8. RESEARCH STRATEGY

A survey of the science community represented by an interdisciplinary workshop convened by NEESPI in April 2003 and summarized in the remainder of this chapter revealed several notable gaps in our current level of understanding of Northern Eurasian biospheric, climatological, and hydrological systems. At the same time, rapidly emerging data sets, technologies, and modeling resources provide an unprecedented opportunity to move substantially forward. Six major research and synthesis challenges with accompanying recommendations for strategic investments in the science of the North Eurasian system are given below. Furthermore, five major directions of the NEESPI studies are formulated.

8.1. Research challenges

Understanding, simulating, and predicting (or assessing the predictability of) contemporary and future biosphere, climate, and hydrological system dynamics and interaction with human activity are greatly limited by the following:

1. There is a sparse observational network for routine monitoring and an absence of integrated data sets of spatial and temporally harmonized biogeophysical information over the Northern Eurasian domain. The variety of biomes from tundra in the North to semi-deserts and deserts in the South amplifies the problem with observations. The situation is far from optimal, and is deteriorating rapidly over much of Northern Eurasia, especially in Central Asia, Mongolia, and Kazakhstan. The Eurasian Arctic has a scarcity of meteorological and hydrological data. This reinforces the need for reliance on historical data, but also shows the necessity of improved data collection.

Recommendation: **A substantial commitment should be made to rescue, maintain, and expand current environmental, meteorological, and hydrological data collection efforts.** Establishing high-resolution gridded maps of climatic, hydrologic, topographic, vegetation, and soil temperatures and property attributes for Northern Eurasia is strongly advised. Additional resources must be invested in scaling techniques, including the expanded use of a combination of modeling and remote sensing. Support for free and open access to the Northern Eurasian environmental data sets is essential to future progress. Coordination with existing national and international monitoring programs is critical.

2. There are numerous gaps in our current understanding of basic scientific principles and processes regarding the interdisciplinary issues of the energy, biogeochemical, and water cycles over the entire Northern Eurasian domain. There is a lack of cross-disciplinary synthesis research and modeling to decipher feedbacks arising from changes in Northern Eurasian climate, land cover, ecosystem, hydrological processes, and cryosphere on the entire Earth system and on society.

Recommendation: **Support should be given to integrative research that identifies the unique role of Northern Eurasian hydrological systems and ecosystems in the broader Earth system.** An assessment of the feedback mechanisms through which progressive environmental change influences both natural and human systems is urgently needed. New research devoted to establishing quantitative linkages between the biogeophysical and socioeconomic research communities is strongly advised. We must develop a better physical understanding of processes controlling feedbacks; meaning we must develop better models to assess the vulnerability of society to changes in climate, fresh water/sea-ice, vegetation, dust production, seasonal snow and other parameters of the natural systems. Integrated models of atmospheric, environmental, hydrological and cryospheric processes, nutrient transport, the ecosystem and societal dynamics must be developed and verified within the major river basins of Northern Eurasia and eventually around the entire continent.

3. We must link terrestrial processes with riverine and coastal responses. We must also quantify how each of these processes has changed over the recent past (50-100 years) and project how they will continue to change in the next 100 years. Changes in soil moisture are an important factor affecting the local, regional and global climate and environment. We must characterize how land use changes (naturally occurring disturbances and anthropogenic perturbations, including afforestation and deforestation) and changes in permafrost extent affect surface soil moisture with subsequent impacts on energy and water balances, and carbon accumulation as well as losses in bogs and forest that grow on peatland.

Recommendation: **Intensive study of soil moisture should be continued and enhanced.** Tools to aid in soil moisture change assessment include: (a) Extensive soil moisture and temperature monitoring at established meteorological stations as well as in other terrain types for target key ecosystems and landscapes, to include different soil types and texture; (b) Development of field techniques to quantify soil moisture levels over spatial areas that would represent a pixel size in a satellite image; (c) Development of remote sensing methods to accurately measure soil moisture levels over large areas; (d) Development of methods to quantify historic levels of soil moisture; (e) Quantifying historic and future changes in precipitation patterns and amounts; (f) Improving understanding of the relationship of soil moisture to other processes; (g) Determining if widespread drying/inundation of soils is occurring and if so, determine the subsequent climatic and ecosystem impacts; (h) Improving our spatial database and distributed modeling expertise on snow cover distribution and re-distribution, changes in forested area, permafrost and active layer dynamics and river discharge; (i) Synthesizing Northern Eurasian water balance studies from around the entire continent; and (j) Development of reliable databases and climatology are required for driving distributed, biospheric, hydrological, and permafrost models, for calibration of remote sensing data/products and for validation of model outputs. Given the scarcity of observational networks in the high latitudes, Siberia, and desert areas of Central Asia, remote sensing and model simulation will play a major role in Northern Eurasia hydrology, atmosphere, ecosystems, and cryosphere studies.

4. Drastic aridization and deglaciation are occurring in the interior of the continent due to an aggregation of global and local anthropogenic causes.

Recommendation: **Extensive monitoring and mitigation strategies should be developed for the Central Asian region.** The current situation in the Central Asian region must be recognized as a complex societal and environmental problem. Studies should include implementation of water and upper soil preserving technologies, modifications of land use, and improved crop management.

5. The coastal zone encompasses the most densely populated and economically developed areas in Northern Eurasia. Unfortunately, it also includes the most vulnerable regions in the current climate and in the forthcoming climate.

Recommendation: **The coastal zone should be explored in detail to quantify its sensitivity to climatic and environmental changes and to the sea level rise.** Estimates of possible damage to the environment, economy and infrastructure should be done on a regional level. The most vulnerable areas must be identified and mitigation strategies proposed for their further development.

6. Society will be affected by anthropogenic and naturally caused environmental changes and react to them. These responses must be guided by an understanding of both the anthropogenic and natural systems, so as to optimally mitigate negative impacts.

Recommendation: **Assessments of the consequences and feedbacks of societal actions in response to environmental change (mitigation strategies) should be carried out.** These assessments must be based on comprehensive models of environmental change that include human actions as an indispensable component of simulations and allow feedback loops of societal reactions to the change. A suite of societal actions (e.g., in the areas of agriculture, water resources, forest management practices, environment protection actions, economy development plans, demography planning) should be among the internal blocks of the models of environmental change.

8.2. Major Assumptions

- **Human-caused global and regional climate change will continue for decades to come.** Changes of greenhouse gases and aerosols in the atmosphere, along with land use change will continue to have a global anthropogenic impact. The global consequences of these anthropogenic climate forcings will continue through the 21st century.
- **Numerous feedbacks within the Biosphere-Global Climate-Human Society system have been and probably will be amplified over Northern Eurasia**. Some of these feedbacks are significant and yet are not well understood.
- **Regional anthropogenic environmental impact in Northern Eurasia has been and probably will be non-linear**. In some fragile ecosystems (e.g., in tundra, semi-deserts, and alpine mountains), this impact has been (and is projected to be) especially strong. Potentially, this impact will increase with time and affect all ecosystems in Northern Eurasia.
- **A responsible society empowered by knowledge of climatic and environmental processes can foresee major consequences of anthropogenic environmental impact**. Thus this impact may be mitigated to some extent.

8.3. Five suggested research directions

A. EXTRACTION AND PRESERVATION OF PAST OBSERVATIONS

Unique observational programs. Several sets of environmental data made during the past 60 years in the former USSR are unique. Among them is a set of water and heat balance observations from agrometeorological stations and soil temperature and soil moisture networks; pan-evaporation and actual evapotranspiration measured at the lysimeter network; and lidar monitoring of tropospheric and stratospheric aerosols (baseline atmospheric quality monitoring) (Chapter 5). These networks were established at co-located meteorological and agro-meteorological stations and, therefore, are accompanied by a suite of standard and auxiliary meteorological data. Many of these unique environmental data are stored only in manuscripts or publications (reference books). Therefore, these observational data still need to be digitized, quality controlled, and organized on computer media in a database. These data sets will then be available for use with standard meteorological and present environmental observations and the next generation of observations (e.g., vertical turbulent heat and water vapor flux measurements made by the eddy-covariance flux method and satellite-borne radiation, soil moisture and temperature, and surface heat flux measurements).

Routine observations. Standard meteorological observations in Northern Eurasia have been carried out at more than 15,000 locations. At its peak, the hydrological network included 8,000 river gauges. During the past century, observational programs in Eastern Europe, Nordic countries, the former USSR, Mongolia, and (during the past 50 years) in China have been traditionally rich and include (in addition to standard observations), a set of special observations (Chapter 5). Environmental monitoring included air and water quality control, crop monitoring, and agricultural land and forest inventories. However, during the past 15 years, the in-situ network in Northern Eurasia has substantially deteriorated. To stabilize and (if possible) restore the density of standard meteorological, hydrological, and environmental observations in the regions of the most prominent contemporary and simulated future changes to climate and land surface in Northern Eurasia is a requirement of highest priority to implement NEESPI science. We have to ensure an adequate representative network for each biome affected by these changes.

B. MONITORING.

Modern observations from space allow accurate and comprehensive quantification of many otherwise unavailable characteristics of ecosystems. Among them are snow cover, glacier area and denudation, soil moisture, forest cover and its attributes, bog area, forest fire area (including past forest fire scars), a host of other land-cover types and, the condition of major agricultural crops. It is also possible to link these characteristics and to estimate, for example, the area of forest located on wet bog and what is still covered by snow.

Since the mid-1960s, international and national satellites have carried various suites of instrumentation that monitor and estimate important parameters of the Earth climate system. Now and in the nearest future, a new generation of satellites (Terra, Aqua, and those to come thereafter) allow enhanced observations of the Earth's energy, water, and biogeochemical cycles (Chapter 5). Generally, satellite measurements that target the surface are more challenging over the land than over the ocean due to heterogeneous terrain with changing properties (vegetation, soil moisture, and seasonal snow cover). It is still difficult to distinguish from space low stratiform cloudiness from snow cover, to "see" snow cover under the canopy, and to assign the "surface" layer to skin temperature measurements over forested areas. Nevertheless, many land surface properties are currently monitored from space and detailed digital elevation data allow fine spatial downscaling of numerous remote, in-situ, and blended land surface observational products.

The accuracy of these products, however, still has to be improved. This can be done with the help of information from in-situ observations and/or regional model data assimilation. The better this information is, the more reliable the monitoring can be. Some algorithms used in interpretation of remote sensing products exist only because of a lack of a choice or no validation data available to properly re-calibrate (or even to discard) these algorithms. For example, the latest intercomparison with in situ observations shows that for North America, using the regional weather forecast ETA model with a 12 km horizontal grid interval, daily surface radiation fluxes at the 0.5° x 0.5° grid can be estimated with the accuracy of 25 W m^{-2} and hourly fluxes with an accuracy of 90 W m^{-2} (Pinker et al. 2003). Similar estimates for Northern Eurasia have been made only up to 1997 with a 2.5° horizontal grid interval. But, these estimates (a) can be easily continued up to date with the same 2.5° spatial resolution (Rachel Pinker, University of Maryland, personal communication, 2003) and (b) if augmented with an appropriate regional hydro-dynamic model and land surface information, can be done with the same spatial and temporal resolution and accuracy as for North America. Expanding the modern in-situ network (FLUXNET) into Northern Eurasia may substantially improve the situation. A large scale investment to properly calibrate the remote sensing algorithms for the Northern Eurasia region is required.

There is the risk that future climatic and environmental changes in Northern Eurasia could negatively affect human society (e.g., aridization, inundation, thunderstorm activity, forest fires, water deficit). Given this background, the risk of extreme events will be more frequent, including catastrophic floods, droughts, fires, forest wind-throw, and landslides. In this situation, the need for comprehensive monitoring with the ability of short-term prediction of detrimental events cannot be underestimated.

C. PROCESS STUDIES

Carbon cycling in terrestrial ecosystems in Northern Eurasia. This is one of the major processes in Northern Eurasia of global importance that require thorough study. The region is the largest terrestrial reservoir of organic carbon where significant past and future changes in climate, cryosphere, disturbance regime, and land use combined with ongoing socio-economic transformation are expected to cause large but very uncertain changes in the magnitude and distribution of carbon sources and sinks. Even the sign of the resulting changes in this distribution is uncertain because several competing factors have affected (and probably will affect) the dynamics of the terrestrial ecosystems in Northern Eurasia. The major threats include (a) intensification of naturally occurring disturbances and anthropogenic perturbations including forest and bog fires, wind-throw, and insect outbreaks; (b) thawing of permafrost (leading to changes in land cover, carbon cycling in vegetation and soils, and changes in surface and subsurface hydrology); (c) changes in land use associated with rapid socio-economic change; (d) changes in ecophysiological processes of vegetation, plant mortality and organic matter decomposition; (e) change in anthropogenic nitrogen deposition; and (f) redistribution of species, changes in successional processes, and shifts of vegetation zones.

Special field campaigns of the past. Northern Eurasia is actually a well-studied region. Numerous seasonal and long-term field campaigns have covered the region during the past century. All environmental topics had been covered in these studies from topographical, geological, and geophysical to biological. It would be a massive effort to repeat many of these surveys instead of collection of all these research materials accumulated in archives of Institutions of the National Academies of Sciences, Hydrometeorological, Forest, and Agricultural Services. Many of these studies can shed light on the past state and historical evidence of dynamics of processes within the Northern Eurasian environment (atmosphere, biosphere, hydrosphere, and cryosphere) that otherwise cannot be acquired. Others can provide clues to a new generation of researchers. Thus, an important task within NEESPI will be to collect the past research data, append and blend them with a new generation of environmental field studies.

Modern field and process-oriented studies. We need a general advance in process-oriented studies specific to Northern Eurasia (cold land processes, large scale interaction with boreal and tundra ecosystems, sustainable agriculture in zones with high risk of incremented weather). To evaluate climate change and variability and land use impacts on the ecosystems' well-being, the following questions need to be solved at the plant and micro-meteorological levels: (a) to determine inter and intra-species variability of stomata resistance/conductance and to organize their databases for the dominant tree species for each ecosystem; (b) to determine transpiration rates and their variability in relation to climate and soil moisture (sap flow method), and pre-dawn water potential for the dominant tree species in the key ecosystems; (c) to determine the boundaries of the ecosystem sustainability; and (d) to determine the thresholds when the structural changes will occur (permafrost thaw, desertification, inundation, swamps advance or degradation, forest degradation, massive insect infestation, soil erosion, and irreversible changes in soil fertility). At the ecosystem and regional scales the following questions should be addressed: (a) What are the major factors of climatic change and human activity that affect seasonal, annual, and interannual variability of key components of energy, water, and biogeochemical cycles within the ecosystem at regional scales? (b) What are the risks of bogging and droughts under various climate change scenarios? (c) How will variability and changes in the cycling of water through the ecosystems be linked to variability and changes in the cycling of carbon and nitrogen within the ecosystems and regional scales? (d) How will changes in the water balance and its components influence the regional climate?

Developing model representations of processes and feedbacks. State-of-the-art climate models suffer from inadequate representation of some physical, chemical and biological processes presumably playing crucial roles in the response of the climate system to changes in forcing. This is associated with insufficient understanding of these processes and limits the models' ability both to simulate natural variability and to simulate realistic scenarios of future changes of the climate system. Model representations of individual processes are to be developed on the basis of and validated against observational data. Within NEESPI, developing of model representations of processes and feedbacks associated with the land-surface, terrestrial hydrology, cryosphere, and vegetation, and their testing of skill using observations, should receive high priority.

Block insert 8.1. Paleoclimatological studies.

Glaciers, frozen ground, swamps, peat, buried soils and wood, tree rings, and lake sediments provide a unique opportunity to unlock many clues about the recent past and present climates, and their system responses, due to the memory stored in them. Integrating process data with paleoclimate data should provide a more powerful basis upon which we can verify simulations of climate states and system responses to climate change. For example, impacts of soil moisture and trace gas feedbacks from the tundra and boreal forest regions, and ice sheet instabilities are critical for accurate model simulations of potential future climates. These analyses are possible due to a unique combination of events and processes that exist nowhere else on Earth. Glaciers in the Arctic and in the high mountains are extremely sensitive to subtle changes in climate and display the effects of long-term trends through their impacts upon surface features. They may provide unique climatic information that can be linked to changes in atmospheric circulation, temperature, snow accumulation, atmospheric composition, marine and continental biogenic activity, aerosol loading/volcanic eruptions, continental dust source regions, forest fire activity, anthropogenic emissions, solar variability and radionuclide deposition. Thus, ice cores need to be collected in Arctic islands and in the high mountains of Northern Eurasia. Also, it has been shown that records of previous climates may be extracted from temperature profiles of deep wells in permafrost because energy transfer is limited to conductive heat transfer only. Analysis of the fossil indicators of permafrost changes (including subsea, subglacial and periglacial permafrost) and glacial history and dynamics with complementing paleothermometery analyses of permafrost can yield valuable information on temporal and spatial climatic dynamics. Given the fact that large parts of Central Asia and Siberia were not glaciated during the last Ice Age, we now realize that many of the geomorphologic features that evolved under different climates are still evident. Actually, each ecosystem has its stored memory (peat, ice, buried soil and wood, lake sediments). Historical records (including data on climate extreme events since the 10^{th} century and on land use since the 17^{th} century) are another source of the environmental information for the pre-instrumental period that should still be carefully examined. It would be possible to resolve many of the complex interactions of atmospheric, terrestrial and oceanic processes through an integrated examination of mass and energy fluxes through these systems, thus constructing a more complete picture of past climates and improving our understanding of climatic forcing mechanisms and feedbacks, and to calibrate climate models.

D. NEESPI MODELING STRATEGY

The NEESPI modeling component concentrates on developing and validating models of different systems and scales capable of reproducing Northern Eurasian natural system states and evolution observed in the past and present, describing interactions of the Northern Eurasian socio-environmental systems with global systems, and, finally, assessing the predictability and, when possible, projecting the future of Northern Eurasia in the context of global and regional change. Proposed modeling efforts are to be organized on three scales: local, regional and global. Such structuring determines clear links between observational and modeling components of NEESPI. The three-scale approach implies using or developing a wide range of models, including atmospheric boundary layer models, soil-vegetation-atmosphere transfer models of different levels of complexity, permafrost models, air pollution models, data assimilation schemes, regional 3-D atmospheric models coupled to comprehensive land surface components, regional high-resolution hydrologic models (including river routing), dynamic general vegetation models, global climate models, including, general circulation models and Earth system models of intermediate complexity; and integrated assessment models. The modeling activity is to be supplemented with developing model diagnosis and intercomparison tools, data assimilation, and down- and up-scaling techniques.

Local scale modeling. A local scale signifies a scale finer than 10 km^2. It is the scale of single experimental point sites at which individual fluxes or cycle components can be measured directly and individual processes can be modeled explicitly. In forested areas it corresponds to elementary inventory unit (stand). Such studies are crucial before integrating the processes at regional or global scales.

Modeling priorities at the local scale include recognizing the most important processes specific for different Northern Eurasia regions and those affecting the regional and global environment. Local-scale modeling is focused on developing (1) detailed parameterizations of the surface processes crucial for different Northern Eurasia regions (e.g., areas of permafrost, swamps, lakes and wetlands, complex relief, non-uniform vegetation and soil, high level of ground water, insufficient soil water content); (2) advanced algorithms to describe impacts of anomalous weather and climate events (e.g., droughts, floods) on water and carbon cycles of different vegetation types; (3) sophisticated approaches (1- and 3-D) to describe energy, water and carbon storages and exchanges between soil, mixed (coniferous and broadleaf species) forest stands and the atmospheric boundary layer; (4) parameterizations of exchange of atmospheric pollutants (greenhouse gases, aerosols) between the land surface and the atmosphere; and (5) new methods to describe spatial heterogeneities of the land cover and meteorological input parameters that allow up-scaling the effects of the heterogeneities to the regional scale.

Regional scale modeling. A regional scale signifies a range of $10\text{-}10^6$ km^2. At this scale, local-scale processes are integrated over heterogeneous land surfaces. Interactions in the horizontal between the local scale processes come to a focus. Horizontal interactions can be either direct (e.g., horizontal flows within river catchments), or indirect (e.g., between land surface points via atmospheric circulation). Regional scale modeling provides a bridge between local ecosystem behavior and sub-continental through global-scale phenomena. The finer spatial scales are particularly important for assessing extreme events.

Modeling priorities at the regional scale include direct incorporation of improved parameterizations developed in local-scale studies and developing different types of models, such as (1) atmospheric regional models customized for Northern Eurasia sub-regions; (2) comprehensive air pollution models; (3) dynamic general vegetation models; (4) comprehensive river routing models combined with land surface, vegetation and permafrost models; and (5) two- and three-dimensional permafrost models that include the thermal effect of changing vegetation, moving ground waters, and changing ground surface geometry. Techniques are to be advanced of one-way and two-way nesting of hydrological, permafrost, dynamic general vegetation and other environment component models into regional climate models; as well as data assimilation schemes that incorporate modern satellite products and ground-based observations.

Global scale modeling. Studies of direct and feedback effects of Northern Eurasia within the Earth system require employing comprehensive Global Earth-system Models (GEMs, based on atmosphere-ocean general circulation models with biological components), and those of intermediate complexity. These studies are closely connected with simulating observed and potential future climates. For current and past climates, this includes testing the model for predictive global and regional skill. Thereafter, we may be in a better position to develop reliable projections of the future climate. A major emphasis within the NEESPI modeling program is given to developing and improving GEM representations of the land surface including terrestrial cryosphere, aerosols, carbon cycle, dynamic vegetation and atmospheric chemistry. Progress in improving the corresponding model components is heavily dependent on the progress in local and regional modeling. Foci of NEESPI global-scale modeling are: (1) incorporation of improvements in process understanding at local and regional levels into comprehensive interactive hydrological, vegetation, and cryospheric components of GEMs; (2) studying effects and feedbacks of environmental changes in Northern Eurasia in the global context; (3) studying feedbacks between the atmosphere and land surface at the decadal, centennial, and millennial time scales and comparison with instrumental, historical, and palaeo data; (4) estimates of extreme ranges in climate change impacts in past and in present for the entire Northern Eurasia; (5) assessing the predictive skill of the models using the spectrum of important simulated climate variables; and (6) projecting the future.

Integrated assessment modeling. A systematic, integrated environmental change assessment study is to be conducted for Northern Eurasia and its parts aimed at representation of the environmental (climate) change problem within the framework of a quasi-closed system such that the social and environmental consequences of policies to adapt to or to limit the environmental (climate) change are seen in their totality. An explicit mechanism for incorporating and addressing stakeholders' (decision-makers) questions and concerns regarding global change is to be developed to carry out integrated assessment as applied to Northern Eurasia. The mechanism should provide, first at all, for the interests of the major industry/agricultural sectors (oil and gas industries, energy production, forestry, and agriculture) and related societal and economic activities.

Interaction between NEESPI modeling and observational components. There are three main aspects of mutual concern of the NEESPI modeling and observational components: (1) observational data needed for model development and validation; (2) assimilation of observational data into model runs; and (3) employment of models in planning and directing observational campaigns and optimizing observational networks.

Interaction between NEESPI modeling components and modeling components of related on-going programs. NEESPI modeling activity inevitably overlaps with modeling components of a number of already existing programs, and thus includes learning from them. Expectations of model development and improvement are associated with the increasing international activity in the field of model intercomparison exercises, allowing the identification of model errors, their causes, and how they may be reduced. NEESPI-oriented diagnostic subprojects are to be initiated (if not already) in major on-going model intercomparison projects (MIPs) and similar international efforts.

E. IMPACT ON SOCIETY AND THE FEEDBACK LOOP

The impacts of climate change on society, and the feedbacks of societal actions on climate, will be an important part of the NEESPI research program. Studies that address these societal issues can be grouped into the following five major groups.

Human health and well-being. Studies are needed to analyze the interconnections between climate and human health. In particular we need to investigate how past and future climate changes in Northern Eurasia interact with urban and industrial development and social/political changes, and their combined effects on land use/land cover change, on the productivity of the land, and on ecosystem services. This includes studies of the vulnerabilities and capacities of human and ecosystems to adapt to these changes. Lessons must be learned from past land use practices and ecosystem responses throughout Northern Eurasia in order to develop more sustainable natural resource management and future development practices. Studies are needed to assess and inventory the nature, extent and severity of the pollution problems associated with industrial development, as well as with nuclear and toxic test sites, dumps, spills, and accident sites. These studies should include health effect studies of the people living in affected areas, possible mitigation actions, and improved decisions and policies for future actions proposed. Studies are needed to identify relative vulnerabilities of targeted societies and populations (urban, rural, indigenous, those in close proximity to mining and industrial operations) to health impacts from environmental, weather, pollution, and climate factors, and to identify mitigation actions to reduce risks.

Ecosystem Health. Projects that seek to better understand and quantify the effects of global and regional changes on biodiversity, productivity and sustainability of ecosystems and their interactions in Northern Eurasia should be encouraged.

Agricultural and forest productivity. Research work is needed to improve the description and quantification of the impacts of climate and environmental variability and change on agricultural and forestry productivity, to include a feedback loop that accounts for social, economic, political and governmental policies, practices, and management. In particular, while improving current biophysical descriptions of agricultural and managed forestry systems within existing ecosystem models, we need to include in these models genetic and management factors, as well as influences of policies and social factors.

Water management and quality. Studies are needed to analyze lessons learned from previous water management projects in Northern Eurasia and elsewhere and to find methodologies for integrating these lessons into future planning efforts on water management projects in the region. In particular, these lessons should be used to assess the proposed plans to transfer river waters from Siberian rivers to Central Asia. Studies are needed to assess the magnitude and impacts of pollutants as well as the present and potential impacts of anthropogenic influences and climate change on quality of water supplies in Northern Eurasia. Implications of this assessment should be analyzed and possible mitigation measures suggested when and where needed.

Natural hazards and disturbances. Studies are needed to more clearly define the frequency and intensity of extreme events, extensive fires, and natural disasters in the different regions of Northern Eurasia as well as the vulnerabilities of the people in the region to these events and their capability to cope with disasters. This should include improved efforts to monitor, predict, and to feed back that information to people in the region for emergency preparedness. Assessment of anticipated additional effects that could result from environmental changes in the region on the severity and nature of the extreme events, extensive fires, and natural disasters and their impacts on people of the region should also be done. In particular, studies are needed on the evaluation of risks associated with "dirty fires" and anthropogenic accidents that involve radioactive and toxic materials and on the relationships between human activities, ecosystem changes, climate changes, and the initiation of the large dust storms. Assessment of the impacts of extreme desertification and dust events on human and ecosystem health and development viable strategies to mitigate these effects and improve land management practices are needed.

In summary, NEESPI needs to implement a general modeling framework linking socio-economic factors, crop, pollution, land use, ecosystem, and climate models with observational data to address key research questions within Northern Eurasia. As an integral part of these activities, a set of educational activities for students, educators, and the general public is needed as well as interaction with appropriate components of the related ongoing scientific and operational programs. A major objective of NEESPI will be to provide information, which empowers society and decision-makers to plan and react

wisely, to mitigate negative and to benefit from positive consequences of environmental changes.

8.4. Milestones to accomplish the project goals

These milestones will be developed at the NEESPI Implementation Plan stage. The project goals (listed in Chapter 2) are repeated below to round up the story. In the next decade under the NEESP Initiative, we would like to have:

- An integrated observational knowledge data base for environmental studies in Northern Eurasia that includes validated remote sensing products
- Systems proven in the research domain in collaboration with operational partners that can serve the emergency needs of the society (early warning / management / mitigation of floods, fire, droughts, and other natural disasters)
- A suite of process-oriented models for each major terrestrial process in all its interactions (including those with the society)
- A suite of global and regional models that seamlessly incorporate all regionally specific feedbacks associated with terrestrial processes in Northern Eurasia and serve as a major tool for both future environmental change projections and for informed decisions on land use and environmental protection policies.

The "physics" of the abovementioned suite of models dictate the measurement and field research requirements (and not vice versa). The initial steps to accomplish the project goals (approximately over next three years), therefore, should be:

1. Development and testing of sophisticated process-oriented models for major terrestrial processes in Northern Eurasia and collection of measurements that support these models (flux towers, boreholes, socio-economic studies, and data digging).
2. Identification of insufficiently known macro-parameters of the above models and efforts to evaluate these parameters (i.e., an addressed search for means of their determination from space and on the ground).

Thereafter, blending of the acquired information and models should be conducted into an integrated observational knowledge data base for environmental studies in Northern Eurasia. This data base should already include validated remote sensing products and a suite of models that describe a block of processes within Northern Eurasia. Finally, linking the above with Global Climate Models and their extensive use for numerous practical applications in the region (and worldwide) should complete the research objectives of NEESPI.