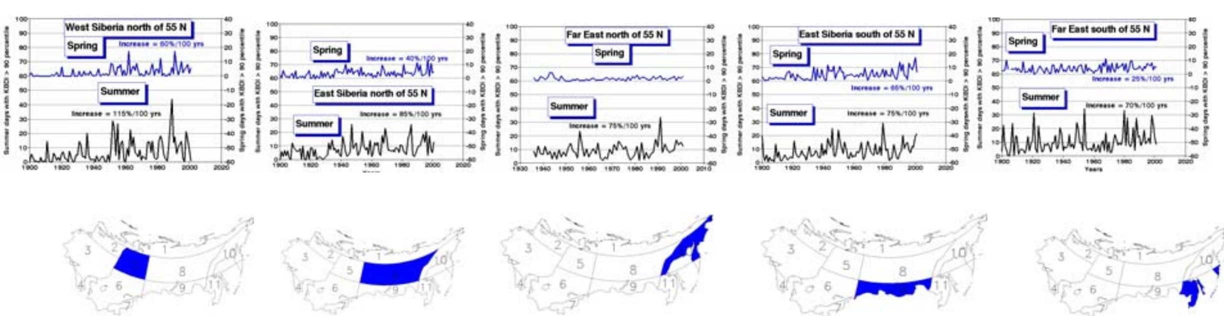


Figure 3.5.5. Region partition of Siberia and the Russian Far East and time series of the number of summer and spring days with daily KBDI values above the upper 10 percentile of its seasonal distribution. The index makes use of daily temperature and precipitation data. Higher values of this index characterize a higher potential for forest fire.

Table 3.5.2. Changes in temperature-derived characteristics over Northern Eurasia east of 30°E, north of 50°N during the past 50 years (adapted from Groisman et al. 2003a).

Characteristic Region	Trend, %/50 yrs
Heating-degree days: East of 80ºE West of 80ºE	-6 -7
Degree-days below 0ºC: East of 80ºE West of 80ºE	-12 -19
Degree-days above15ºC: East of 80ºE (only)	12
Duration of the growing season (T> 10ºC) East and West	8
Frost-free period: East of 80ºE (only)	10

Table 3.5.3. Increase in mean regional frequency when summer KBDI (index of potential forest fire danger introduced by Keetch and Byram [1968]) exceeds the "non-zero" 90th percentile of its distribution during the reference period 1961-1990 (Groisman et al. 2003b).

Regions south of 66.7° N	Period assessed	Frequency changes, %/100yr
West Siberia, north of 55° N	1900-2001	115
East Siberia, north of 55° N	1900-2001	85
Far East, north of 55° N	1936-2001	75
East Siberia, south of 55° N	1900-2001	75
Far East, south of 55° N	1900-2001	70

3.5.2.2. Environmental changes that have most directly affected regional climate and society

On a small scale, the climatic consequences of the land cover changes are vivid and we observe direct changes of near-surface regional climate associated with oasis effects and effects of cities, such as changes in strong winds, temperature, and humidity. Other regional climatic changes are less obvious and have a meso-scale nature. So, in the areas adjacent to large reservoirs in the steppe zone of southern Russia and the Ukraine, precipitation has decreased (Kuznetsova 1983). Heat islands around big cities affect the circulation around them and modify precipitation patterns. Landscape alterations, which change its heterogeneity, affect the transport of heat, moisture, and momentum in the atmosphere and feedback in cloud formation and regional precipitation (Pielke 2000; Avissar et al. 2004). The large scale consequences of the environmental changes on the regional climate, however, are uncertain and should be studied on comprehensive global models (Pielke et al. 1991, Pielke 2001)

All cause by HA changes of environment (listed in 2.8) were d*esigned* to directly affect the society. Building a pond, irrigation system, channel, factory, pipeline, or road; all these HA served some societal need and have their rationale. However, frequently, the long-term and/or large-scale consequences of HA were left unaccounted for (or intentionally neglected). Now, many years later, some of these consequences are vivid, considered as negative, and efforts are made to reduce their impact on human health, agriculture production, fishery, and regional environment. Others appear to be unexpectedly beneficial. In addition to burning fossil fuels, some of the consequences of HA (e.g., decomposition of woody debris remains after careless logging) add greenhouse gases to the atmosphere. Other HA (e.g., reforestation) help to reduce their amount. In 3.5.1, we listed major feedbacks that are associated with land cover and land use changes (LCLUC). They are numerous, complex, and quite powerful. Thus, it would be reckless to continue the "business as usual" HA that affects LCLUC without careful projections of its remote consequences (Marland et al. 2003). It is better first, to investigate the feedbacks in the entire scope of the potential impact of the projected type of HA, to ask the question "What should be better understood of this impact?", to find the answers, and then to act according to the newly acquired knowledge. ***The rich history of environmental changes, societal experiments, climatic changes, and high natural variability in Northern Eurasia allow creation of reasonably well documented "training samples". They can be used for testing and fine-tuning the comprehensive suite of models. Then the best of these models should be used to project major expected environment consequences of each future large-scale project prior to its implementation.***

One type of HA (pollution) practically always has negative consequences. Effects of air and water pollution on ecosystems are considered in 3.4. Water contamination has created major social problems in several regions such as the low reaches of Central Asian rivers (and remains of Aral Sea), the Sea of Azov, the northern coast of the Black Sea, and the Baltic Sea. It is discussed in 3.6.2. Below we outline a couple of possible feedbacks of the pollution impacts.

- For the major part of Northern Eurasia, anthropogenic emissions remain localized in comparatively small, hot spots, including major cities, industrial agglomerations, and transportation routes. However, the high sensitivity of the regional ecosystems, e.g., tundra and the boreal forest, to pollution, some of which comes from the outside of the region (e.g., anthropogenic CO_2, N trace gases from Europe), makes the consequences of anthropogenic impact noticeable (3.4). Aquatic systems (eutrophication, acidification, nitrate leaching to groundwater), biodiversity (not all species can sustain the pollution level imposed on them and their frost, drought, or pest resistance would decrease), and soils affected by acidification are at risks. Specific risks are found in northwestern and western regions of Northern Eurasia which receive additional air pollution from industrial western countries and where headwaters of main rivers of Eastern Europe are located. One of the terrestrial ecosystems' functions here is a boundary protection absorbing industrial CO_2. Exactly in these European regions of Northern Eurasia, there are soil areas "with an exceeded buffering capacity and high nitrogen deposition" (Renn et al., 2001) which are predicted to increase. The resulting biochemical feedbacks of pollution here will affect neighboring countries, too (3.4).
- The Aral Sea story is a very striking example (Box insert 2.1). The Aral Sea disaster is an effect of an enormous irrigation project and a significant increase of aridity, including degradation of glaciers and permafrost in the Sea Basin during the last several decades. Its shrinkage coupled with the desertification of the surrounding area caused huge changes in evapotranspiration and aerosol loading in the troposphere. Biochemical and biophysical feedbacks from transport and deposition of these aerosols are affecting environment, soils, economics, human health, and climate (3.4, 3.6.3).

Chapter 3.6. Topic of special interest

Several sub-sections and box inserts presented below were moved from Chapter 3.6 to the Scientific Background Appendix

3.6.1. COLD LAND REGION PROCESSES

3.6.1.1. Introduction

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Geography of the Cold Regions in Northern Eurasia

The zones with permafrost and mountain glaciers in Northern Eurasia can be subdivided into three major parts (see Figure 3.6.1): the entire arctic tundra biome in the northeast and a narrow coastal zone across Siberia and European part of Russia, the boreal forest (taiga) with permafrost (in the northern Scandinavia, north-eastern European Russia, the north of West Siberia, most of Central and East Siberia, northern Mongolia, north-east China, and the Russian Far East), and high elevation mountain permafrost and glaciers (mountain ranges such as Ural, Chersky, Koryak, Kamchatka, Alati-Sayan, the Tien Shan, and other ranges of Central Asia, and the Caucasus). The majority of the area is drained by the major rivers flowing into the Arctic Ocean (Ob, Yenisei, Lena, Kolyma although in the Far East other rivers flow to the Pacific Ocean and there is internal drainage in some of the basins in Central Asia). Zonally, the vegetation zones transition occurs southward from tundra to boreal forest to forest-steppe and steppe/desert, but there are also opposite vertical gradients in the mountain regions.

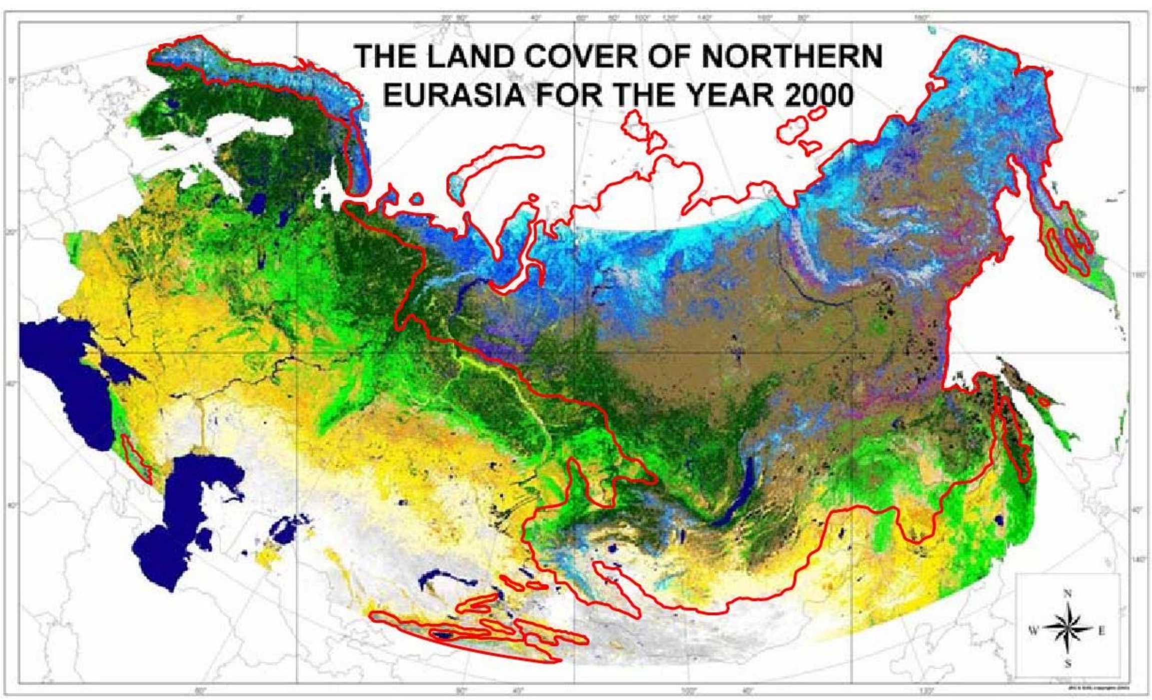

Figure 3.6.1. The land cover type distribution and the boundary of the Cold Land Regions in Northern Eurasia.

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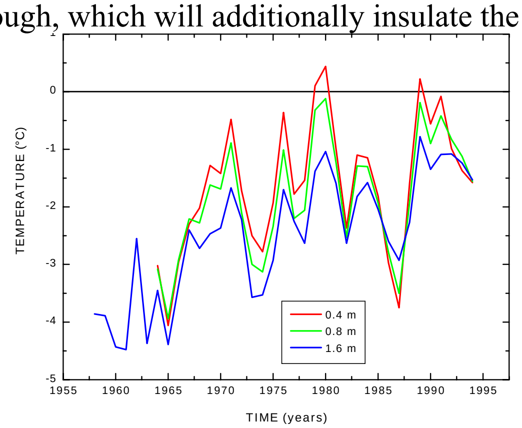
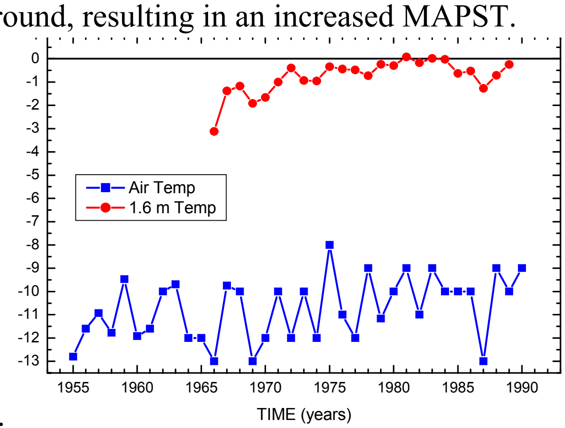
3.6.1.2. Contemporary and predicted permafrost changes in the Cold Land Regions.

All Global Climate Model projections for the next 100 years are such that permafrost and glaciers (especially temperate glaciers) will progressively degrade. This process will start from the south and lower elevations and progress northward and to the higher elevations. In the polar areas, where permafrost will still be stable, the depth of the seasonal active layer will increase significantly (Anisimov et al. 1997; Nelson et al. 2001; Stendel and Christensen 2002; Sazonova and Romanovsky 2004).

Analysis of the long-term records of the near-surface permafrost temperature dynamics, obtained from different parts of the permafrost zone in northern Eurasia, shows a significant warming trend during the last 30 years (Pavlov 1994; Oberman and Mazhitova 2001; Romanovsky et al. 2001 and 2002). Ground temperature trends generally follow the trends in the air temperatures with more pronounced warming in the lower latitudes (between 55° and 65° North). This recent climate warming brought soil temperatures in Northern Eurasia to a surprisingly high level, about 1 to 3°C warmer than long-term averages (Figure 3.6.2a). Within some areas the permafrost temperatures now are very close to 0°C (Figure 3.6.2b) and at some sites a long-term permafrost degradation already started (Fedorov 1996; Fedorov and Konstantinov 2003; Gavriliev and Efremov 2003). The mean annual permafrost surface temperature (MAPST) is important because it reflects the existence and thermal stability of the permafrost. When MAPST exceeds 0°C, the winter freezing front does not reach the surface of the permafrost (permafrost table) by the end of cold season, resulting in a talik formation and the start of permafrost degradation. The permafrost degradation could also start with MAPST still below 0°C. If the increasing active layer thickness reaches the ice horizon, or the ground layer with high ice content, the ice begins to melt and the ground subsides. Surface water will flow into the deepening trough and can form pools and lakes (thermokarst formation). This new presence of water on the surface will help thermal energy to penetrate the ground faster, resulting in an acceleration of the permafrost degradation. In winter, more snow will settle into the deepening trough, which will additionally insulate the ground, resulting in an increased MAPST.



A.



B.

Figure 3.6.2. Mean annual air and ground temperatures in East Siberia (a) at different depths at the Churapcha meteorological station (62.03°N, 132.6°E) and (b) surface air and ground temperatures at 1.6 m depth at the Tongulakh meteorological station (60.7°N, 114.9°E). Threshold at 0ºC is outlined. Data were obtained from the Monthly Climate Bulletin (Klimatologicheskii spravochnik … 1961-1992).

This will prevent the winter freeze from penetrating to the permafrost table, further accelerating degradation of permafrost (Kudryavtsev et al. 1974; Yershov 1998). Because of these effects, once permafrost begins to thaw and a significant settlement of the ground surface occurred, the process would continue even through colder winters, which would otherwise be expected to resist the degradation process.

If recent trends continue, it will take several centuries to millennia for permafrost in the present discontinuous zone to disappear completely in the areas where it is now actively warming and thawing. However, negative consequences of this degradation will be pronounced from the very beginning because the highest ice content in permafrost usually is found in the upper few tens of meters (Figure 3.6.3). Future projections of changes in permafrost temperature and integrity strongly depend on a specific scenario of the future climate changes and on quality of the permafrost models used for these projections (Anisimov et al. 1997; Sazonova and Romanovsky 2003; Sazonova et al. 2004; Malevsky-Malevich et al. 2004). While the increase in permafrost temperatures may change many of its physical properties that can have some negative effects on infrastructure, the major threshold occurs when permafrost starts to thaw from its top down. At this moment, many processes (some of them very destructive) will be triggered or intensified. The most significant impacts on ecosystems, infrastructure, carbon cycle and hydrology will be observed in areas where permafrost contains a considerable amount of ground ice. In the polar areas, where permafrost will still be stable, the depth of the seasonal active layer will increase significantly.

Figure 3.6.3. Extremely ice-rich permafrost (so called "Ice Complex") at the Duvaniy Yar site on the Kolyma River, East Siberia (photo by S. Davidov).

3.6.1.3. Past changes in North Eurasian glaciers and future predictions of their dynamics.

In the NEESRI-region there are about 175,000 km^2 of area covered by glaciers (Figure 3.6.4), which constitutes 26% of all mountain glaciers and subpolar ice caps on Earth, outside the Greenland and Antarctic ice sheets. About 30% of NEESR-region glaciers are in the Russian Arctic; others are unevenly distributed between several large Central Asia mountain regions and high latitude Siberian mountain ranges. The distribution of glaciers in the Russian part of the Arctic (Figure 3.6.1.4) shows distinct eastward decrease in glaciation because of a decrease in precipitation and an increase in the continentality in that direction. The major sites of glaciation in the Russian Arctic archipelagos lie along the branches of the atmospheric trough which originates in the North Atlantic.

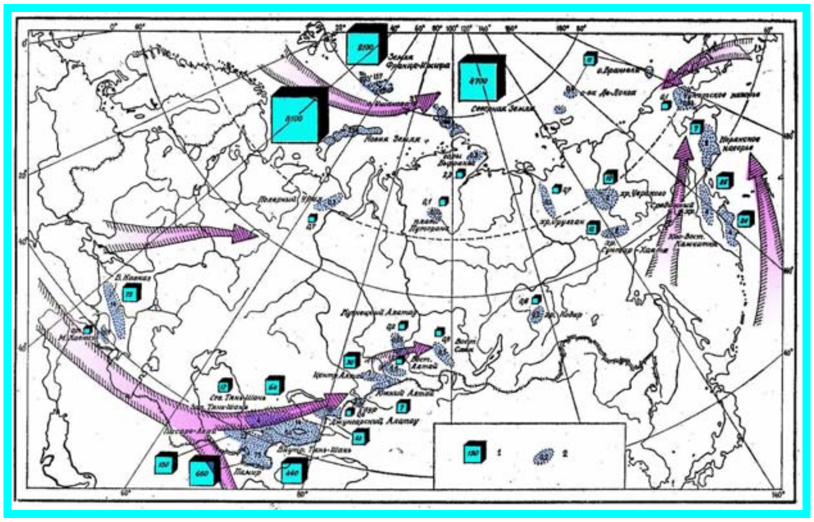
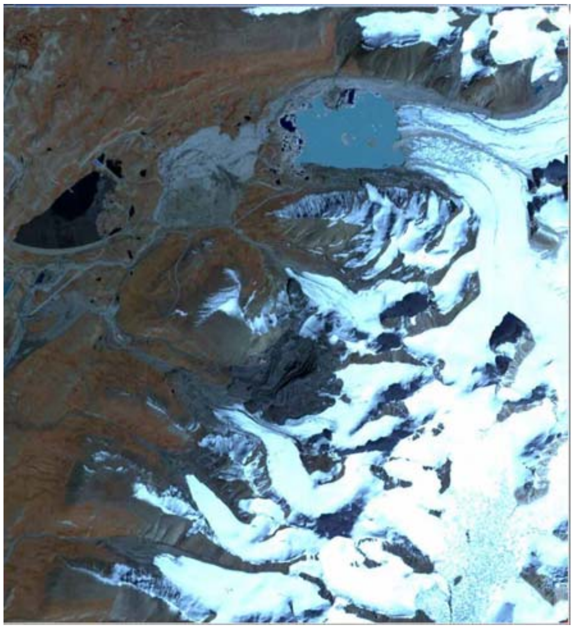


Figure 3.6.4 Glacier regions of northern Asia. Ice volume in km^3 is shown as cubes, arrows show major low-pressure tracks (Krenke 1982).

Throughout the previous century, glaciers in the Cold Land Regions of northern Eurasia showed a negative mass balance; their volume is decreasing (Table 3.6.1) presumably in response to climate warming in the Northern hemisphere (Jania and Hagen 1996; Dowdeswell et al. 1997; Serreze et al. 2000; Dyurgerov and Meier 1997, 2000; Meier et al. 2003). Minor advances in ice margins of some Arctic glaciers are significantly smaller than widespread retreat (Glazovsky 2003). The marine ice margins reveal the digression trend all over the Western Russian Arctic in the second half of 20th century. The largest net recession occurs on Novaya Zemlya (on average –1.5 km, maximum –5.56 km). Because of the general recession of marine ice margins, the ice-covered areas on Russian archipelagos have diminished by 725 km^2 (-375 km^2 on Franz Josef Land, -284.2 km^2 on Novaya Zemlya and -65.4 km^2 on Severnaya Zemlya). The average rates of the glacier front retreat are -30 m/yr for Novaya Zemlya, -17 m/yr for Franz Josef Land, and -3 m/yr for Severnaya Zemlya (Glazovsky 2003). Recent studies show that mass balance of the dry arctic glaciers is mostly affected by the summer temperatures, but for the wetter regions fall and spring temperatures are just as important. Glaciers on Severnaya Zemlya, Franz Josef Land and, in lesser extent, on Novaya Zemlya belongs to the dry type, therefore summer temperature changes might strongly influence their mass balance and dynamics in the future.

Table 3.6.1. Long-term changes in area and volume of glaciers in selected mountain regions

Region	***Time period***	Loss of area, %	Loss of volume, %	*References*
Caucasus	1894-1970	-29	-50	Meier et al. 2003
Elbrus (Central Caucasus)	1887-1997	-14		Zolotarev et al. 2002
Tien Shan	1955-1995	-15	-22	Meier et al. 2003
Zailisky Alatau (W. Tien Shan)	1955-1990	-29	-32	Vilesov et al. 2001
Akshiyrak (internal Tien Shan)	1943-2001	-26		Khromova et al. 2003
Gissar-Alai (Pamirs)	1957-1980	-16		Shetinnikov 1998
Adylsu (Caucasus)	1974-2000	-5		Nosenko et al. 2003
Polar Ural	1953-2001	-55		Nosenko et al. 2003



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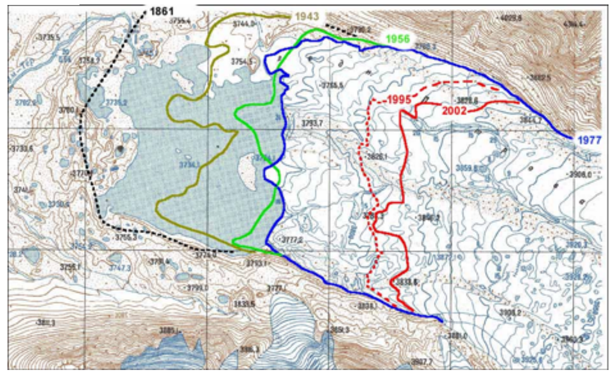

Figure 3.6.1.5. Example of a central Tien Shan glacier recession. Petrova Glacier in the Akshiyrak area, ASTER image, September 2002 (A), and instrumental topographic data (B) (Aizen and Kuzmichonok, 2003).

The 143 glaciers in Polar Urals occupy only 28.7 km^2. New assessment based on set of ground photogrammetry data and ASTER images shows strong reduction of Polar Ural glaciers from 1953 to 2000. They lost nearly half of their area in this period, and the negative trend in the last decade seems to accelerate (Nosenko et al. 2003). There are 96 glaciers in the northern, highest part of the Byrranga Mountains in the Taymyr Peninsula with a total area of 30.5 km^2. From 1960 to 1977, more than 10 glaciers have disappeared (Govorukha 1989).

In central Asian mountains there are approximately 30,000 glaciers with a total area equals to approximately 25,000 km^2 there. During the period 1940-1998, the average rise in air temperature was 0.01°C per year in Tien Shan and Pamir high altitudes (Aizen et al. 1997) and 0.02°C per year in the Altai alpine regions (Aizen et al. 2003). A strong warming signal occurred with significant correlation of temperature trends with elevation, i.e., increase in air temperature is larger at the high elevation where the glaciers and mountain permafrost are most common (Aizen et al. 1997; Marchenko 1998a). This increase in air temperature already has a noticeable effect on glaciers and mountain permafrost. During the period from the 1950s to the 1990s, 80% of glaciers were retreating in central Asia (Haeberli 1990). A negative glacier mass balance is typical for central Asian glaciers (Aizen et al. 1997a,b). In the Tien Shan Mountains, glaciers covered 7,273 km^2 in 1955 (Krenke, 1982). This area has been reduced by 29.1% by the end of the last century. Rough estimations show that glaciers lost up to 27% of their mass. Up to 12% of glaciers with area less than 1 km^2 have disappeared. The largest glacier recession has occurred in northern and central Tien Shan (Figure 3.6.5). During 1952-1998, Altai glaciers lost about 10% of their mass and were retreating by 2-8 m per year.

Records of temperatures in permafrost and the active layer at 3330 m in the Tien Shan Mountains, Central Asia, have indicated a positive trend from -0.8°C to -0.3°C under the natural conditions and up to -0.1°C under an anthropogenic load (Marchenko 1997). The seasonal soil thaw has increased by 35%. Pleistocene and Holocene moraine complexes are wide spread in the periglacial area in Central Asia. Typically, it is an ice-rich formation. The upper layer (10-15 m) of such deposits contains 10-50% of excess ice. Alluvial and lacustrine sediments very often contain 30-60% or more of excess ice. During the Holocene, these formations have kept most of this ice, but recent warming caused degradation of ground ice and accompanying changes of landscapes. General circulation models suggest that the increase in summer diurnal temperatures over central Asia is likely to be higher relative to that in other regions (ICCP, II, 2001). Therefore, we expect a further degradation of glaciers and alpine permafrost.

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3.6.2. COASTAL ZONE PROCESSES.

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Box Insert 3.6.1 . Example: The Sea of Azov and its basin

The Sea of Azov and its basin is a system highly susceptible to climatic and anthropogenic impacts. Approximately 15% of the population of Russia and the Ukraine is located in the basin area of 0.57 x 10^6 km^2, along with approximately 20% of the industrial and 25% of the agricultural production of these countries. Most of the basin is in a steppe climatic zone, which receives unpredictable and insufficient moisture. Water resources of the basin consist of the Don River (28 km^3yr^{-1}), the Kuban River (12 km^3yr^{-1}) and a few small steppe rivers (~2 km^3yr^{-1}). The annual streamflow of the Don and Kuban Rivers have very high interannual fluctuations (from 22 to 68 km^3yr^{-1}). The spring runoff makes, up to 56% of the total annual river volume (and about 70% for the Don River alone). Twenty percent of the Kuban River streamflow originates from the melting high-mountain snow and glaciers of the Caucasus Mountains.

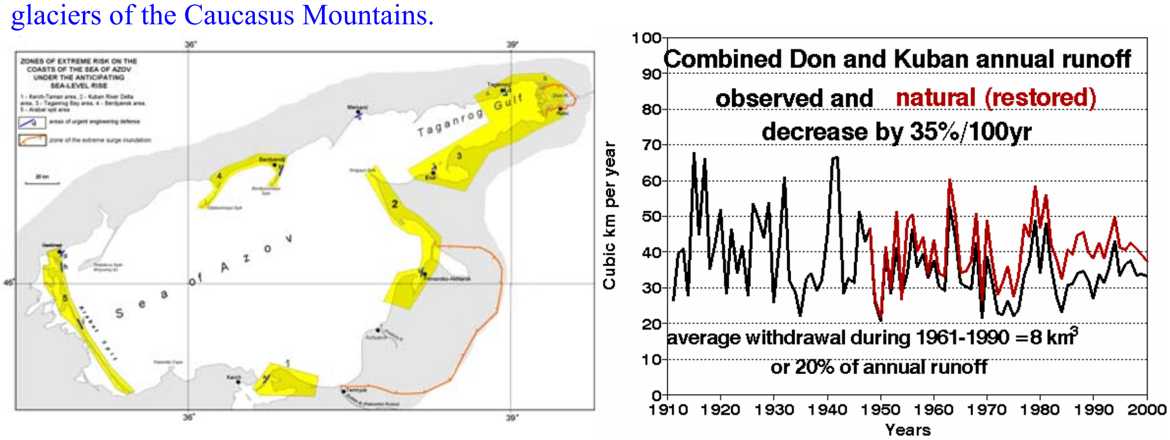

Figure 3.6.11. Sea of Azov coastal zones at extreme risk, and variations of actual and natural (estimated without human impact) runoff into the Sea (km^3 yr^{-1}).

Fluctuations of water and bioorganic matter runoff considerably affect the Sea ecosystem. The Azov is a shallow (the mean depth is 7 m) water body with a small area of 0.04 x 10^6 km^2 and volume of 320 km^3. Its hydrological regime is formed by interaction of river inflow with saltier Black Sea water and very salty waters from Sivash Bay, the lagoon in the western part of the Sea of Azov. Streamflow and inflow of the Black Sea waters each contribute 13% of total Sea volume, and precipitation contributes ~ 5%; the outflow to the Black Sea and Sivash Bay is 21%, and the evaporation from the water surface is 10% of the Sea volume (Fedosov and Vinogradova 1955). Streamflow has the greatest effect near river mouths. The major areas of river input are the Taganrog Bay in the Don River mouth and the extensive Kuban River mouth in the southeastern corner of the sea, where the greatest volume of biogenic river runoff accumulates.

The basin area is characterized by extraordinarily high water withdrawal that affects the state of the Sea's marine ecosystem (Koronkevich et al. 1999). Up until 1952 the river runoff was mainly determined by climatic fluctuations, and only to a small extent influenced by construction of numerous ponds on small rivers (Sementsov and Eremenko 2000). Filling the Tsimlyanskoe reservoir (from 1952 to 1955) with the maximum withdrawal of river runoff coincided with increased atmospheric precipitation. The response of the marine ecosystem to this major disturbance was a small increase of the Sea's salinity (up to 11-11.2 pro mille) and a decrease of productivity due to reduction of autochthonous biogenic runoff. From that time until the late 1980s, an expansion of arable lands, an increase in irrigation and fertilizer use, a growth in livestock population, an increase in industrial production accompanied by increased water withdrawal, and a return of waste waters resulted in a loss of 30% of annual Don runoff and 44% of Kuban annual runoff to the Sea, significant changes in the rivers' hydrograph, and deterioration of the water quality (Shiklomanov and Georgievsky 1995; Lurje and Panov 1999). The nitrogen content in the streamflow increased, especially since the construction of large reservoirs on the Don and Kuban, and the content of phosphorus decreased (Bronfman and Khlebnikov 1985; Environment of Ukraine 2001). In the late 1980s, the human impact became equal to or even greater than the natural processes, causing dramatic changes in the Sea's ecosystem (Shlygin 1975; Bronfman et al. 1979; Smolyakova and Shlygin 1980; Remizova 1984; Makarov et al. 2000). The most pronounced negative consequences of the anthropogenic load manifested themselves in the years with low river runoff. The average salinity increased considerably, reaching critical values for the survival of the natural ecosystem (13.4 – 13.8%o). The natural balance of the biogenic elements nourishing the Sea was disturbed by a nitrogen surplus and a deficit of phosphorus (Bronfman and Khlebnikov 1985; Environment of Ukraine 2001). In the Taganrog Gulf and the adjacent sectors of the northern Sea of Azov along the Ukrainian coast, blooms of blue-green algae started to develop periodically due to a surplus of autochthonous organic matter (Tamaitchuk 2002). In the open part of the Sea (the part most subjected to Kuban River runoff impact), regions with anoxic bottom waters have been recorded (Simonova, 1987). In the 1990s, many of these tendencies were reversed due to a reduction of anthropogenic impact and an increase in precipitation. During the past 15 years, desalination of the Sea to a level equal to that obtaining during the first half of the 20^{th} century and a reduction of biogenic matter content in the waters of the Sea have gradually taken place (Environment of Ukraine 2001). However, the natural potential of the Sea of Azov did not recover (Yakushev et al. 2003).

Coastlines of the Sea of Azov are retreating under present conditions at a rate of up to 5-7 m/yr at coastal scarps composed of loose Quaternary sediments (loesses), and at a rate of up to 2-3 m/yr at depositional bodies such as beaches, spits and barriers. The process is, and will continue to be aggravated by changes in water salinity. The problem is that productivity of mollusk shells, of which the majority of depositional bodies are composed (up to 90-95% at several coastal segments), depends heavily upon water salinity. *Cerastoderma glaucum (Cardium edule),* the most important "beach builder", flourishes at a water salinity of 11-12 pro mille. This organism suffers much from either higher or lower salinity, and decreased productivity of this mollusk results in faster degradation of beaches. Intensive development of coastal areas creates substantial problems in terms of coastal dynamics and water pollution. For example, in the middle 1990s, an underground lens of kerosene from the air force base in Eisk, the Taganrog Gulf, was eroded, polluting coastal waters.

Box insert 3.6.2. Coastal Zone of the Pechora Sea

The Pechora Sea is located in the southeastern corner of the Barents Sea between the islands of Kolguev and Vaigach (Figure 3.6.12). Here, intensive economic development is occurring in the coastal zone and in the inner shelf due to the prospecting for, exploring, and exploiting of numerous oil and gas fields. The estimated resources of exploited fields are 2.4×10^9 tons of oil and 1.2×10^{12} m^3 of natural gas. The density of these resources in the coastal zone is 19,300 ton/km^2, the highest in Russia (Romankevich et al., 2003). Prospecting for and exploiting

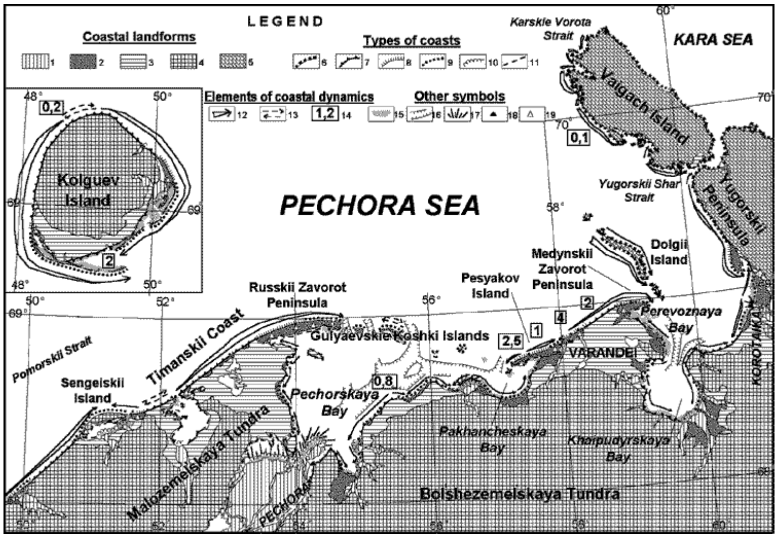

Figure 3.6.12. Morphology and dynamics of the Pechora Sea coasts (modified from Kaplin and Selivanov 2003; Ogorodov 2003). See "1" in Figure 2.5.a for the general position.

these resources has already damaged the natural ecosystem and degraded the living conditions of the local population. The traditional economy of the local population is based on reindeer breeding and salmon fishing. Both occupations suffer much from the present development activity. Tractor-trailer traffic, oil, gas leakages from exploited fields and pipelines crossing the coastal zone, increasing coastal erosion due to a reduced sediment supply, and re distribution of along shore sediment flows all threaten to destroy the unique ecosystem in this region. Unfortunately, the Pechora Sea coastal zone ecosystem is highly vulnerable to both natural changes and anthropogenic impact. This vulnerability is determined by the following factors:

- A high ice content of the permafrost coastal slopes in loose Quaternary sediments and depositional bodies like spits and barriers;
- A high intensity of tides and wind surges; and
- A strong impact on the coastal zone dynamics of the highly variable sediment supply from the Pechora River and smaller rivers and the alongshore movement of these sediments.

The human impact has already created serious problems for the traditional economy and the coastal zone ecosystem. Coastal retreat and related processes (decrease of potable water quality, degradation of a unique salmon population) are among the most important adverse consequences. Presently, several coastal areas of the sea retreat at an average rate of over 4 m yr^{-1}. In some areas, the increasing development activity has resulted in the doubling of this retreat rate (Ogorodov 2003). The most economically developed Varandei area has suffered the most from these processes. This area, which was a peninsula several decades ago, has become an island. Coastal erosion in the Varandei area has greatly intensified due to both natural factors (sea level rise, decrease of river sediment supply from the Pechora River and sea floor) and anthropogenic activities. Several living and industrial quarters in the Varandei settlement area have already eroded. Oil tanks that were quite far from the coast line in the past are now in serious danger. The distance from several oil tanks to the coastal scarp decreased by over 40 m since their construction in 1987, to a distance of less than 6 m in 2000 (Figure 3.6.13; Ogorodov 2003). The local airport is also situated in the zone of possible erosion during the next decades.

During the present century, the projected global warming and sea-level rise will most likely be aggravated by the "Arctic amplification" effect (3.3.2). Thus, intensified Pechora Sea coast destruction is a very probable scenario, due to continued thawing of permafrost and related processes such as thermoerosion, thermoabrasion, and thermodenudation (Kaplin and Selivanov 2003). The erosion may reach a rate of over 10 m yr^{-1}. Many industrial and infrastructure facilities in the region are currently located within several dozen meters of the present shoreline. Among them are existing and/or planned oil/gas exploitation areas, pipelines, infrastructure and housing developments. They all will be inevitably destroyed during this century. Specifically, the barrier islands/peninsulas in the outer parts of the Pechora Sea are doomed to partial or complete degradation over the next several decades. Furthermore, coastal retreat and degradation will be enhanced in the bays with high tides. The general tendency for coastal erosion to prevail over deposition may be amplified by a decrease in river sediment discharge. This has occurred recently in the Pechora River basin, one of a few Arctic slope regions with decreased precipitation and runoff during the past several decades (van Eerden 2000; Razuvaev et al. 2003). All of these facts clearly prove the necessity for integrated studies of coastal zones in Northern Eurasia, especially of the most vulnerable Arctic coasts, for justification of their economic development strategies.

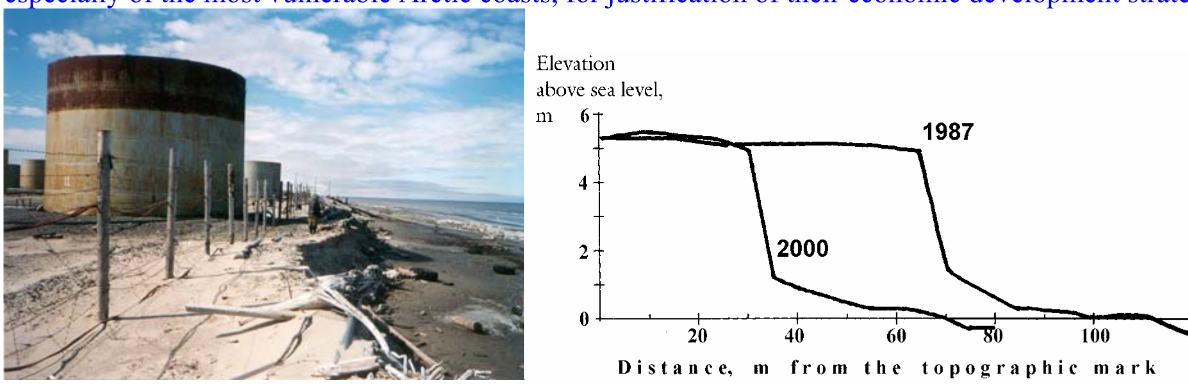

Figure 3.6.13 Endangered oil tanks in the coastal zone (Varandei settlement, the Pechora Sea coast) and the shoreline retreat in this particular region from 1987 to 2000 (Ogorogov 2003).

Box Insert 3.6.3. The Baltic Sea issues (pollution and coastal erosion)

Introduction. The Baltic Sea is a semi-enclosed large non-tidal brackish water body of 390 000 km^2 influenced both by natural conditions and by the 80 million people living within the large drainage area (2 mln. km^2). It has a very limited connection with the North Sea which does not exceed 5-7% of the total water budget. The Baltic Sea is characterized by brackish water conditions that result from riverine and precipitation inputs of freshwater and periodic wind driven inflow of saline water from the North Sea. Under average conditions, salinity decreases and the halocline deepens from west to east and north due to the increasing distance from the North Sea influence. A corresponding decrease in oxygen content is also observed. The salinity fluctuates markedly due to the intermittent nature of the saline water influx. No significant inflows of saline waters from the North Sea have been observed since 1994. This has led to a reduction in salinity in the Baltic Sea, particularly in the north and east, which has been exacerbated by increased levels of precipitation in recent years. Being semi-enclosed, the Baltic Sea is flushed slowly and it takes 25-30 years for complete water renewal. Therefore, changes in biogeochemical processes are slowly reflected in the sea system over several decades. There are several international agreements covering various aspects of the sea and coastal zone study, monitoring, and management. Several international bodies are working in this area with mandates to harmonize research activities and industrial developments and make regular assessments of the state of the marine and coastal environments. The Helsinki Commission (HELCOM) is one of them. *Currently, dozens of European Union (EU)-funded programs are being run by various science institutions in the area Thus the aim of the NEESPI activities in this region is not a duplication of those projects but* re-*consideration of their results and major findings through the prism of NEESPI goals.*

Pollution problem of the Baltic Sea. Excessive amounts of ***nitrogen and phosphorus*** *compounds* entering the sea cause eutrophication, disturb the balance of the Baltic marine ecosystem, and cause biological, chemical and physical changes in the population structure of flora and fauna. The excessive nutrients encourage plant growth, particularly micro-algae. The algae sink to the seabed where they are metabolized by benthic bacteria in processes that require oxygen. If the numbers of algae are excessive, this decay can lead to a completely anoxic seabed, devoid of much of its life. In 1996-1997 benthic communities in the Gulf of Finland collapsed as a result of oxygen deficiency caused by eutrophication.

The majority of these nutrients enter the Baltic Sea from rivers draining surrounding farmlands and cities; just five rivers, the Neva, Daugava, Vistula, Oder and Nemunas, account for almost half of the nitrogen entering the Baltic Sea. Extreme weather events exacerbate the pollution problem. For example, severe flooding of the Vistula and Oder rivers in 1997 and 2002 led to increased nutrient loading in the Gulf of Gdansk and the Pomeranian Bight, and subsequent algae blooms. In addition to *nutrients*, *hazardous substances,* and *oil,* there are other forms of pollution in the Baltic, including *dumped munitions, dredging* and *spoil dumping.* Thus "time-bomb" effects should be taken into account when various scenarios of climate change are applied to the Baltic Sea and its coastal zone. Due to temperature rise, coastal erosion, sea level rise, and other processes, harmful substances could be released to the Baltic Sea. ***Hazardous substances*** are those which are toxic, persistent, and liable to bioaccumulate, or give other cause for concern, such as affecting the endocrine system. They include organochlorines, heavy metals and hydrocarbons. The Baltic Sea is semi-enclosed, and these chemicals remain for a long time in the coastal water. Therefore, despite the reduction of input during the past decade, concentrations of polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) are still much higher in the Baltic than in the North Sea. The main pathways by which hazardous substances enter the Sea are from industrial and municipal wastes draining into the rivers, atmospheric input, and shipping. Most ***oil*** comes from ships ignoring international law by discharging oily waste and flushing tanks and cargo holds. Oil spills contaminate the surface water and smother marine plants and animals. Many chemicals in oil are toxic, and can have serious cumulative effects as they build up in ecosystems. Spills can also have severe repercussions for tourism, while the necessary clean-up operations may themselves unavoidably harm marine life and coastal habitats. Oil can negatively impact fisheries; toxic compounds can damage eggs (especially those which float, such as cod eggs), and larvae, and spills will effectively shut down any fisheries in the area due to concerns about toxins and oil fouling fishing gear. Many of the Baltic States, and also HELCOM, operate monitoring planes and vessels to detect oil pollution and those responsible. Based on the results of pilot (experimental) satellite monitoring of the Baltic Sea carried out in the 1980s and subsequent space-borne observations (Victorov 1996), in 2003 several Baltic states launched project OCEANIDES which aims to use satellite imagery to monitor and map oil spills in the Baltic Sea.

Coastal zone problems in the Baltic Sea. Currently much effort is applied to study the problem of Baltic Sea pollution. It seems that less effort is expended to study global climate change effects on the Baltic Sea and its coastal zone. An attempt to analyze potential impacts of future climate change on the freshwater inflow to the Baltic Marine Area was made by Graham et al (2000). Based on regional downscaling of Global Climate Models carried out within the Swedish regional climate modeling program, it appears that global warming may lead to a changed annual cycle and less pronounced spring floods as winters become less stable. According to these scenarios, freshwater inflow to the Baltic Marine Area will generally increase in regions fed by the northernmost parts of the drainage area and decrease in the Baltic Proper. One project - the SEAREG project - focuses on assessing the socio-economic and environmental impacts of climate change in the Baltic Sea region, especially the sea level rise and the changing river runoff patterns. Both these changes may lead to major flooding events, which would severely impact the spatial development of cities and regions, as well as the sustainable development of the entire Baltic Sea Region. The German, Polish, Russian (Kaliningrad area), and Lithuanian Baltic coasts are flat, low-lying and micro-tidal and hence vulnerable to sea level rise. These coasts are not so highly developed as the North Sea coasts, but there are important harbours and cities such as Gdansk. Further east and north, Lithuania and Estonia still benefit from glacial rebound and hence relatively less sea level rise. The main concern here is for the extensive coastal wetlands, which are also under threat from economic development. Unfortunately, the Russian and Latvian Baltic coasts are understudied. At the opposite site of the Finnish Gulf, Finland may actually benefit from global sea level rise, because it would stop relative sea level fall, which is problematic for water transport infrastructure. These benefits have yet to be estimated. The level of the largely enclosed Baltic Sea is not only influenced by global sea level rise, but also by precipitation and temperature change in the Baltic Basin (Tol, 2000). Overall, the diversity of Europe's coasts and their vulnerabilities to sea level rise is striking. This diversity is not due simply to great differences in the natural environment. Economic standards and decision making cultures are also very different. It is also clear that sea level rise cannot be studied in isolation from other changes (climatic and otherwise). In a number of cases, looking at sea level rise alone may even yield a bad first approximation of the 'real' impacts of sea level rise. To understand the impacts of sea level rise, a better understanding of the social dimensions and capacity for adaptation is required (Tol 2000).

Box insert 3.6.4. Coastal zone changes in the Eastern North Eurasian Arctic and biogeochemical consequences of these changes.

Transport of terrestrial material. Most of the eroded terrestrial organic matter accumulates in coastal zones; however, significant amounts of this material are transported further offshore by different processes, such as sea ice, ocean currents, and turbidity currents. The near-shore system of *the Laptev and East Siberian seas is the most climatically sensitive area in the Arctic and the highest rates of coastal retreat occur* here (Are 1999; Grigoriev and Kunitsky 2000; Figure 3.6.14). The broad shelves of the Arctic are important to many processes, and export of

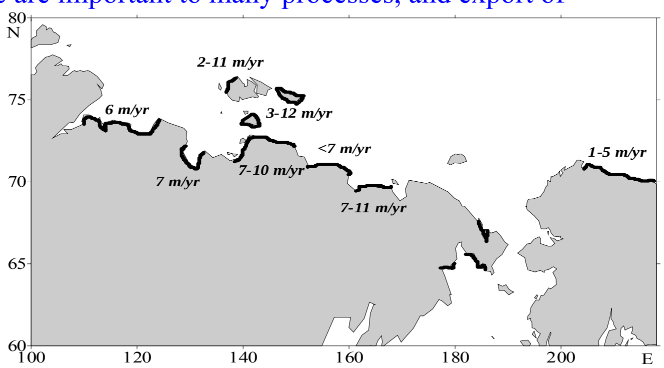

Figure 3.6.14. Rates of coastal erosion along the North Asian Arctic Rim (Semiletov, 2003).

terrestrial eroded carbon from these shelves plays a crucial role in regional fluxes of carbon, nitrogen and phosphorus. The high rates of coastal erosion and deposit of organic materials are often associated with coastal ice-complexes. Smith and Hollibaugh (1993) estimate that about one third of land-derived organic matter is re-mineralized rapidly within estuaries and coastal zones. The increase of pCO_2 in the surface sea water in the coastal zone from west to east in the Laptev and East Siberian Seas system is correlated with an eastward increase in the on-shore area covered by the ice complex deposits. Because permafrost with higher ice content is more susceptible to thermokarst and coastal thermal erosion processes, it is possible that the eastward increase in pCO_2 values might be related to the general eastward increase in land surface erosion (Figure 3.6.14) induced by thermokarst, coastal thermal erosion, and sea hydrodynamics (3.6.1). Apparently, a fraction of the terrestrial carbon does get remobilized and released in CO_2 form to the atmosphere and ocean in the near-shore environment. High values of pCO_2 were found both near the mouths of the Siberian rivers and at the coastal sites located far from the riverine inflow (Semiletov et al. 1996; Semiletov 1999a,b; Semiletov et al. 2004): pCO_2 values reach 4,000 ppm in the bottom water and up to 1,500-2,000 ppm at the surface (Semiletov 1999a,b; Figure 3.6.15). A high positive CO_2 gradient (more than 1000 μatm) between the surface waters and air in the sites remote from the river's influence indicate the existence of non-river sources of CO_2 for the coastal waters [Semiletov 1996, 1999a]. The existence of anomalously high values of pCO_2 in the water adjacent to a rapidly retreating coastal ice complex is correlated well with the low oxygen saturation (down to 30%) and high nutrient values (Figure 3.6.15), which could result from destruction of the eroded organic

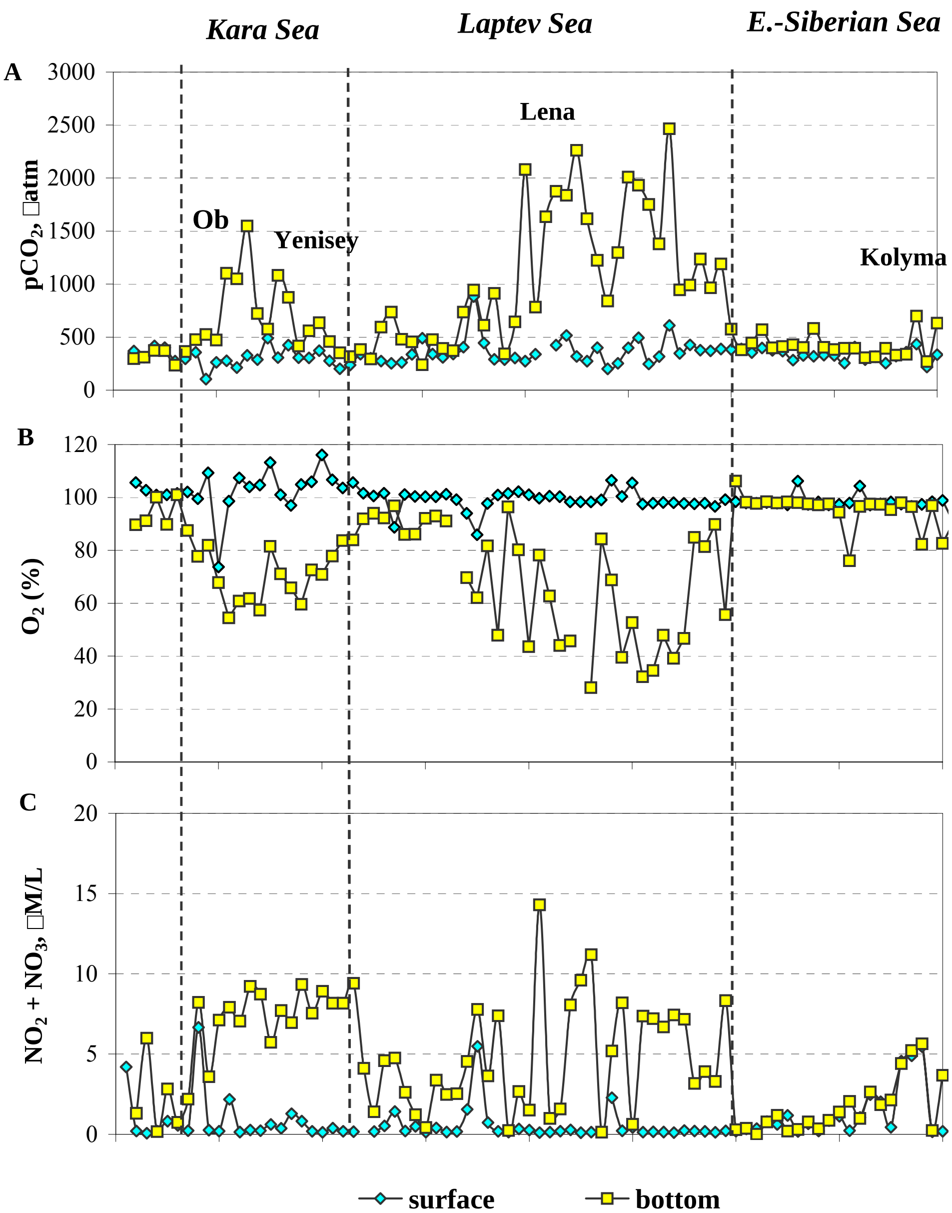

Figure 3.6.15. Distribution of (A) - CO_2 partial pressure, µ atm, (B) - oxygen saturation (%) and (C) - nitrate-nitrite sum (µ M/l) in the coastal zone of the Eurasian Arctic seas in 2000 (Semiletov 2003). The highest values of pCO_2 and nutrients found in the near-shore zone are due to coastal erosion. At the same time, low values of dissolved oxygen (down to 40% of saturation) indicate high rates of destruction of old terrestrial organics. Results are supported by the data of previous expeditions (Semiletov 1999a,b).

carbon. This source of organic matter may be more significant over the wide and shallow northeastern Asian shelves than over the narrow shelf of the North American shelves. An evaluation indicates that about 50-70Tg of eroded solid matter is deposited offshore along the Laptev and East Siberian coastline (Grigoriev and Kunitsky 2000), whereas a major portion of the fluvial sediment load is dispersed within the delta channels (Rachold et al. 1996). Following Rachold et al. (1996), we assume that only 5 Tg of the Lena River sediment load reaches the Laptev Sea shelf. It has been argued that coastal thermal erosion in the Laptev and East Siberian Seas makes a significant contribution to the coastal sediment input: it may be up to one order of magnitude higher than the fluvial sediment discharge (Semiletov 1999b; Dudarev et. al. 2001). The finding of anomalously high concentrations of benthic organisms (up to 100-200 g C per square meter) within the depressions in the Laptev Sea shelf (Gukov et al. 1999) could be associated with near-shore accumulation of the coastal old organic carbon.

Global Change, erosion, and the Biogeochemical Cycle in the coastal zone. Present data indicate that under global warming, the rate of coastal erosion in the Arctic might change from a few meters per year, which it is now, to tens of meters per year. During the 20th century, many small ice complex islands disappeared along the Siberian coast; for example Semenovsky and Vasilievsky islands in the Laptev Sea, and St. Diomid Island in the East-Siberian Sea (Gavrilov et al., 2003). According to Tomirdiaro (1990) and Are (1999), mean rates of coastal erosion in the Arctic are near 2-6 m per year, whereas the coastal ice complexes of the Siberian Arctic have been retreating at annual rates of up to 11-30 m (Tomirdiaro 1990). Bottom erosion can be high also (Gavrilov et al. 2003). Observations of the Northern Route Hydrographic Service show an increase in the sea water depths in the near-shore zone of up to 0.8 m over 14 years (Tomirdiaro 1990). This is also important for navigation. Therefore, *coastal and sea bottom erosion can cause changes in the lifestyle of native people and can also affect navigation in the future*.

Many factors influence Arctic sea coastal retreat[68]. Rates of coastal retreat might be increased by changes in the coastal marine hydrology[69] and by observed decrease in the ice cover and increase in open water season on the Arctic shelves (Morrison et al. 2000; Manson et al. 2001). The increase of about 15 cm per 100 years in sea surface height (IPCC 2001) could accelerate terrestrial material transport into the sea. During the glacial-interglacial transition and sea level rise (by ~ 100-120m), a huge amount of buried terrestrial organic carbon was involved in biogeochemical cycling (Fahl and Stein 1999; Bauch et al. 2000). The coastline at 7.5kyr BP was 150-250 km north of its current position (Romanovsky et al. 2000). This means that the rates of coastal permafrost degradation and flooding of coastal lowlands were extremely high over the past millennia. Crude calculations of the mean transport of particulate organic carbon from land to the Laptev and East Siberian Seas estimate 2.5 - 7.0 Tg yr^{-1} and we can assume that during the last 5,000 years, when the sea level did not change significantly, total transport of eroded carbon was equal to 12.5-35 Gt {Semiletov 1999b). This is a significant portion of the modern dissolved carbon capacity of the Arctic Ocean (about 450Gt). Thus, the off-shore transport of eroded carbon and its consecutive degradation will influence the carbonate system, nutrients, and sedimentation, especially in the near-shore zone, and affect the productivity of the coastal marine ecosystems, both past and present (Semiletov 1999a, b). Evidence of recent 50-year large-scale changes in redox conditions in the Arctic Ocean basin sediments (from oxic to anoxic diagenesis) most likely originated with the enhanced organic carbon fluxes to the sea floor (Gobeil et al. 2001). This might be related to a reduction in the ice cover, which led to an increase in coastal retreat causing an increased seaward transport of terrestrial carbon previously sequestered in the coastal permafrost. It could also be a significant factor for the increase in atmospheric burden of the main greenhouse gases, because the upper 100 m layer of permafrost alone contains not less than 10,000 Gt of organic carbon that could be involved in biogeochemical cycling in the form of methane (CH_4) and CO_2 (Semiletov 1999a). The current atmospheric CO_2 and CH_4 burdens are ~750Gt C- CO_2 (Quay et al. 1991). Therefore, small changes in the current carbon stock of coastal permafrost might significantly affect present and future concentrations of the main greenhouse gases in the atmosphere.

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[68] Permafrost ice content, height and slope of bluff, air temperature, direction and speed of winds, duration of open water season, water temperature, waves, tides, ice-edge dynamics, timing of freeze-up and break-up, surges and currents, and near-shore bathymetry.

[69] E.g., the increase in seasonal amplitudes of the Siberian rivers' discharge and temperatures in their watersheds after the 1970s (Savelieva et al. 2000) indicate that the contemporary climatic changes manifest themselves not only by global warming, but also by secular changes in the atmospheric circulation. These changes are observed, for example, in the temporal change in the atmospheric CO_2 seasonal amplitudes (Conway et al. 1994).