EXECUTIVE SUMMARY

Northern Eurasia Future Initiative (NEFI): Facing the challenges and pathways of Global Change in the 21st century.

1. Introduction

During the past 12 years, NEESPI has been quite successful at conducting, highlighting and advancing research in Northern Eurasia. Its Science Plan was prepared in 2004, peer reviewed and released at http://neespi.org/science/science.html. Its Executive Summary was prepared in English, Russian, and Chinese and later published as a peer-reviewed article. The NEESPI research domain is shown in Figure 1 and its duration was estimated to be 10-12 years starting from 2004. The NEESPI implementation program has accommodated 272 projects focused on different environmental issues in Northern Eurasia, funded by multiple national and international agencies, and have involved in different years a total of more than 750 scientists from 200 institutions representing 30 countries.

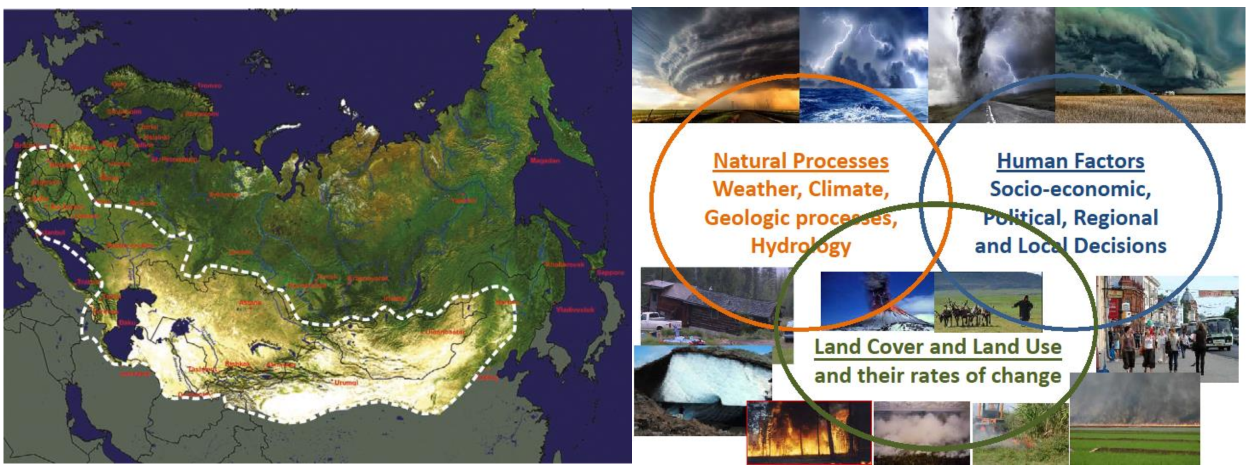

Figure 1. Left. The NEESPI study area is loosely defined as the region between 15°E in the west, the Pacific Coast in the east, 40°N in the south, and the Arctic Ocean coastal zone in the north. In this map green corresponds to vegetated lands. Light brown and yellow indicate sparse vegetation and arid areas, respectively. The Dry Latitudinal Belt of Northern Eurasia (DLB) is sketched on the map by a dashed white line. *The latest NEESPI findings hint that DLB is and will be expanding northward.* **Right**. Major natural and direct anthropogenic processes that affect Northern Eurasia.

More than 1500 peer-reviewed journal papers and 40 books have been published during this period. This created a new research realm because NEESPI scientists self-organized in a broad research network, accumulated the knowledge and developed new tools (observations, datasets, models, and collaborative networks) to deliver new results, and can now apply these results to directly support decision-making for various societal needs. Furthermore, during the same period, two important changes have occurred:

- The Global Earth System has significantly changed with the changes in Northern Eurasia being substantially larger than the global average. Subsequently, the NEFI endeavor is to analyze this ***new state*** with its unexpected novel features and distributions –from shifts of the seasonal cycle in various climatic characteristics to changes in intensity, frequency, and spatial and temporal distributions of extreme events. These changes have already occurred, but their impacts upon (and feedbacks to) inertial components of the Earth System are ongoing. These include atmospheric, biospheric, cryospheric, oceanic, and macro-socioeconomic processes. Socio-economic dynamics in the major nations of Northern Eurasia have dramatically changed, including their ability to withstand and adapt to the adverse manifestations of environmental change.

- An innovative trans-disciplinary objective has been proposed to the Earth Science communities worldwide. Instead of addressing questions, such as those that define the understanding and quantify the amount of change currently and by the end of the 21st century in the Earth System, our communities have begun to increasingly receive inquiries about what mitigation and/or adaptation strategies are possible for the upcoming decades. These questions were reformulated in the framework of the new International Council for Science Union research initiative *Future Earth* that focuses on sustainable societal development under changing climatic and environmental conditions. In this vein, the major NEESPI Science questions have been reformulated for NEFI. The former overarching objective remains intact: **"How do Northern Eurasia's terrestrial ecosystem dynamics interact with and alter the biosphere, atmosphere, and hydrosphere of the Earth?"** However, this objective has been reformulated and expanded altering the academically curious **"how?"** into the practical **"what?"**: **What dynamic and interactive changes will affect societal well-being, activities, and health, and what might be the mitigation and adaptation strategies that could support sustainable development and decision-making activities?**

NEESPI researchers and all those who are interested in contributing to the regional research in Northern Eurasia can build upon past achievements by using the results of NEESPI scientific research, data, models, and knowledge to directly support decision-making activities that address societal needs. This will address the core motivation of NEFI which is to best use science to serve the decision-making process, the Earth System "health", and society.

2. Three Unique Features of Northern Eurasia of Global Concern and Related Major Science Questions

To develop effective mitigation and adaptation strategies, future NEFI activities will need to consider three unique features of Northern Eurasia: 1) the sensitivity of land surface characteristics to global change that feedback to influence the global energy budget; 2) potential changes in the Dry Latitudinal Belt of Northern Eurasia that will have a large influence on the availability of water for food, energy, industry, and transportation; and 3) evolving social institutions and economies.

Sensitive land surface characteristics to global change. The Arctic, Arctic Ocean shelf, and the Boreal Zone of Eurasia are areas of substantial terrestrial carbon storage (e.g., wetlands, soil, boreal forest, terrestrial and sea shelf permafrost) and powerful carbon-cryosphere interactions and variability that (a) intertwine with strong climatic and environmental changes (cf., Figure 2), and (b) can generate positive feedback to Earth System changes via both biogeochemical (changes in atmospheric composition and plant metabolism) and biogeophysical (surface albedo, fresh water budget, and thermohaline circulation of the World Ocean) impacts.

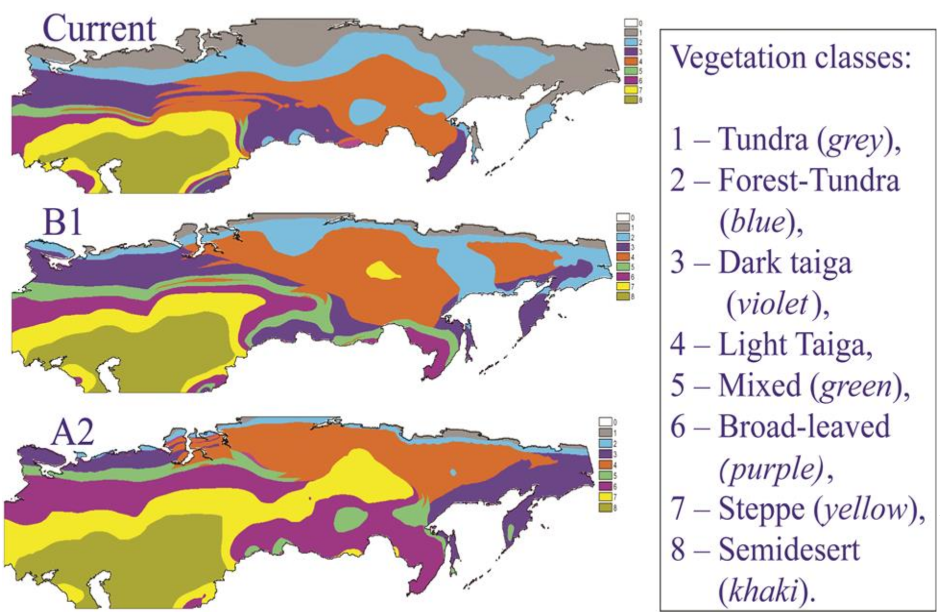

Figure 2. Vegetation distribution under present conditions and equilibrium vegetation distribution under future climate conditions (scenarios) over Northern Eurasia in current climate and by year 2090 calculated by ecosystem model using the CMIP5 ensemble GCM output for B1 and A2 scenarios (i.e., for corresponding greenhouse gases induced global warming to 2090 by 3 - 5°C and 6 - 8°C).

The first Major Science Question is thus: "How can we quantify and project the ecosystems dynamics in Northern Eurasia that influence the global energy budget when these dynamics (a) are internally unstable (e.g., operate within narrow temperature ranges); (b) are interrelated with highly variable components of the cryosphere (seasonal snow cover) and/or are vitally controlled by components that have been systematically changing (e.g., glaciers and permafrost); and, (c) have a potential to impact the Global Earth system with unprecedented rates of change over few decades due to, for example, catastrophic forest fires, dust storms, and controversial future methane release from frozen ground in high latitudinal land and shelf areas?"

Dry Latitudinal Belt of Northern Eurasia. The interior of the World's largest continent is mostly cut off from the water vapor transport from the tropics by mountain ridges and plateaus spread across the central regions of Asia, thereby creating the Dry Latitudinal Belt of Northern Eurasia (DLB; shown in Figure 1), the largest dry area in the extratropics. The DLB may expand northward (cf., Figure 2) as it has in past millennia. Parts of the DLB are quite densely populated and have fertile land. However, the DLB has physical limitations: (a) it has very limited fresh water supply which is highly dependent upon irregular extra-tropical cyclones (mostly from the North Atlantic) and a shrinking regional cryosphere; (b) increases in evapotranspiration from increases in warm season temperatures and expansions of the growing season in DLB are generally not compensated by precipitation increase, and (c) changes in spatio-temporal shifts in precipitation pattern increase the probability of various unusual (extreme) events affecting the livelihoods of regional societies and their interactions with the global economy. This region is a source of dust storms that can adversely impact the environment, climate, and human well-being. ***The second Major Science Question is thus: "What are the major drivers of the ongoing and future changes in the water cycles of Northern Eurasia and how will their changes affect regional ecosystems and societies, and feedback to the Earth system and global economy?"***

Evolving social institutions and economies. Institutional changes in Northern Eurasia in the past decades have led to large changes in the socio-economic fabric of societies in the region, affecting land use and the natural environment, and resulting in emerging challenges. One of these challenges includes the transitions from command-driven to market-driven economies in the countries of Northern Eurasia which have occurred at different rates and societal costs, and created unexpected economic and environmental opportunities and problems. As a result, many of these outcomes became important concerns with policy implications at the national and intergovernmental levels. The countries of Northern Eurasia with 'transitional' economies are playing an increasingly important role in the World Economic system. However, they are now facing an imperative challenge to find their places in highly competitive economic conditions under additional stresses of climatic, environmental, and internal societal changes. ***The third Major Science Question is thus: "How can the sustainable development of societies of Northern Eurasia be secured in the near future by overcoming the 'transitional' nature of their economics, environmental and climatic change challenges, and by untying restrictive institutional legacies?"***

3. Major Research Foci: Why do they matter?

During the past 20 months, the direction of future research over Northern Eurasia have been discussed in light of the new information gained from past NEESPI activities and the unique features of Northern Eurasia of global concern. Nine major research foci have been identified for potential future NEFI work (listed in no specific order):

1. **Global change, particularly the warming of the Arctic;**
2. **Increasing frequency and intensity of extremes (e.g., intense rains, floods, droughts, wildfires) and changes in the spatial and temporal distributions of inclement weather conditions (e.g., heavy wet snowfalls, freezing rains, untimely thaws and peak streamflows);**
3. **Retreat of the cryosphere (snow cover, sea ice, glaciers, and permafrost);**
4. **Changes in the terrestrial water cycle (quantity and quality of water supply available for societal needs);**
5. **Changes in the biosphere (e.g., ecosystem shifts, changes in the carbon cycle, phenology, land-cover degradation and dust storms);**
6. **Pressures on agriculture and pastoral production (growing supply demand, changes in land use, water available for irrigation, and food-energy-water security);**

7. **Changes in infrastructure (roads, new routes, construction codes, air, water, and soil pollution, and strategic planning);**
8. **Societal actions to mitigate the negative consequences of environmental change and to benefit from the positive consequences; and**
9. **Quantification of the role of Northern Eurasia in the global Earth and socioeconomic systems to advance research tools with an emphasis on observations and models.**

Socio-economic research challenges are the top priority for several of these foci. Below, we examine the issues related to these proposed major research foci in more detail.

Global Change and the Arctic. Global changes are ongoing and until the causes of these changes are eliminated or mitigated, there are no expectations that they will slow down. Regionally, the temperature changes in Northern Eurasia have been among the largest. However, there are special reasons to list the changes in the Arctic among major concerns for future environmental well-being in the extratropics. This small sliver of the globe plays an important role in global climate. Its changes in the past decade were unprecedented for the period of instrumental observations (Figure 3) and well above the 2°C warming threshold set by the recent United Nations Climate Change Conference. There are two main consequences of Arctic warming: (a) changes in the Arctic sea ice and (b) changes in the meridional gradient of air temperature. The first one increases the heat and water vapor exchange with the atmosphere, especially in the cold season with direct practical implications for transportation, regional infrastructure development and maintenance, and fisheries. The second one controls the heat and water vapor transport from the North Atlantic into the interior of the Eurasian continent. Both of these features of the Arctic are highly volatile. Furthermore, the Arctic is closely interlinked with the North Atlantic Ocean and together they control (drive), to a large extent, the World Ocean thermohaline circulation providing most of the cold water influx into the deep ocean. ***Future studies within this focus area should be concentrated on (a) enhanced monitoring of changes in the Arctic, and (b) integrated assessments, including Earth System Model (ESM) simulations, of the hemispheric consequences in the energy and water cycles, cryosphere, land cover, economy, and human well-being that are associated with changes in the Arctic.***

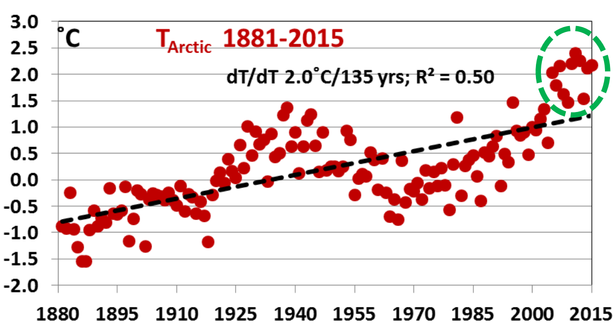

Figure 3. Annual surface air temperature (°C) area-averaged over the 60°N - 90°N latitudinal zone (the Arctic). Anomalies from the long-term mean value for the 1951-1975 period.

Frequency and intensity of extremes. In the past decades, changes in the frequency and intensity of various extreme weather events have been documented in all areas of Northern Eurasia. These events include increase in intense rainfall and prolonged no-rain periods (Figure 4), extraordinary temperature anomalies accompanied by droughts in summer and cold outbreaks and/or thaws in winter, an increase in the frequency of extensive and intense wildfires and intense dust storms. The impacts of these events often extend far beyond Northern Eurasia sending aftershocks into global markets and raising concerns about global food security. Societal consequences of changes in the frequency and intensity of extreme events has become an urgent task to address for the entire Earth Science research community.

Figure 4. A string of beads with a fixed number of beads illustrates how we can encounter in the same region increases in prolonged Wet Day and Dry Day Periods even with unchanged precipitation totals. The arrow shows a major tendency in the past decades across most of the northern extratropics including Northern Eurasia.

Extreme events that affect the biosphere (i.e., disturbances) and their temporal and spatial changes represent a special focus for NEFI studies because they directly affect human well-being. Regardless of whether the disturbance is natural or anthropogenic, the altered landscape interacts with biospheric processes and the climate to maintain ecosystem functioning, diversity and services. Human- and climate-induced changes in disturbance regimes are currently acting in concert to force ecosystems to move more quickly towards a new equilibrium with the climate. Under the control of weather and climate, wild and anthropogenic fires are important drivers of ecosystem changes. Under current climate change scenarios, it is predicted that boreal fire frequency and area burned are expected to increase by 25-50% or more. Severe fire events *are increasingly becoming the new normal across Siberia.* For Northern Eurasia, it is predicted that cumulative fire severity would increase by three times and fire season length could increase by 20 days by the end of the 21st century. ***Future studies within this focus should be concentrated on (a) risk assessments based upon the projections of changes in the probabilities of each type of extreme event and disturbance over Northern Eurasia; (b) development of new protection strategies against wildfires and hydrological extremes; and (c) transition to adaptive forest and agricultural land management within the paradigm of sustainable management of regional ecosystems on a landscape-ecosystem basis.***

Retreat of the cryosphere. In the last 30-40 years, observations indicate a warming of permafrost in many northern regions with a resulting degradation of ice-rich and carbon-rich permafrost. Increases of permafrost temperatures have resulted in the thawing of permafrost in natural, undisturbed conditions in areas close to the southern boundary of the permafrost zone. One of the main objectives of the future NEFI efforts related to cryosphere is to evaluate the vulnerability of permafrost under climate warming across the permafrost regions of the northern and high-elevation Eurasia with respect to ecosystems stability, infrastructure, and socioeconomic impact. The cryosphere retreat has a continent-wide spatial scale with temporal scales that vary from the millennia to century for glaciers and permafrost to seasonal for snow cover extent. This retreat affects (a) the continental energy balance changes due to surface albedo decrease, increasing heat flux into the upper surface layers, earlier spring onsets and longer growing seasons; (b) depletion of the continental water storage accumulated during the past millennia in ground ice with the subsequent desiccation of lands that rely upon water supply from glacial melt and permafrost thaw; and (c) *large-scale biosphere changes* (cf., Figure 2) that are especially prominent in the regions where cryosphere was intrinsically linked with the survival/dominance of major species within biomes. ***Future studies within this focus should be concentrated on further analyses of the consequences of the cryosphere retreat for the environmental stability and social well-being across Northern Eurasia, particularly in highland areas.***

Changes in the terrestrial water cycle. Mountains cut off Northern Eurasia from the major sources of water supply in the tropics. Even in the regions of "sufficient" moisture, this sufficiency is secured not by an abundance of water, but rather by suppressed evapotranspiration during the lengthy cold season, soil insulation from the atmosphere by seasonal snow cover, and by external water supply from the cryosphere storage. The rest of the water is provided through unstable atmospheric circulation (e.g., cyclones). Changes caused by global warming decrease and/or redistribute water supply from the cryosphere, increase the vegetation period, and affect the water vapor transport from the oceans into the continent interiors where both absolute changes and variation in the water vapor transport matter. Both natural ecosystems and human activities rely upon the stability of the water supply. Looming changes include: (a) depletion of relatively stable water sources (cryosphere), (b) an already unstable water source (atmospheric circulation) becoming even more variable, and (c) a longer and warmer periodfor vegetation growth thereby increasing the biospheric water demand. Given these, it becomes clear that changes in the terrestrial water cycle across Northern Eurasia can adversely affect the well-being of local societies as well as the world economy. Most of Northern Eurasian land surfaces are not "wet" and a temperature increase does not automatically induce an increase in evaporation, opposite processes may prevail due to evaporation suppression by dry upper soil. Finally, future ecosystem shifts can dramatically change the vegetation composition (Figure 2) and the transpiration rate of the new communities can induce further nontrivial changes to the regional water cycle. These processes should be assessed within a new generation of models that properly account for the interactions among the atmosphere, soil, biosphere, *and* human activities. The hydrological aspects of changes are of particular importance, because they have pronounced effects on local and regional economies and the well-being of the Northern Eurasian residents with immediate implications for water supply, irrigation, energy production, navigation, land and water transport, and structural engineering. ***Future studies within this focus should be concentrated on (a) the thorough quantification of ongoing and projected changes in the terrestrial water cycle over Northern Eurasia for the coming decades; (b) understanding and quantification of causes of these changes through extended monitoring and improved representation of physical processes at different scales in hydrological models; (c) analysis and projection of possible consequences of the changes in the regional water cycle for human societies and infrastructure; and (d) the preemptive development of mitigation measures (infrastructure investments, new technologies in water management and agriculture practices) based upon newly conducted risk assessments related to the plausible future regional water cycle states.***

Changes in the biosphere. In the long term, terrestrial ecosystems establish a dynamic balance with the states of climate, water resources, the lithosphere, and cryosphere. When these four driving forces are changing, the biosphere also begins to change, but it has its own resilience (stability). Numerous negative feedbacks support ecosystem functioning in less than optimal conditions and/or actively resist changes in the near-surface climate to preserve the once-achieved equilibrium, e.g., by the regulation of transpiration, access to otherwise unavailable water resources (e.g., oases), etc. Ongoing climate change already impacts ecosystems of Northern Eurasia. The most visible impacts have been observed in forests as these tree species have a long life span. While productivity of forests at the continental level is increasing during the last decades due to increasing temperature and lengthening of the growth period, there are large territories with decreasing productivity and enhanced mortality of trees mirroring the general picture for the entire boreal belt where the forests over large territories in different regions of Northern Eurasia are exposed to substantial dryness. ***Future studies within this focus should be concentrated on (a) development of an integrated observing system on environment, land, landscapes and ecosystems, capable for early recognition of changes in terrestrial biota; (b) development of new classes of ecosystem process-based models on the structure, growth, productivity and resilience of vegetation (particularly forests) under global change at different scales and complexities as part of both integrated observing systems and the scientific background for sustainable ecosystem management; (c) development of integrated modelling clusters that would include ecological, social and economic components as inputs to Earth system models that incorporates external forcing, internal Earth System feedbacks, and scenarios of human activities within and beyond Northern Eurasia; and (d) development of strategies, technical programs and policy recommendations for sustainable ecosystem management, including adaptation to, and mitigation of, expected climate change.***

Pressure on agriculture and pastoral production. (A) *Land abandonment*. During the past quarter-century, land abandonment is associated with fundamental institutional changes regarding agricultural production and land use across temperate Europe and Asia, caused by the breakup of the Soviet Union in 1991. Approximately, 59 Mha of sown areas became abandoned from 1991 to 2000 across the post-Soviet countries. After 2000, a partial recultivation of abandoned lands has been observed but the recultivation rates were leveled off by ongoing agricultural land abandonment. In the temperate zone abandoned fields are often slowly, but steadily encroached by shrubs and forests. By 2010, approximately 5 Mha of new forests were observed on formerly agricultural fields in Eastern Europe cultivated during the Soviet time. Overall, the abandoned agricultural fields in Eastern Europe and Russia represent a great amenity in terms of the increase of forest cover, becoming a major terrestrial carbon sink for the world during the late 20th and early 21st centuries and provides options for future cropland expansion. Adverse demographic conditions in Eastern Europe with the exodus of rural population and hollowing of the rural areas in China may trigger additional land abandonment. ***(B) Dryland belt of North Eurasia (DLB).*** Over the past three decades, the DLB has gone through several major changes that drive regional agricultural and pastoral land changes. First, the regional population has increased at a moderate rate similar to the global population trend. Second, there was an institutional shift, primarily in the Central Asia region, where the former Soviet Union coordinated resources uses (e.g., food and water), but the newly independent states have disparate natural resource endowments. To balance food security with commodities for export, these new nations have shifted agricultural priorities that has changed regional water demands and subsequently resulted in agricultural abandonment in some places and intensification in others. Both processes (abandonment and intensification) strongly impact the regional carbon budget shifting the C stocks in soils and vegetation. Third, most countries within the DLB implemented various reform policies to promote economic growth while improving quality of life. The new governance and policies increased GDPs, but at the same time resulted in shifting food demands, moving towards more processed, high protein animal products, which drive an increase in grasslands-based livestock production. A large-scale land-use change analysis of the DLB with MODIS data suggests spatial heterogeneity in land-use change with cropland abandonment in Central Asia (Figure 5) and expansion on the Mongolian Plateau (not shown) driven primarily by shifts in governance and economic development. Therefore, the region has seen an increase in the demand for food quantity and quality on one hand, and a decrease in food production on the other hand, resulting in unbalanced pressures on agricultural and pastoral lands. ***Future studies within this focus should be concentrated on (a) assessing agricultural potentials under multiple constraints of water availability, accessibility, and distribution, (b) balancing the local production and*** **demand, given the shift in diet, to achieve a sustainable strategy to prevent overgrazing and C losses while** ***ensuring sufficient food supplies, and (c) improving regional coordination for efficient resource utilization to account for differential natural resource endowments.***

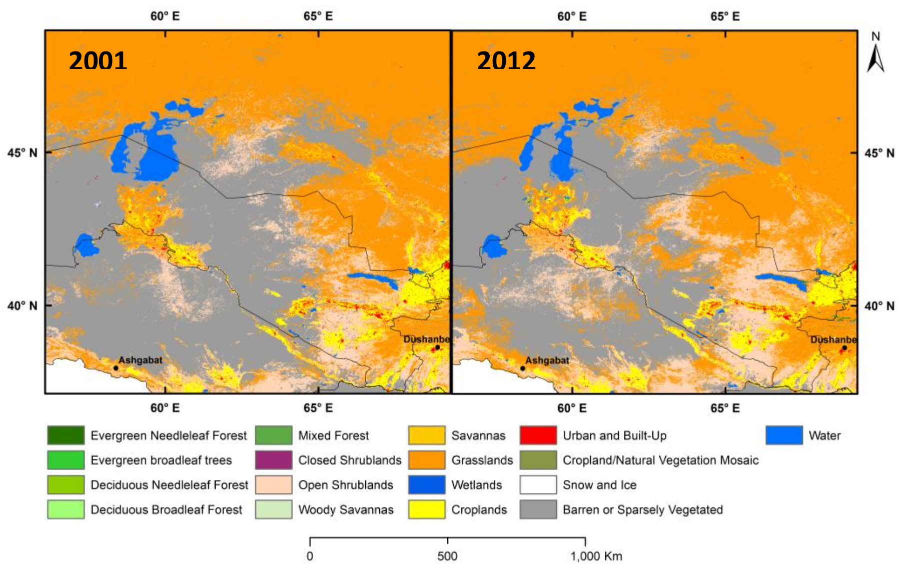

Figure 5. Land use and land cover change of the Central Asia dryland from 2001 to 2012 with focus on Uzbekistan.

(C) Cryosphere in montane areas of Central Asia*.** The mountains and plateaus of Central Asia are a major regional source of fresh water for surface runoff, groundwater recharge, hydropower plants, community water supply, agriculture, urban industry, and wildlife habitat in all countries of the region. Central Asia is included in water-stressed areas where projected climate change could further decrease stream flow and groundwater recharge. The ongoing climate warming has already affected the surface and ground ice of these mountain ecosystems. During the past few decades, most glaciers in Central Asia have substantially thinned and retreated. Projections point to a substantial decline in water resources provided by the mountain cryosphere in the near future, but the decline in a particular catchment depends upon the nature of the catchment. It is anticipated that under the current climate warming trend in the mountainous DLB, the recession of glaciers in Central Asia will accelerate, leading to a runoff increase in the dry season on a short time scales (from 10 to 50 years). However, on longer time-scales (> 50 years), the crucial dry season glacier runoff will be substantially reduced, as glaciers will lose most or all their ice storage. In the same period, the melt of ground ice (initially trapped and accumulated in the permafrost) could become for a while an increasingly important source of freshwater in the region. Food security in Central Asia critically depends on the water availability from the mountains, especially given the drying, browning, and brightening trends that characterize the region during the past 15 years. Some parts of High Asia have already experienced water scarcity, imposing a major threat to food production. Some countries started taking practical measures by constructing reservoirs in order to ensure their economic development. These actions would have short-term benefits, but long-term adaptation and mitigation strategies are needed to develop estimates of contemporary and future water resources that will originate from the high mountain cryosphere at the regional scale. These estimates will be used for socio-economic vulnerability assessments of the benefits for local communities whose livelihood depend on the quantity and seasonality of water discharges from the Central Asian mountains with respect to regional and national priorities. This specific objective will require blending geosciences and social sciences to evaluate the role of high-elevation ice storage in permafrost and glaciers for levels of vulnerability and the resilience of mountain ecosystems and the people who live there and downstream. ***Future studies within this focus should address the following science and societal questions: (a) What is the impact of climate change in Northern Eurasia on permafrost dynamics in the mountainous environment in Central Asia (permafrost and ground ice, glacier ice, snow cover) and how does the cryosphere change impact river runoff patterns and downstream freshwater availability? (b) What is the volume of subsurface ice that could be a potential source of freshwater and what is the amount of melt water that ice-rich permafrost could contribute to total river runoff in connection with recent climate change across the High Asia? and (c) What are the feedback mechanisms among glaciers, hydrology, snow cover and ice-rich permafrost in montane areas and how can we detect, quantify, and model these interactions? (d) The most important science question for this region is: "How do changes of the mountain cryosphere-controlled regional water resources affect the livelihood and prosperity of local communities in densely populated downstream regions?"

Changes in infrastructure. (A) ***High latitudes of Eurasia.*** Recent decades show marked social, economic, and institutional change across the circumpolar North. However, socioeconomic changes attributable to drastic political and economic transformations have been most pronounced in the Arctic regions of Northern Eurasia. Here, several socioeconomic processes, likely to affect other Arctic regions in the near future, have being functioning as major anthropogenic drivers of environmental change since the 1960s, including migration, urbanization, and industrialization. Ongoing and projected climate-induced changes in natural systems will impact the human environment with direct, immediate implications for land use, the economy, subsistence, and social life. ***Future studies within this region and focus should be concentrated on: (a) Integrative analysis of the cumulative effects of northern infrastructure in the context of both social and natural systems and the implications of climate and socio-economic changes on ecosystem services, residents, and industry; and (b) research aimed at developing new construction norms and adequate, economically-viable adaptation and mitigation strategies for northern communities and areas of intensive industrial development in the Eurasian Arctic.*** ***(B) The Taiga and Far East zones.*** In the realm of population, infrastructure and forest resource trends, the taiga – especially in the eastern Siberian part, and the Russian Far East – has seen particularly dramatic pendulum-like shifts between the late Soviet, early post-Soviet, and the present eras. This time span has also been punctuated by multiple severe fire years and the growing implications of climate change. As governance and institutions have regrouped after the early post-Soviet transition era, emerging developments in the forest and energy sectors have begun to come to the fore. For example, it is of significant current economic importance that the Siberian and the Russian Far East regions are rich in oil, gas and mineral resources. The ESPO (Eastern Siberia-Pacific Ocean) pipeline has recently been completed, as has a spur directly into northern China. Furthermore, Russia sees its energy sector as a central pillar to its re-establishment as a global economic power and it is likely that such extraction and associated infrastructure will increase. ***Future studies within this region and focus should be concentrated on: (a) integrated modeling of forest growth, fire, logging, infrastructure and other human land-use decisions, along with climate, providing the ability to build different combined scenarios based on proximate and underlying drivers; (b) new remote sensing approaches – direct or indirect – for observing and monitoring illegal logging, and (c) envisioned sustainable futures involving legitimate economic uses of forest and geologic resources which also preserve carbon sinks and biodiversity.*** ***(C) Temperate zone of East Europe.*** After the collapse of the Soviet Union and subsequent cessation of the state subsidies for the cultivation of less productive agricultural, large areas of croplands were abandoned. Afforestation of abandoned croplands is likely to have major impacts on carbon budget of the region. However, afforestation of abandoned croplands is currently not included in the official forestry reports, and the legal status of these lands remains uncertain. Climate-smart agricultural systems are resilient to climate change and offer carbon and GHG emissions mitigation potential without compromising on productivity, food security, and the livelihoods of those working in the agricultural sector. The temperate zone of East Europe will need to invest in climate-smart agriculture techniques to sustain and/or continue improved agricultural yields and livestock production given forecasted climate change. This is a region with heavy anthropogenic impacts on ecosystem services. The monitoring of the ecosystems' status using novel tools and integrated approaches remains an important task, at least, for the next decade. ***Future studies within this region and focus should be concentrated on: (a) mapping the intensity of land use more frequently than on a decadal basis; (b) in-depth research of the underlying and proximate land-use change drivers and how socio-ecological interactions cause land-cover change; (c) regional quantification of the relationships between land-use change and biotic and abiotic processes such as greening/browning, hydrological changes, wildfires and anthropogenic fires, and vector borne diseases; (d) assessment of trade-offs between land use and regional ecosystem services revealing optimal strategies for resource and climate-smart agriculture and land use, including shift in diets and agricultural management; and (e) impact of wildfires and anthropogenic fires on carbon management, CO_2 emissions, and short-lived climate pollutants.*** ***(D) Central Asia, Mongolia and Northern China.*** Along with drastic changes in economics, institution and governance, land use in Central Asia, Mongolia and China of the dryland Asia region includes the improvements of major infrastructures that have facilitated or resulted in the transition of these nations. ***Future studies within this region and focus should be concentrated on (a) how these infrastructure changes have facilitated regional food security from both production and consumption perspectives, (b) if and how these major infrastructure changes reduced or escalated socioeconomic disparity at different spatiotemporal scales within and across the states in the region, and c) what are the infrastructures needed to enable rural communities to improve their well-being and sustainable livelihoods.***

Societal feedbacks in response to environmental changes. In the distant past, humans reacted to environmental changes passively – they migrated away from environments that became adverse or unsustainable for their well-being. Now, common approaches to addressing adverse environmental changes include irrigation, construction of dams and dikes, diversion of water streams, large-scale geo-engineering projects, mandatory ecological standards to curb pollution, more effective agronomic practices and robust crops, new construction codes, and the application of ecological expertise to each new large development. Implementation of these activities has associated costs and requires careful planning based upon numerical experiments with models that realistically describe processes of environmental changes in all their complexity and interactions. Human activities became the drivers of certain ongoing environmental changes. It is important to recognize the loop: societal feedbacks in response to these changes may facilitate the recurrence of disasters or cause a second cycle of inadvertent environmental change. This means that studies of the impact of environmental changes on societies and the development of adaptation and mitigation measures in response to their detrimental consequences should be accompanied by thorough assessments of the "end state" resulting from the environmental changes and the actual and projected societal response to these changes. ***Future studies within this focus should be concentrated on development of models with direct and explicit social feedbacks***.

Role of Northern Eurasia in the global Earth and socioeconomic systems. Being a substantial part of the land surface of the Earth (19%; and 60% of land surface north of 40°N) where climatic and environmental changes were among the largest in the past century and socioeconomic conditions were subjected to dramatic changes, Northern Eurasia is a key part of the Global Earth and socioeconomic systems. In many aspects, changes here presage the rates of global change. ***Therefore, future studies within this focus should be concentrated on exploitation of Earth System models (mentioned in the previous Focus and described in Section 4) under different environmental and socioeconomic change scenarios with tracking how changes within the Northern Eurasia domain affect, and are influenced by, changes beyond the Northern Eurasia domain (i.e., teleconnections).***

4. Global Change Modeling for Northern Eurasia

Northern Eurasia consists of a variety of complex and dynamic ecosystems that have different time-varying responses to changes in climate and land, water and energy management associated with global change. In turn, these regional ecosystem responses may feedback to affect Earth system processes that will modify how global change evolves in the future and the ability of the Earth system to provide ecosystem services to humans. Over the past few decades, a substantial effort has been put toward the development of a variety of models to organize and improve our knowledge of Earth system processes in Northern Eurasia including their interactions and their future responses to global change. In most of these modeling studies, however, global change has been imposed on

Northern Eurasia without any feedback effects on Earth system processes. More recently, Earth system models (ESMs) have been developed by coupling together models of different Earth system components. Some ESMs have even been linked to economic models to form Integrated Assessment Models (IAMs) that allow economic decisions to respond to changing environmental conditions to support mitigation and adaptation efforts. A detailed representation of the human system, including the global economy, demography, technologies and user preferences, is essential to study potential impacts of future global change. The work is still ongoing toward a suite of **ESMs and IAMs for Northern Eurasia.** ***Development of this suite and its applications will be among the major objectives of NEFI researchers.*** With these modeling resources, NEFI researchers can serve, interact, and provide guidance to decision makers in their joint goal to secure sustainable and prosperous development of the societies in Northern Eurasia and around the World.

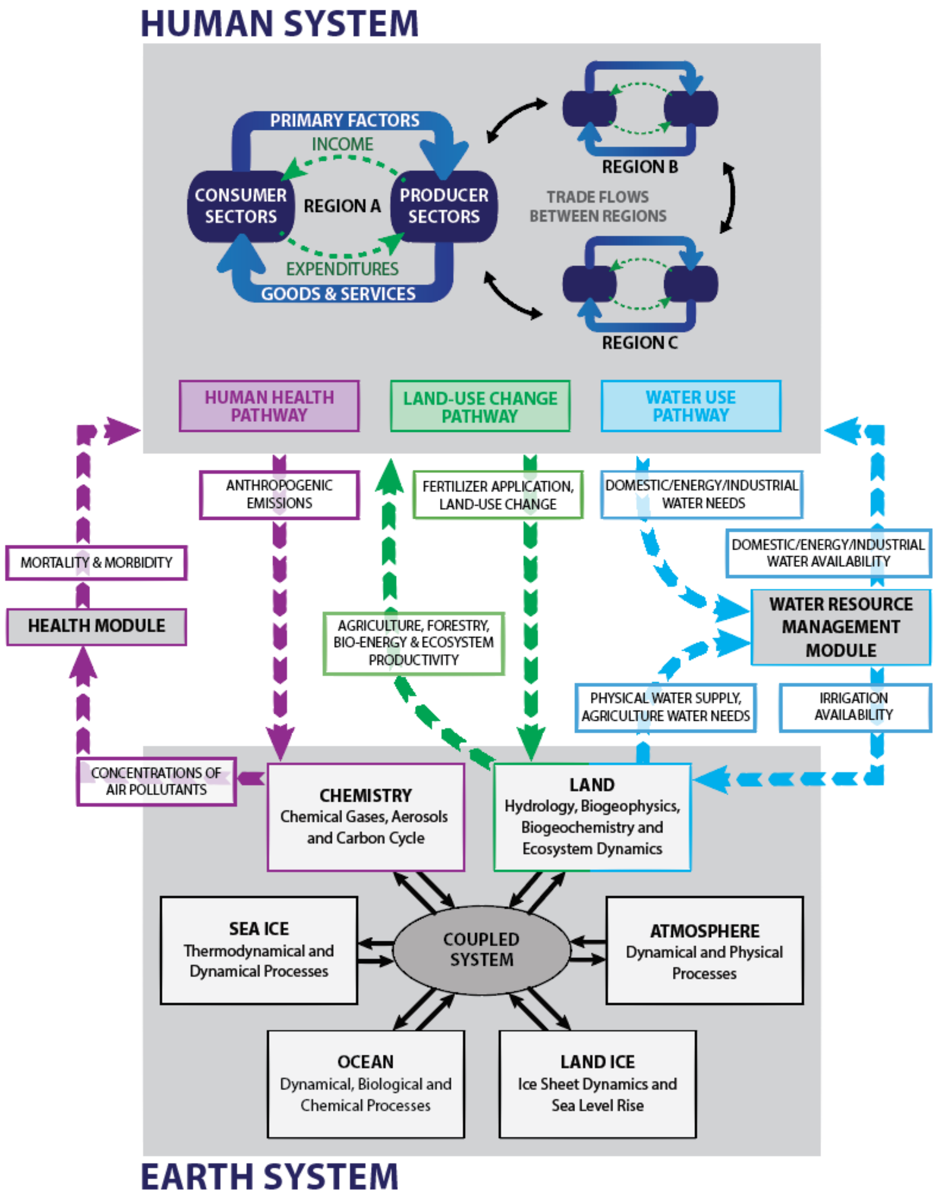

Figure 6. Example. Schematic of an Integrated Assessment Model that couples a human activity model and an Earth system model with a focus on three feedback pathways: health, land-use change, and water resources.

Why new approaches are needed? Most studies of climate change impacts rely on standard scenarios of climate change. A common experimental design for these studies is to prescribe climate change and to examine the varied response of a particular component of the Earth system. In such an approach, many potential global and regional feedbacks that can have major implications for the climate system are overlooked. The alternative is to use modeling frameworks that are able to represent the many feedbacks in the Earth system, both at the global and regional scales, i.e., ESMs. ESMs provide tools to investigate the response of the system to changes in external forcings that not only affect each of the components individually but also the interactions among them. Furthermore, climate change impacts cannot be examined without considering the role of human activity. ***Therefore, a new generation of IAMs should be developed and employed by the NEFI researchers for studies of the impact of global change on Northern Eurasia. It has to represent an integrated modeling framework between the Human and the Earth systems.*** IAMs are no stronger than the underlying natural and economic science that supports them and the underlying science is often not in a form suitable for immediate use in IAMs. At the frontier of integrated assessment modeling, a large number of issues have emerged with the ongoing development of coupled human-earth system models for Northern Eurasia. These issues include consideration of the availability of water for irrigation, sustainability of the food-water-energy nexus, the effect of land ownership and land use on food production, the consequences of more intense fertilizer and pesticide use for water quality and biodiversity, the shifts in energy production technologies that may reduce greenhouse gas emissions but may produce other environmental effects, the effect of changes in the cryosphere (i.e., permafrost degradation) on infrastructure and the effect of reduced Arctic sea ice on transportation, energy exploration, and timber harvest. ***Future NEFI studies should address these issues in concerted efforts to build credible IAMs in order to allow decision-makers to employ them. Thus, resilience-based ecosystem stewardship for Northern Eurasia must be a major overarching focus of NEFI.***

5. Final Words.

NEESPI has great reason to be proud of its success and it has been an outstanding prologue to the present challenges. In particular, we must incorporate our knowledge of the consequences of human and social dimensions onto assessing the current and future changes in Northern Eurasia. Across the region, the future strongly depends on these assessments to appreciate how we can ameliorate environmental change, how human populations will be affected by change, and how we bridge the considerable gaps in research procedures, capacity for prediction, and time- and space- scales that complicate the integration of human dynamics with environmental dynamics. The region has a central role to play in the “Future Earth” international program. It has undergone significant environmental changes, already having experienced a warming in the past few decades that already exceeds the warming limits adopted in Paris. Many of the new international programs are emphasizing resilience and transformation of human/environmental systems in the face of environmental change. Northern Eurasia presents a range of such systems ranging from modern industrial societies to traditional indigenous cultures, all undergoing significant social change. Through its new program "*Northern Eurasia Future Initiative*”, NEFI the work in the NEESPI region is moving to more effectively address shared goals with interdisciplinary programs at the global level. The research record that will help us launch NEFI is a logical consequence of the accomplishments of NEESPI. This situation and the need for progress are critical.