Proceedings of the Northern Eurasian Earth Science Partnership Initiative (NEESPI) Regional Science Team Meeting devoted to the High Latitudes

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RESULTS OF THE MEETING

This chapter provides the notes of the discussion session and the data session held in the NEESPI Regional Science Team Meeting, 2-6 June, Helsinki, Finland.

1.1. Discussion session summary

Cold land processes in the Northern Hemisphere continents and their coastal zones: regional and global climate and societal-ecosystem linkages and Interactions (IPY 138).

1. General questions

What are the critical questions that need to be addressed within the NEESPI framework regarding cold land processes?
- Their dynamics

What are the criteria for determining if a cold land surface process is important for NEESPI?
- Importance to society
- Availability of appropriate expertise and data

What cold land processes need to be considered and what is the relative importance of each of them?
- Permafrost thaw
- Snow cover changes
- Glaciers’ retreat
- Vegetation changes
  - Sublimation and evaporation
  - Runoff generation
  - Soil Moisture
  - Land-atmosphere interactions
  - Biogeochemical fluxes
  - Coastal processes

2. What do we need to provide in terms of knowledge and data products?

a) By the end of this phase of NEESPI (2015)?
   i) Estimates and syntheses related to land use and global changes in terms of impacts on:
      - permafrost temperature and stability and the active layer processes,
      - hydrological cycle and the surface water regime,
      - changes in the arable land,
      - water resource management decisions due to glacier reductions, changing water use patterns, changing seasonality, etc.
      - coastal changes due to thermal erosion and marine ice reduction
      - condition, productivity, and dynamics of vegetation
      - forest composition and wildlife habitat.
   ii) new understanding of:
      - feedbacks to the global earth system
      - the role of natural geomorphological processes in changing landscapes,
      - the role of anthropogenic and natural disturbances (e.g., fire) on the ground thermal regime and the stability of permafrost affected regions,
the integrated surface/subsurface hydrological system,
- the role of vegetation, soil, and land use on the hydrologic cycle,
- the net impact of thawing permafrost on the carbon cycle,
- the role of regional models in integrating processes,
- the potential benefits of including human processes in regional and global models
- impact of glacier reduction on ecosystems, landscape transformation, hydrological cycle and surface water regime,
- human life in Arctic and Northern Eurasia mountains.

iii) a suite of regional models as a key to integration processes in high latitudes

b) in order to meet the expectations of IPY (2010)?
- synthesis of the net role of surface and subsurface processes on the hydrologic system.
- exploitation of remote sensing in monitoring change in the land surface.
- understanding of processes that cause landscape change (e.g., development, reindeer, climate, etc)

3. Where are we now relative to these goals and how has NEESPI contributed with research that has been done to date?
These activities are listed in the reports of the RAS and US NEESPI representatives and on the NEESPI web site.

4. What specific steps do we need to take in the next two years to ensure:

a) that the goals for NEESPI IPY projects are met?
- carry out a PILPS-type model intercomparison for the NEESPI Arctic Ocean Basin,
- develop a fully coupled regional climate models using state of the art land surface schemes,
- seek opportunities to interact with social scientists regarding the human dimension aspects of NEESPI with appropriate groups (The American Association of Geographers, The Russian Geographical Society, IHDP, etc),
- develop techniques for modifying statistical distributions of hydrological variables based on observed changes in seasonality,
- take steps to more effectively utilize remote sensing products (e.g., soil wetness products) in hydrologic modelling,
- explore the possibility of launching a GEO task related to NEESPI data systems and services,
- assess the available inventories of wetlands and small lakes over the NEESPI area to determine if they meet the requirements of hydrologic modellers for this type of information,
- develop a plan to use data from the heat balance network in NEESPI energy budget studies and hydrologic models.

b) that we can effectively address the priority NEESPI questions by 2015:
- develop a scientific foundation for understanding the consequences of abrupt global and regional changes in the NEESPI area,
- explore the concept of risk management as a means of integrating NEESPI science into a regional policy framework,
- develop a strategy for using remote sensing data and reanalysis products in the earth system modeling over the NEESPI domain.
1.2. Data session summary

← NEESPI research needs different spatial and temporal data resolutions and each data “scale” requires separate treatment and delivery tools; however, methods (protocols) to blend these diverse data should be developed and always “at hand”
← Developing a single system/database architecture to account for different data disciplines and different resolutions, is very expensive.
← A more feasible approach is to have a distributed system of systems (using GEOSS approach). Each system is responsible for its own discipline / field /region.
← The NEESPI Focus Research and Science Data Support Centers should serve as these subsystems.
← It is vital for these subsystems to be interoperable, i.e., they should be able to access each other’s metadata and data via standard protocols.
← Each system should develop and integrate converters from their data formats into common formats.
← A NEESPI Meta-portal should be established to provide a gateway to all NEESPI data. At first, it should provide easy data discovery and access to all NEESPI data (similar to the LBA site).
← In the future, if funding is available, it may allow exploration of data at a coarse resolution in a Giovanni-like interface, and then zooming to a specific focus field or an area.
← Practically, in the near future, a couple of centres should establish machine-to-machine connections allowing access to remotely located data:

- Example 1. Data Centres working with similar spatial resolution data (e.g., glaciological and social economical data at the NASA NEESPI Data Centre and the Russian Institute of Geography) may start working on IPY and a larger Digital Earth database;
- Example 2. Downscaling from sub-continental to regional scale (e.g., data of Siberian Integrated Regional Study can incorporate Irkutsk Regional Area Information System being developed at the Friedrich-Schiller University at Jena, Germany).

• For the next NEESPI meeting, there should be a technical session on the system of systems, with tech reps from focus centers and their PIs present.
The role of NEESPI in GEWEX
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**Introduction**

The Global Energy and Water cycle EXperiment (GEWEX) has been conducting research on global and regional water and energy budgets since 1990, and has made substantial progress in (1) the development of global data products that rely on satellite data, (2) the development of data assimilation systems and process understanding used to enhance models and increase fidelity in simulating critical Earth System processes, (3) the validation of prediction models and assimilation systems, and (4) diagnostic studies aimed at closing regional water budgets and related applications. Regional studies of water and energy budgets and their contribution to global budgets are coordinated through the Coordinated Energy and Water cycle Observations Project (CEOP). GEWEX activities related to global data sets are led by the GEWEX Radiation Panel while those related to model validation and process understanding are led primarily by the Global Modeling and Prediction Panel, which puts its emphasis on cloud, land surface, and boundary layer processes. An overview of GEWEX research activities is available in Soroosh et al. (2005).

In 2002, GEWEX moved from Phase I (1990–2002) of its project strategy, which emphasized the development of analysis tools, to Phase II (2003–2013), emphasizing the application of these tools in the development of a better understanding and predictive capability for energy and water cycle processes and budgets. The specific goals of Phase II are:

1. Produce consistent research-quality data sets complete with error descriptions of the Earth's energy budget and water cycle as well as its variability and trends on interannual to decadal time scales, for use in climate system analysis, and model development and evaluation.
2. Enhance the understanding of and quantify how energy and water cycle processes contribute to climate feedbacks.
3. Improve the predictive capability for key water and energy cycle variables and feedbacks through improved parameterizations to better represent hydrometeorological processes, and determine the geographical and seasonal characteristics of their predictability over land areas.
4. Undertake joint activities with operational hydrometeorological services, related Earth System Science Partnership (ESSP) projects such as the Global Water System Project (GWSP), and hydrological research programs to demonstrate the value of GEWEX research, data sets, and tools used to assess the consequences of climate predictions and global change for water resources.

The Northern Eurasian Earth Science Partnership Initiative (NEESPI) is a large environmental program focused on northern Asia and Europe in a large
geographical expanse that stretches as far south as northern China and the Ukraine. It involves a number of disciplines and seeks to address the following questions:

- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences of changes in the Earth system for human civilization?
- How well can we predict future changes to the Earth system?

Initially NEESPI was launched as a collaborative project between the Russian Academy of Sciences and the United States (NASA). It has now broadened to include partners and funding support from many countries.

During the past decade, GEWEX has nurtured the development of 10 Continental Scale Experiments (CSEs) under the GEWEX Hydrometeorology Panel (GHP) (Lawford et al., 2004). During 2005 and 2006, NEESPI and GEWEX interacted extensively to explore the possibility that NEESPI could become a CSE. In developing its proposal for GEWEX, NEESPI assessed a number of its activities to see how they could be adjusted to better satisfy GEWEX criteria, including free and open data exchange, regional modeling, the involvement of a Numerical Weather Prediction (NWP) center, and the operation of a data centre, among others. In 2007, the GEWEX Scientific Steering Group (SSG) accepted NEESPI as a GEWEX CSE, or Regional Hydroclimate Project (RHP) as these experiments have become known. The SSG made this decision because of the scientific contributions that NEESPI was expected to make and NEESPI’s progress in meeting the CSE/RHP approval criteria. In addition, GHP and the Coordinated Enhanced Observation Period merged in 2007 to form the Coordinated Enhanced Energy and Water Cycle Observations Project (CEOP). Since NEESPI became a part of GEWEX, its progress has been monitored by both CEOP and the International GEWEX Project Office (IGPO).

In order to guide its activities, GEWEX adopted a roadmap for the project’s progress between now and 2013. This roadmap is a living document that can be found at www.gewex.org. It outlines what GEWEX would like to achieve during the next six years and sets timelines for its activities. Under Objective 4, for example, GEWEX looks to RHPs (including NEESPI) to provide leadership in the study of issues such as land use change and the application of climate information for water resource management and regional water budgets. Due to its strategic location and large area, NEESPI is ideally situated to address issues related to global environmental change at high latitudes.

NEESPI has succeeded in stimulating a great deal of environmental research in northern Eurasia and has developed programmatic affiliations with a large number of relevant environmental research projects. It is also the focal point for many scientists and projects that have an interest in carrying out research in the northern Eurasia area. Furthermore, NEESPI has been formally recognized by a number of global environmental programs, including GEWEX, GWSP, the
Climate and the Cryosphere (CliC) project, and the International Geosphere Biosphere Program (IGBP) and its affiliates (i.e., the International Land-Ecosystem-Atmosphere Processes Study (iLEAPS) and the Global Land Project (GLP). NEESPI coordinates the research activities of scientists from this large area, including the U.S.A., Russia, Europe, China, Japan, and former Soviet Union countries such as Kazakhstan. In terms of scientific impact, the rate of new applications for remote sensing data over northern Eurasia has increased since the inception of NEESPI.

However, NEESPI still has the potential to grow as an international program. If this initiative wishes to strengthen its lasting impact, and to develop into a sustainable program by contributing in a substantive way to the global change programs that have endorsed it, NEESPI will need to become more integrated and focused on certain strategic areas of scientific interest. Integration would be enhanced by periodic reviews and the development of thematic syntheses of NEESPI research results. Another issue that deserves further attention involves the development of an enhanced NEESPI data system—one with an extensive metadata information component and common-interest high-use data sets on one central computer—as well as specialized and investigator-specific data sets available on individual investigator computer systems that are accessible from the central system. This would allow NEESPI data access from a single portal access point and will enable NEESPI to take better advantage of new Group on Earth Observations (GEO) technologies.

Because NEESPI has been operating for more than four years, it has produced enough research results to benefit by taking steps toward better integration and the promotion of its results. It is recognized that some integrating mechanisms have been included in NEESPI plans and have enjoyed partial implementation. For example, the plan has identified critical themes, such as aerosols, water and permafrost, which are functioning successfully, although in some cases with less coordination activity than hoped. NEESPI also represents a specific geographical area that provides a place-based focus for NEESPI research and thereby promotes regional integration. At the program coordination level, however, there are opportunities for NEESPI to develop an integrated field project and an improved synthesis of the state of knowledge regarding the region’s overall impact on global climate and regional ecosystem services. A field project would of course require considerable advance planning, as well as the prioritization of processes most important to and merit ing the investment of NEESPI’s limited resources. Data systems are also an effective way to enhance integration. NEESPI has a number of modeling activities that could serve as a focus for NEESPI research but it is unclear how these activities would be integrated into a larger modeling framework. Possibly increased collaboration with the Analysis, Integration and Modeling of the Earth System (AIMES) project, the Earth System modeling effort within IGBP, would help in this area.

What GEWEX expects from NEESPI

GEWEX was pleased to adopt NEESPI as an RHP because it filled a large void in the geographical coverage of current RHPs. There is no other region of the
world where terrestrial processes influence the atmosphere over such a large spatial expanse. While one area in Eurasia had been previously addressed by the GEWEX Asian Monsoon Experiment (GAME)-Siberia, no single project had considered the overall regional energy and water budgets for this vast area. This expectation could be effectively addressed by regional modeling projects for the NEESPI domain.

GEWEX contributes heavily to two major World Climate Research Programme (WCRP) crosscuts (specifically, the monsoon regions of the world and Extremes) that could benefit from more NEESPI contributions. It is clear that although Northern Eurasian processes influence the northern extension of monsoons in the summer months, the region itself is not known for being dominated by monsoonal circulations. Extremes, however, are common in the NEESPI area because the region is very sensitive to climate warming, and it is expected that the frequency and significance of extremes will increase as the climate changes. NEESPI can offer a platform to monitor change, since the frequency of extremes as well as the processes that may be responsible for their trends will probably become quite evident in its study area. The GEWEX approach to Extremes has in the past involved examining each phase of an extreme event including the processes responsible for its beginning, intensity, continuation, and termination. NEESPI could use this approach in addressing major extreme events in the Northern Eurasian region.

NEESPI is expected to put substantial effort into achieving its commitments for the GEWEX roadmap, including the following goals (Groisman, 2007):

1. To have in place by 2010:
   - a suite of tested land surface and regional climatic models that will account for the peculiarities of the energy and water cycles in Northern Eurasia
   - major components of the data support system for these models, including near-real time dataflow
   - the first version of the biospheric blocks needed for these models
2. To complete all funded International Polar Year (IPY) activities in the region
3. To organize during the 2008–2010 period up to 20 summer schools and/or special courses for the training of Earth Science K–12 teachers and a new generation of NEESPI-domain Earth Science researchers.

Certain aspects of these goals are unique to NEESPI while others are shared with other RHPs. It is anticipated that NEESPI will work closely with other RHPs in the CEOP framework to make these plans a reality. Furthermore, the CEOP data system, which provides effective data support for many of the RHPs, provides an excellent platform for NEESPI data integration activities.

It also should be noted that it is less than two years until 2010 at the time of this writing. The promised NEESPI contributions related to models will require a focused effort to consolidate the relevant NEESPI contributions to IPY and other interim goals into an overall modeling framework.
**What GEWEX can offer NEESPI**

GEWEX maintains strong links with a number of other international programs and projects and is continually looking for opportunities to interact with these programs through the expertise and deliverables within each GEWEX project. For example, GEWEX interacts with the Climate Variability and Predictability Project (CLIVAR) on issues related to monsoons, extremes and climate prediction; with CliC on cold region processes; with GEO on observational systems; with iLEAPS on land-atmosphere processes; with GWSP on water management issues; with the United Nations Educational, Scientific, and Cultural Organization (UNESCO) on semi-arid land processes and with many national programs. Through NEESPI contributions, GEWEX could strengthen these links and expand the scientific impact and influence of NEESPI science and scientists. In addition to promoting linkages between NEESPI and different elements of these programs, GEWEX could also facilitate the collaboration of NEESPI with other RHPs such as the Baltic Sea Experiment (BALTEX) and the Monsoon Asian Hydro-Atmospheric Science Research and prediction Initiative (MAHASRI), and would strongly encourage NEESPI to help develop the central data services of CEOP. In the past, the IGPO has supported many of the administrative and coordination functions within NEESPI: it could continue to provide some of these functions to the extent that resources are available for special services.

**Summary**

NEESPI has made excellent progress in many areas during this past year. The number of projects it coordinates continues to grow and new results are being published. However, it is hard to gain a full appreciation for the extent to which these numerous activities contribute to answering fundamental climate questions without more integration and synthesis. In addition, NEESPI would benefit from a stronger focus between the overall goals of NEESPI and the environmental programs that have supported it.

**References:**

Russian Academy of Sciences International Polar Year Programs

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In accordance with the International Polar Year 2007-2008 the Russian Academy of Sciences established two special programs. Some projects of these two programs are closely related to NEESPI.

Program № 16 of Presidium of RAS “Natural processes in polar areas of the Earth and their probable development in the next decades”

The main goals of this program are analysis of nature and socio economical changes in polar regions for the last 50 years, and assessment of modern status and prediction of the future in connection with global climate changes. To achieve these goals the main task was formulated: systematization and analysis of knowledge of processes in polar atmosphere, polar oceans and sea ice, terrestrial glaciations and permafrost of Polar Regions, terrestrial and marine ecosystems, geological history and lithosphere of Polar Regions, socio-economic development of polar regions. This program includes 25 projects and 16 of them are related to NEESPI (list below preserves the original numbering and, therefore, has gaps. Major scientific topics and projects related to NEESPI.

- Modeling and diagnostics of climate regime in polar and sub polar regions. PI - I. Mohov. Institute of atmosphere physics RAS
- Temperature regime, small gas admixture, dynamic and chemical processes in atmosphere of polar and sub polar regions. PI - N. Elanski. Institute of atmosphere physics RAS
- Changes of snow cover in the Northern Eurasia induced by atmospheric processes. PI - A. Shmakin. Institute of Geography RAS
- Numeric modeling of magnetic dip poles behavior impact on ionosphere and thermosphere structure. PI – A. Lyahov, Institute for Geospheres Dynamics
- Investigation of polar climate changes. PI - G. Panin Institute of water problems RAS.
- Present day status of Arctic glaciations, glacier instability and calving icebergs. PI - A. Glazovsky. Institute of Geography RAS
- Reaction of Arctic and Sub Arctic soils to Earth conditions changes: study of dynamics and boundary states. PI – S. Goryachkin Institute of Geography RAS
- Analytic base development for IPY studies. PI – V. Kotlyakov. Institute of Geography RAS
- Change trends of temporary transformations of ice phenomenon in estuary areas of North European Russia rivers. PI - V. Debolsky. Institute of Water Problems RAS.
- Polar atmosphere pollution in polar regions. PI - Vinoradova. Institute for Atmosphere Physics PAS, Institute of Oceanology, PAS
• Study of number and areal of animals and plants in polar areas under climate changes and economical activity. PI - A. Tishkov. Institute of Geography RAS and Murmansk Sea Biology Institute
• Study of processes of nuclear pollution transportation and sedimentation in Kola landscapes. PI - V. Velichkin IGEM RAS
• Geochemical and biotical criteria’s of polar landscapes stability. PI - T.Kuderina. Institute of Geography RAS
• Reliability and safety of economic and social infrastructure, and also life conditions of North native people. PI - E. Andreeva. Institute of System analysis. RAS
• The search of stable development way of natural and socio-economical systems in North polar area. PI Vlasova. Institute of Geography RAS.
• Russian history memorials on Svalbard archipelago. PI. V. Starkov. Institute of Archeology RAS.

Program № 14 of RAS Division on Earth Sciences “History of formation of Arctic Ocean Basin and Regime of modern natural processes in Arctic regions”

Program includes 23 projects and 12 of them are NEESPI related. The main goal of this program is a detection of regularities of modern natural processes and phenomenon in Arctic regions in conditions of changing climate.

Major scientific topics and projects related to NEESPI are listed below:
• Diagnostics and modeling of recent river run-off changes in permafrost regions. PI - I. Mokhov. Institute of Atmospheric Physics RAS.
• Research of landscape distinctions and their account at the forecast of probable changes of a hydrological cycle and a river runoff in permafrost regions. PI - L. Kuchment. Institute of Water Problems RAS.
• Zonal and landscape regularities of recent changes of river runoff in permafrost regions of Eastern Siberia. PI - A.G. Georgiadi. Institute of Geography RAS
• Spatial variability of parameters of the snow-ice phenomena and dynamics cryolithozone of Arctic regions in conditions of changing climate. PI - N. Osokin.Institute of Geography RAS.
• Spatial variability of ice phenomena in estuarial areas of West Arctic in conditions of changing climate. PI - V. Debolski. Institute of Water Problems RAS.
• Mathematical modeling of Arctic cryolithozone based on combination of determinate and probabilistic methods. PI - G. Perlshtein. Institute of Ecology RAS.

• Economic estimation of damage caused by changes of climate and snow cover in Northern and Arctic regions of Russia. PI - A. Shmakin. Institute of Geography RAS.
• Modern trends of changes of Arctic reservoirs biota with Murmansk area as an example. PI.- N. Kashulin. Institute of industrial ecology problems NKSC RAS
• Climate and anthropogenic factors of biota and ecosystems changes in Russian Arctic: analysis of modern trends and forecast. PI – A. Tishkov. Institute of geography RAS.
• Information supply of IPY geophysics studies. PI. - Y. Kharin. Geophysical Center RAS.
• Development of information supply of IPY cryosphere studies. PI - T. Khromova. Institute of Geography RAS.

First results: Processes in the atmosphere of polar latitudes

By means of model calculations, relationship between different climatic characteristics in polar latitudes in XXI century has been estimated. Analysis of natural and anthropogenic causes for the climate changes in high-latitudinal regions has been performed. Model estimates of possible changes in the permafrost were made under different scenarios of the climate change. Variations of both cyclonic and anticyclonic activity characteristics in polar and subpolar latitudes for the last decades were estimated. Analysis of Cyclonic activity in Arctic latitudes based on reanalysis data for last decades with diagnostics of intensive cyclones input and evaluation warming changes has been done. (Figure 1). Mathematical models for analysis of forecasting of hydro- and thermo-dynamic parameters of the atmosphere were developed and brought into use. A role of blocking and other circulation mechanisms for regional structure of snow cover and other climatic parameters of the North Eurasia were investigated. The climate model of intermediate complexity developed at the A.M. Obukhov Institute of Atmospheric Physics RAS (IAP RAS CM) was extended by modules of soil thaw/freeze cycles and methane cycle. (Figure 2) The contribution of the snow accumulation changes to the runoff regime of large rivers of the North Eurasia for the 20th century has been estimated.

Other activities include: a series of experiments with numerical models of local energy- and moisture exchange, mesoscale climate and the atmosphere general circulation for investigation of a relationship between snow cover and other climatic parameters, including those under different scenarios of the climate change; testing of an improved scheme of the snow cover parameterization with consideration of its vertical structure and snow crystal types for the above numerical models.

First results: Terrestrial glaciation and permafrost of Polar Regions

Data on the present-day iceberg runoff of glaciers in the Russian Arctic have been collected and processed. A complex of direct and remote observations of surface balance of the glacier mass and the motion velocity of its surface has been performed. A repeated radar survey of the Fritjof glacier (the Spitsbergen) was carried out for the purpose to study its hydrothermal structure after a surge together with complex investigation of the Amundsen glacier plateau (the Spitsbergen) on localities of supposed accumulation of water on the glacier bed and in upper parts of outlet glaciers on the plateau. Study structure of the ice sheet Austfonna (Svalbard) in the region of the ice divide and heads of two outlet glaciers for estimation of the ice runoff. Decoding of space images of both optic and radar ranges will be performed for the under-satellite bordering parts
of Novaya Zemlya and the Franz Jozef Land. Regional features of the state and dynamics of the glaciers in the mountain regions of Northern Eurasia under in condition of climate change were investigated. First results show the glaciers retreat in all test areas. (Figure 3).

Other activities include: measuring of variations in the snow cover thickness and the water equivalent in Eurasia; study of correlation between rate of the snow cover spring loss and the flood volumes in large river basins in their multi-year regime; investigation of influence of changes in the snow cover thickness in the pre-winter period on the frozen ground regimes. It is supposed to also investigate different-period tendencies of variability of thermal and ice regime of rivers in north of European part of Russia and to estimate influence of the river runoff on heat and salt balance and the ice regime of the Arctic ocean basin. Bases for prediction of catastrophic situations, related to the ice events in the mouth areas, are to be developed on the basis of data from observations and numerical models.

Figure 1. Comparison of the distribution function of number of Arctic cyclones, particularly winter ones, in relation to their power, revealed the tendency of increasing the number of intensive cyclones in 1990s compared to 1960s.
Figure 2. Methane emission from bogs of Northern Eurasia.

Figure 3. Glacial retreat across Northern Eurasia.
Climate change in the high latitudes of Eurasia
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Abstract
Climatic changes over the high latitudes of Northern Eurasia in the 20th century have been reflected in many atmospheric and terrestrial variables. This extended abstract shows only a few examples, while the presentation (http://neespi.org/web-content/meetings/Helsinki_2008/Day1_8_Groisman.pdf) provided a more complete picture.

Temperature
Magnitudes of contemporary warming are higher over high latitudes than over tropics (Figure 1). They are higher over continents than over oceans and in the cold season than over the warm season (IPCC 2007). Thus, Northern Eurasia is the region where the changes are among the highest over the Globe with annual winter temperature increased by more than 2°C during the period of instrumental observations and summer temperature in the Eurasian Arctic showing an increase by 1.35°C since 1881 (Archive of Lugina et al. 2007). The summer warming in the Eurasian Arctic is a new phenomenon observed during the past several decades. Summer temperatures control most of polar vegetation in the region where surface radiation balance (SRB) is positive only for a short period of the year. But, in the middle of this period, it exceeds the SRB values in Sahara or southern California. The consequences for land cover composition of this SRB and temperature changes are not yet well understood.

Sea Ice
North of the Eurasian coast, The Arctic Ocean is located in a region that is ice-covered most of the time. Sea ice extent in the Arctic varied in the past (e.g., it was estimated to shrink by 10% by the end of 1930s; Fletcher 1970). During the past three decades a new decline in sea ice extent and depth has occurred. The changes, being now monitored from satellites and submarines, are more reliable and substantial (Figure 2a). It looks like the Arctic Ocean is moving to perennial ice-free conditions and has already lost nearly half of its end-of-summer extent since the late 1970s. This change, while causing some impact on the regional albedo, affects dramatically the cold season
heat fluxes from the Ocean (with temperatures around 0°C) into the atmosphere whereas in the presence of the sea ice that insulates the “warm” ocean the surface temperature can be -40°C. Recent GCM simulations (Sokolov 2008; Figure 2b) show that the atmospheric forcing by the sea ice changes in high latitude land areas is responsible for more than half of the regional warming with a peak in December. These numerical experiments were run with different boundary conditions but always with the sea surface temperature (SST) forcing. The experiment the SST forcing but with an unchanged sea ice extent generated the near-surface land atmospheric warming that was alike in the tropics and in the high latitudes of the Northern Hemisphere. Note, that the changes reported in land areas north of 60°N in Figure 2b and Figure 1 are practically the same. Thus, the NEESPI domain, particularly in its Arctic part, is being affected by global and regional “external” factors that are causing its change and the positive feedbacks to this forcing may further exaggerate the situation (cf., Shugart; Goetz; and N. Shiklomanov in this issue).

**Snow cover**

Snow cover is the most dynamic component of the cryosphere. From 1 week to 10 months, seasonal snow cover is observed practically over the entire Northern Eurasia and substantially controls the energy and water balances of the region and terrestrial ecosystems. The longest satellite data set (started in the late sixties of the past century) delivers snow cover extent variations over the Northern Hemisphere (Robinson et al. 1993; Figure 3) was recently expanded into the past for Northern Eurasia (Brown 2000; Groisman et al. 2006). Analyses of these and the in situ snow cover data show that (a) during the past 40 years there were no systematic changes in winter and a systematic retreat of spring snow cover with a general decrease of the period with snow on the ground while maximum snow depth in the Eurasian Arctic has increased (cf., Bulygina and Razuvaev, this issue).

**Temperature derivatives**

While changes in surface air temperature and precipitation are most commonly addressed in the literature (cf., ACIA 2005), changes in their derived variables (variables of economic, social and ecological interest based upon daily temperatures and precipitation) have received less attention. The list of these variables (indices) includes: frequency of extremes in precipitation and temperature; frequency of thaws; heating degree days; growing season duration; sum of temperatures above/below a given threshold; days without frost; day-to-day temperature variability; precipitation frequency; and precipitation type fraction. In practice, these and other indices are often
used instead of “raw” temperature and precipitation values for numerous applications that include modeling of crop-yields, prediction and planning for pest management, plant-species development, greenhouse operations, food-processing, heat oil consumption in remote locations, electricity sales, heating system design, power plant construction, energy distribution, reservoir operations, floods and forest fires. These indices provide measurements for the analysis of changes that might impact agriculture, energy, and ecological aspects of high latitudes. Figure 4 gives examples of changes in a few temperature-derived characteristics for the former USSR and Fennoscandia. Two-digit percent changes in these characteristics during the second half of the 20th century indicate substantial changes that directly affect the regional ecosystems and societal well-being.

Water cycle changes
Observational data show that the weather conditions in the western half of Northern Eurasia during the 20th century became more humid while east of The Ural Mountains drier weather conditions prevail. These conditions manifest themselves with an increase in frequency of intense rainfall (over most of the continent), and also with an increased potential forest fire danger, the actual areas consumed by fires, agricultural and hydrological droughts, and prolonged dry episodes (in the east), and with an increase of the water table and lake levels (in the west). Schematically, these changes are summarized in Figure 5. The areas north of the Arctic Circle in Siberia in this figure were left blank due to the inadequate density of the regional in situ network for purposes of documenting extreme events changes during the past century. It is worth noting that this picture over the northeastern part of Eurasia (regions with permafrost) is overlaid with an increase in streamflow to the Arctic Ocean (cf. A. Shiklomanov, this issue) a fact that still requires more in-depth explanations.

Summary
Presented information about changes in global and regional climatic variables over the high latitudes of Northern Eurasia during the past 50 to 100 years implies increases and decreases in risk (when the variables have economic, social and ecological implications). Whatever “implications” would be assigned to these observed changes, it is important to note that many of them have been significant enough to be noticed above the usual “weather” noise level (in particular, during the past 50 years) and thus should be further investigated in order to adapt to their impacts.

References


Figure 1. Annual surface air temperature anomalies, °C, area averaged over the Northern Hemisphere (top), Northern Eurasia north of 40°N (middle), and north of 60°N (bottom) for the past 127 years (1881-2007). Anomalies were calculated from the long-term mean values for the 1951-1975 reference period. Time series show statistically significant temperature increase (estimated by linear trends) equal to 0.95°C, 1.4°C and 1.7°C per 127 years respectively. Vertical line marks the year when the first projection of the current global warming was published by Budyko and Vinnikov (1976). Note the difference in scales of the plots for Northern Hemisphere and Northern Eurasia. Thus, while the last year anomaly exceeds 1°C for the Hemisphere, it is well above 2°C for Northern Eurasia and 2.5°C, for Eurasia north of 60°N. Prior to 2005, the regional Arctic warming of the 1930s (cf., the bottom panel) was characterized by higher temperatures anomalies than thereafter. This fact generated arguments about the concept of the global warming as a global phenomenon. Data source: Archive of Lugina et al. (2007 updated).
Figure 2. (left) Satellite-derived Northern Hemisphere sea ice extent anomalies in September (%) updated to 2008; Slope of decrease (dashed line) during the period of observations is \(-11.1\%\) (10yr\(^{-1}\)) with standard error of linear trend equal to \(3.3\%\) (10yr\(^{-1}\)) (http://nsidc.org); (right) Annual land surface air temperature changes due to “forcing” by SST and sea ice changes (Sokolov 2008).

Figure 3. Winter (DJF) and spring (MAM) snow cover extent anomalies over Eurasia for the period 1967-2008. During these 42 years, spring snow cover extent decreased by \(2 \times 10^6\) km\(^2\) or by 11%. Data source: Global Snow Lab, Rutgers Univ., USA. http://climate.rutgers.edu/snowcover/.
Figure 4. (left) Changes of several temperature-derived characteristics within the former USSR boundaries during the 1951-2004 period. All trends are statistically significant at 0.01 or higher levels. (right) Changes of the frequency of days with thaw over Fennoscandia. Day with thaw is defined as a day with snow on the ground and daily temperature above -2°C. (Archive of McBean et al 2005).

![Figure 4](image)

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<td>Duration of the frost-free period</td>
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Figure 5. Changes in the surface water cycle over Northern Eurasia that have been statistically significant in the 20th century (a composite of results of Karl 1998; Førland, E.J. and I. Hanssen-Bauer 2000; Groisman and Rankova 2001; Mescherskaya and Blazhevich 1997 updated; Dai et al. 2004; Zhai et al. 2005; Niu et al. 2007; Bulygina et al. 2007; Groisman et al. 2005, 2007; and Zolina et al. 2005). Regions with more humid conditions (blue), regions where potential forest fire danger has increased in the 20th century (red), the region where agricultural droughts have increased (circled), and the region where prolonged dry episodes have increased (rectangled) are shown (adopted from Groisman et al. (2009)).

![Figure 5](image)
Changes in snow cover characteristics over the Russian territory in recent decades

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The state of snow cover is one of the most important characteristics of the regional climate. The present work studies snow variations by using empirical and statistical analysis of time series of snow depth daily data.

Data
Regular snow cover height measurements at stations were started in Russia in 1902 and modern snow survey observations, including snow water equivalent, in 1966. Time series of snow depth daily data on the extent to which the near-station territory is covered with snow for Russian stations is prepared at RIHMI-WDC. These data and time series of snow survey data at 450 stations were used for investigation of variations in the most important characteristics of snow cover in recent decades. Since then numerous corrections in methods of observation have been made and special attention was paid to collection of all possible sources of inhomogeneities in data. Unfortunately many of these metadata are in listing form until now. Homogeneity disruption is largely caused by the change in snow observation procedures, including the selection of observation sites; the last substantial change in the requirements for the site selection took place in 1950. Thus the homogeneity of snow height data for 1951-2006 was not affected by the changes in observation procedures.

Procedure
1) The following is calculated for each station:
   - the number of days in a year with snow height >1 cm, from July to June;
   - the number of days in a year with snow height >20 cm, from July to June;
   - mean annual snow depth, from July to June
• the number of days in a year with over 50% of the area around the station
  covered with snow, from July to June;

2) Linear trend coefficients are calculated for each station for the period 1951-2006 and 1977-2006

Results
The study of the snow cover on the Russian territory revealed regional features in the change of snow cover characteristics. To characterize snow cover duration a number of days with more than 50% of the near-station territory covered with snow and the number of days with the snow depth more then 1.0 cm were used (Figure1). The tendency for the decrease in this characteristic for 1951-2006 is found in the western and southern regions of European Russia. The decrease in snow duration was recorded in the Taimyr Autonomous District and in the Altai Territory (4 to 6 days/decade) and in the Tyva Republic. Most of East Siberia is occupied by the zone of positive trends with the maximum values attained in the northwest of Yakutia, central and southern regions of the Krasnoyarsk Territory and in Chukotka (4-6 days/decade).

Over most of Russia the number of days with snow height of more than 20 cm also increased, in some of the regions the increase being rather considerable (Figure2). Throughout the Arctic coast, from the Kola Peninsula to Taimyr, the linear trend coefficients were 6-8 days/decade. The same values were recorded in the east of the European territory, the south of West Siberia, the east of Yakutia, the Amur lower reaches, and Sakhalin. On the other hand, the number of days with snow height of more than 20 cm decreased in Transbaikalia and the Chukchi Autonomous District (4 to 6 days/decade).

In the series of the winter mean snow height for 1951-2006, positive trends were prevailing, which agrees with the above estimates. Maximum values of linear trend coefficients were obtained for the northeastern regions of European Russia (Nizhnyaya Pesha, see the inset in Figure3), the south of West Siberia, northern and central regions of the Krasnoyarsk Territory, and Sakhalin. However, some of the Russian regions show decrease in this parameter.

According to the analysis of changes in snow characteristics for the last 30 years (1977-2006), snow cover duration decreases on the European territory, in the south of West Siberia, and in the Amur Region. At the same time in the South Urals, in
Tatarstan, Bashkiria and Buryatia the tendency is recorded for the increasing snow duration to 4-6 days/decade. As for the mean winter snow height characteristic, the area with negative linear trend coefficients increased on the European territory and in East Siberia, as compared with the period 1951-2006.

Figure 1. Linear trend coefficients in the time series of the number of days with snow cover exceeding 1 cm for 1951-2006.

Figure 2. Linear trend coefficients in the time series of the number of days with snow cover exceeding 20 cm for 1951-2006.
Figure 3. Linear trend coefficients in the time series of mean snow depths for the permanent snow-cover period 1951-2006.
Model performance in simulating snow cover in Northern Eurasia

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Observations of snow conditions serve as a sensitive indicator of global warming. With the help of long time series, important information about climate change especially in northern areas has been obtained. A reasonable description of snow variables is very important in atmospheric general circulation models in order to assess possible changes in the future climatic conditions. It is particularly crucial to describe the snow covered area and surface albedo realistically. Snow and surface albedo are connected through a positive feedback mechanism: when the amount of snow reduces, the surface albedo decreases which affects the radiation conditions and the whole climate system.

In this work, the model performance of the atmospheric general circulation model ECHAM5 (Roeckner et al. 2003) and the ERA-40 re-analysis produced by the European Centre for Medium-Range Weather Forecast (ECMWF) (Uppala et al. 2005) in simulating snow water equivalent and surface albedo on snow covered areas in northern Eurasia considered. The aim of the study was to find out the modelling differences between these two and to examine the ability of the ECHAM5 model to represent the snow conditions of the present-day climate. The ECHAM5 simulations (originally used by Räisänen et al. 2007) were forced by observed sea surface temperature and sea ice. The comparison between ECHAM5 and ERA-40 data was done for years 1986-1990. The ERA-40 data was used also to study snow cover characteristics during a longer period 1971-2000.

According to the ERA-40 results for 1971-2000, the monthly mean snow water equivalent (SWE) in March was largest in western Siberia and in Uralian and Scandinavian mountains (Fig. 1a), while largest interannual variation occurred in northern Europe (Fig. 1b). For the period of comparisons, 1986-1990, ECHAM5 produced in many areas lower values of SWE than ERA-40 (Fig. 1c, see also Fig. 2a). The differences were greatest in the areas where SWE was largest, in the middle parts
of the northern Eurasia. Also the interannual variation of snow water equivalent was smaller in the ECHAM5 data than in the ERA-40 data. Especially in two last years of the period, 1989 and 1990, the values of snow water equivalent in North Europe were very low according to ERA-40 (Fig. 2b). High values of NAO-index (North Atlantic Oscillation) in those years (Hurrell 1995) appeared to be linked with these low SWE values. However, the strongly positive phase of the North Atlantic Oscillation at the end of the 1980s did not seem to affect the snow water equivalent of ECHAM5. The observations used in ERA-40 snow analysis probably mainly accounted for the differences between ERA-40 and ECHAM5. It may also be possible that the forcing used in ECHAM5 (observed sea surface temperature and sea ice) was not strong enough to produce completely realistic distribution of snow.

The surface albedo of the snow covered areas is modified with snow albedo. In ERA-40 this snow albedo is a prognostic variable (ECMWF, 2004) while in ECHAM5 the snow albedo is parameterized (Roeckner et al. 2003). In snow covered areas the surface albedo of ECHAM5 is mainly larger than the surface albedo of ERA-40 (Fig. 2c). The discrepancy between these two is mainly caused by the differences in modelling snow albedo and by factors related to vegetation. ECHAM5 underestimates the snow masking effect of trees as a result of which the surface albedo is too high especially in the boreal forests (Roesch and Roeckner, 2006). The surface albedo of ERA-40 is probably more realistic than the surface albedo of ECHAM5.

Acknowledgements
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References


Figure 1. (a) Mean monthly snow water equivalent in northern Eurasia in March in 1971-2000 based on ERA-40 and (b) its standard deviation. (c) The difference between ECHAM5 and ERA-40 results for the monthly mean snow water equivalent in March 1986-1990. Units: m.
Figure 2. (a) Mean monthly snow water equivalent in northern Eurasia in March in 1971-2000 based on ERA-40 and (b) its standard deviation. (c) The difference between ECHAM5 and ERA-40 results for the monthly mean snow water equivalent in March 1986-1990. Units: m.
Relationships between climate and snow changes, and their economical effect in Northern Eurasia

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The research includes several studies on the role of snow in the climate system, its impact on hydrology and socio-economic processes in North Eurasia. For snow cover studies on scales from local to continental, local heat/water exchange modelling is very important. Land surface modeling (LSM) is a standard tool for such studies. The LSMS usually include full spectrum of the heat/water exchange processes on land (radiation absorption, transpiration, turbulent fluxes, conductive heat flux, infiltration of water into soil, runoff, freezing/thawing of the soil, snow seasonal evolution, etc.) depending on meteorological conditions at each time step (usually 1-3 hours) and vegetation/soil parameters.

New snow cover scheme has been combined with SPONSOR land surface model described by Shmakin (1998). A multi-layer snow scheme includes seasonal metamorphism of each layer. Key difference with the old single-layer snow scheme in SPONSOR is evaluation of density of each snow layer, taking into account its evolution. This, in turn, determines its heat balance (through heat conductivity) and, for the top layer – radiation absorption. The main features of the multi-layer snow scheme include formation of a snow layer after a snowfall, change of its physical properties according to meteorological conditions and unifying the layers if they are close enough by key parameters. The model is tested against observed data on snow water equivalent (SWE). Testing is being conducted at several sites located in different geographical regions of North Eurasia and North America (Figures 1-2). The two curves at each of the figures partially demonstrate degree of the parameters’ uncertainty. Evaluation can be considered successful if the observed points fall within the range between the curves. Spring melting is modeled successfully in most of cases at all experimental sites.
Another study is made on comparison of snow melting intensity in April for two 7-year periods: just before the contemporary warming (1966-1972) and the warmest in the 20th century (1989-1995). The results are shown in Figure 3. The results demonstrate that the largest acceleration of the snowmelt in the end of 20th century took place in the north-east and centre of the East European Plain; in the river basins of Pechora, Northern Dvina and Volga, the increase is equal to 40-50%. In some regions of Siberia (e.g. in the Ob basin beyond the Urals), in spite of the warming, the snowmelt has become slower. In general, in Siberia the changes in the snowmelt intensity are more local and not so large, albeit they can play a role in the spring floods due to faster melting in the upper parts of the basins. The regional specifics of the processes are mostly connected to the large-scale atmospheric circulation (Popova, 2007).

More applied study has been done on expenses of snow removal from streets in several Russian cities, taking into account daily snowfalls of different intensity, and development of the cities during several decades. The results are shown in Figure 4. The reason for increase of the expenses in St. Petersburg from 1950s till 1980s is mostly the city growth with corresponding increase of the street length, while decrease of the expenses since 1980s is explained by the decrease of snowfall number under climate change, with the absence of the city development. In Khanty-Mansiysk, sharp increase of the expenses is a result of increase of both street length (continuing now) and number of snowfalls under the climate change in Siberia.

Overall, one cannot see a single relationship between climate change and snow amount in North Eurasia. The impacts of the snow cover are ambiguous too, depending on region, season and other conditions such as socio-economic processes.

References
Figure 1. SWE (kg/sq.m) at Hyytiälä (Finland, 61°51’N, 24°17’E) in the pine forest in 2003-2004 according to observations (blue diamonds), and 2 versions of the threshold value of air temperature determining rain or snow (red – 1.5°C, green – 0°C).

Figure 2. SWE (kg/sq.m) at Valdai (NW Russia) in the field in 1967-1972 according to observations (blue diamonds), and 2 versions of the threshold value of air temperature determining rain or snow (red – 1.5°C, black – 0°C).
Figure 3. Change of snowmelt volume (% of the SWE at the end of March) in 1989-1995 as compared to 1966-1972.

Figure 4. Expenses of snow removal from streets (conventional units) in St.Petersburg near the Baltic sea (top) and Khanty-Mansiysk in Western Siberia (bottom).
Regional LCLUC and the Human Dimension: Yamal, West Siberia

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The NASA/NEESPI Eurasian Arctic Transect has existing and proposed locations from the treeline near Nadym in the Yamal-Nenets Autonomous Okrug (YNAO) to the High Arctic on Novaya Zemlya in the Nenets Autonomous Okrug (NAO). The NASA/NEESPI project has cooperated with personnel and built directly on the data collected at two sites included in the project Environmental and Social Impacts of Industrialization in Northern Russia (ENSINOR), which was active 2004-07) in both NAO & YNAO. The ENSINOR project was designed to consider primarily oil & gas activities because these were what herders themselves cited as the most important factors affecting them in the years leading up to the development of the project. However, spring and summer air temperatures in NAO and YNAO have warmed over the past 25 to 30 years some 2.5 to 3.5°C. This has major implications for both oil & gas infrastructure and the future of reindeer herding since it means that people and reindeer are potentially exposed to multiple stressors.
A quick overview of Yamal reveals that it: (1) is subject to large-scale gas and oil exploration during the past few decades; (2) comprises traditional pasturelands for the nomadic Yamal Nenets people; (3) is undergoing rapid changes in climate; (4) encompasses tundra that is extraordinarily sensitive to disturbance. The goals of the combined ENSINOR and NASA/NEESPI projects have been to determine the cumulative effects of resource development, reindeer herding, climate change, and role of terrain factors on the Yamal Peninsula.

Both project rely heavily on remote sensing of land use/land cover change on Yamal Peninsula. In ENSINOR we conducted a survey of the detection capacities of different platforms and sensors. We found that Quickbird was the best available sensor for most gas field impacts and significantly better than even detailed ground surveys for detecting off-road vehicle trails (Kumpula et al. 2005). We employed a combined GIS and remote sensing approach to catalog impacts and detected approximately 450 km of visibly affected terrain in the vicinity of the Bovenkovo Gas Field on central Yamal Peninsula.

The ENSINOR project also worked extremely closely with Nenets people, conducting extensive participant observation in all seasons while people were migrating with their reindeer. Trends reveal a significant increase of humans on Yamal since 1926 and in the number of privately owned reindeer since 1981.

Potential ecological effects of large populations of migratory reindeer include heavy grazing, grassification and wind erosion, depending on local animal densities, soil type and moisture regime. On central Yamal Peninsula, our analysis of the impacts of resource extraction to pasturelands revealed large scale transformation of land cover on the summer pasture territory of two brigades, or collective management units, that pass through the Bovanenkovo Gas Field. Indirect impacts from industry include things like blowing, sand, dust and changes in hydrology. In earlier research at km 147 along the road/railway corridor on southern Yamal, also included in the ENSINOR and NASA/NEESPI projects, Nenets herders cited the negative influence of dust on cloudberries, mushrooms and lichens very soon after new roads were built through summer pastures (Forbes 1995). In both YNAO and NAO the ENSINOR project developed maps co-produced in real time with reindeer herders migrating through active oil and gas fields. They were able to discuss both positive and negative aspects of development and to pinpoint them precisely in space and time.
In the NASA/NEESPI project, recent analyses of sea-ice, land surface temperature and NDVI trends in Arctic seas and associated land masses raises the questions of whether the trend in decreasing sea-ice is affecting Arctic vegetation. Since 1980, perennial sea ice extent in the Arctic has declined at the rate of 10.1% per decade, and area trend is -11.4% decade (Comiso et al. 2008). At the same time, analysis of NDVI trends in the Kara/Yamal regions of Russia and in the Beaufort Sea indicate that the much lower NDVI on the Yamal is likely due to sandy wind-blown nutrient-poor soils, and grazing by reindeer. Greater change in Beaufort Region (+0.04 vs. +0.0085 NDVI units/decade) is most likely due to more positive trend in ground surface temperatures in the Beaufort region during the period of record. Among other results, summer warmth explains only 2% of the regional variance in NDVI on the Yamal, while elevation, landscape type, vegetation type, and substrate explain 58% (Raynolds et al. 2008). An overview of general sea-ice, NDVI, climate trends indicates that: (1) Summer land-surface temperature, winter sea-ice concentrations, and integrated NDVI are correlated at all spatial scales; (2) Preseason large-scale climate forces the sea ice while local circulation patterns play a larger role during the summer; (3) Although there is a correlation between NDVI and the summer temperature, summer temperature accounts for only a small proportion of the total variation in NDVI on the Yamal. Other factors such as substrate, vegetation type, and major physiographic boundaries play a much larger role than temperature.

In July-August 2007 a joint ENSINOR and NASA/NEESPI expedition to Yamal Peninsula, Russia took place with the following Goals: (1) to better understand the human dimensions of LCLUC on Yamal; (2) the collection of ground observations to support remote-sensing climate-change studies on the Yamal and circumpolar region; and (3) learn about environmental controls on primary production in the region. A great deal of relevant data were collected during the ENSINOR project over 34 months of participant observation and interviews by the project's social and natural scientists since 2004. In addition, during the 2007 joint expedition, data were collected on plant cover, plant biomass, NDVI and LAI, soils, ground temperatures, active layer by the combined ENSINOR and NEESPI teams.

Terrain factors that make the Yamal region so sensitive to terrain disturbance include sandy nutrient poor soils. These are highly susceptible to wind erosion and are characterized by poor plant production, low plant diversity, and slow regeneration following disturbance. Other factors are extensive massive ground ice conditions. Extreme ice-rich permafrost makes the region very susceptible to landslides, for
example, in the unusually wet year of 1989. At Vaskiny Dachi, near the Bovanenkovo Gas Field, unique successional sequences related to Quaternary history, massive ground ice, landslides and soils. Dense willow thickets develop on old landslides after leaching of salts from clayey marine sediments (Leibman et al. 2003).

In the recent ENSINOR and BALANCE projects, changes in deciduous shrub abundance/height cited by herders as significant in NAO and YNAO within their lifetime (Forbes and Stammler, submitted). In the absence of repeat airphotos in northern Russia, we are currently conducting dendro-chronological analyses of willow shrubs (*Salix lanata*) to see if the warming signal documented in climate and permafrost records is detectable in willow growth over the past century. Preliminary results and correlations with NDVI have been quite promising. A strong relationship between tree-ring width and summer air temperature in *Salix lanata* from Varandei tundra was found not only with data from the climate station 18 km away, but also from Salekhard in a very different climate zone some 350 km away (Forbes, Macias and Zetterberg, unpublished data).

During participant observation in the ENSINOR project we were able to observe first hand response to rapid change as exemplified by extreme weather in the form of widespread and repeated icing over of pastures in winter. Strategies for coping included changes of migration route. The relatively free use of space according to herders’ own needs is therefore a critical factor at present. However, if too much oil & gas infrastructure encroaches on their migration routes, this adaptive capacity will be greatly reduced (Forbes and Stammler, submitted).

In conclusion, with regard to resource development direct, planned impacts are less extensive so far than indirect impacts. Nonetheless, roads and pipelines constitute serious barriers to migration corridors and effects will increase as new fields are developed. For reindeer herding, land withdrawals by industry, increasing Nenets population, and larger reindeer herds all have the potential to increase pressure on the rangelands. The general view from the perspective of reindeer herders is that threats from industrial development are much greater than threats from climate change, but they generally view the gas development positively because of increased economic opportunities (Forbes 2008; Forbes and Stammler submitted).

Climate change effects are currently hard to document because of lack of long-term ground observations. Satellite data suggest that there has been only modest summer
land-surface warming and only slight greening changes across the Yamal during the past 24 years. Summer temperature controls only small amount of total variation in NDVI on Yamal and terrain factors appear to be more important. As for landscape factors and terrain sensitivity, there is high potential for extensive landscape effects due to unstable sandy soils, and extremely ice-rich permafrost near the surface. We recommend comparisons with North American Arctic hydrocarbon development. Useful insights regarding generality of Yamal observations and lessons to be learned for other areas of Arctic developments.

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Figure 1. Dr. Florian Stammler interprets discusses Quickbird and ASTER satellite imagery with herdsmen from Brigade 4, Yarsalinski sovkhoz, near Bovanenkovo Gas Field, Yamal Peninsula, July 2005.
Figure 2. ENSINOR PhD student Nina Meschtyb conducting participant observation with Brigade 2, Yarsalinski sovkhoz, near Bovanenkovo Gas Field, Yamal Peninsula, July 2005.
Introduction
Active microwave sensors onboard satellites provide coarse (scatterometer) to medium (ScanSAR and SAR) resolution backscatter images at regular time intervals. In general, satellites with microwave sensors are polar orbiting platforms. This means that data coverage increases with latitude due to overlapping footprints and swaths respectively. At high latitudes, scatterometers can provide several measurements per day and medium resolution ScanSAR up to daily acquisitions. Microwaves have a high application potential in hydrology since backscatter is amongst others related to dielectric properties and thus water content. Time series can be used to monitor soil moisture, snowmelt, and inundation. This extended abstract gives an overview of some available datasets. Additional information can be found on http://www.ipf.tuwien.ac.at/radar/.

Near Surface Soil Moisture
The ERS-1 and ERS-2 C-band scatterometer have been proven useful for derivation of relative soil moisture (Wagner et al. 1999). Such data are available globally with 50 km resolution since 1992. The long dataset allows the determination of deviations and thus anomalies. Continuation is ensured due to the launch of Metop in October 2006. The new ASCAT instrument on Metop provides even shorter revisit intervals and increased spatial resolution (25 km; Bartalis et al. 2007). The near surface soil moisture can be determined by time series analysis (Wagner et al. 2003). Figure 1 shows an example of soil moisture anomalies for July 2007 over the northern high latitude regions. The quality of the soil moisture retrievals have been assessed in many studies, e.g. by comparing the satellite retrievals with in-situ measurements, modeled soil moisture data and other remotely sensed soil moisture data sets (Scipal et al., 2008). Figure 2 shows the correlation of scatterometer derived soil moisture values with ERA Interim model results (ECMWF) over the northern hemisphere. For most of the regions in the world, the correlation coefficients are positive, with maximum values around 0.9 especially in areas that are characterized by a seasonal cycle of soil moisture.
However, in the boreal and tundra zones, correlations are generally lower than in temperate regions (Figure 2). Due to the very limited availability of in-situ observations in these regions, the reasons for the lower correlation are not yet understood but might be related to the short summer season, retrieval errors and/or high uncertainties in the modeled soil moisture data.

Another source of soil moisture data is the European satellite ENVISAT which carries a C-band SAR instrument onboard. This Advanced SAR (ASAR) provides higher resolution data (image mode) as well as medium resolution ScanSAR (Wide Swath and Global Mode). A similar time series analyses as developed for scatterometer data can be applied to Global Mode data for extraction of near surface relative soil moisture. These data can also be used to derive spatial scaling properties which allow an interpretation of coarse resolution soil moisture from scatterometer (25km) at local scale (1km) (Wagner et al. 2008).

Snowmelt
C-Band (~5.6 cm) as well as Ku-band (~2.1 cm) radars are suitable for snowmelt detection. Changes in the snowpack, however, have stronger impact on backscatter at shorter wavelengths. The SeaWinds Quikscat is a Ku-band scatterometer which provides measurements with 25 km resolution since 1999. Large changes in backscatter between morning and evening acquisitions are characteristic for the snowmelt period, when freezing takes place over night and thawing of the surface during the day. When significant changes due to freeze/thaw cycling cease, closed snow cover also disappears (Bartsch et al. 2007a). The exact day of year of beginning and end of freeze/thaw cycling can be clearly determined with consideration of long-term noise.

Lakes and Wetlands
Due to the backscatter properties of open water (even surface), lakes can in general be easily identified with active microwave data. Although wind may increase surface roughness, lakes can be identified based on time series (Bartsch et al. 2007b). Due to the wider swath and thus increased spatial and temporal coverage of ScanSARs, large regions can be processed. For example, ENVISAT ASAR Wide Swath data with 150 m resolution provide considerably more detailed information in Tundra regions than land cover products from e.g. MODIS (500m; Bartsch et al. 2008). The spatial distribution of lakes can be used for determination of Tundra wetland extent and also estimation of methane emissions. Peatlands are characterized by high soil moisture conditions. They can be identified due to the sensitivity of microwaves to moisture/ dielectric properties.
(Bartsch et al. 2007b). ENVISAT ASAR Wide Swath (150 m) as well as Global Mode (1km) time series are suitable for mapping of large regions such as the West Siberian Lowlands (Bartsch et al. 2008).

Acknowledgments
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moisture and radar backscatter observed by the Advanced Synthetic Aperture Radar (ASAR). Sensors 8: 1174-1197.

Figure 1. Polar view of soil moisture anomalies from ASCAT data from July 2007. Left: 3 day composite (July 29-31). Right: 1-day composite (July 30th).
Figure 2. Polar view of a) correlation and b) correlation of anomalies between scatterometer derived soil moisture and ERA Interim modeling results.
Quantifying the carbon budget in Northern European Russia: CARBO-North studies

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Objectives of the project

The CARBO-North project (web site: http://www.carbonorth.net/) aims at quantifying the carbon budget in Northern Russia across temporal and spatial scales. CARBO-North is an EU-funded project which started in November 2006 and runs for 3.5 years. It involves 16 institutions and over 60 scientists from across northern Europe, Russia and the USA. Project integrates state-of-the-art science in the areas of flux measurements, carbon stock inventories, ecological understanding and Earth System modeling to quantify the long-term fluxes of greenhouse gases from the Northern Russian land mass, in order to support policy discussions in the context of the Post-Kyoto process.

Specifically, we will produce regional carbon budgets for Northern Russia for successive time slices of the 21st century (and beyond) that are used to calculate changes in net radiative forcing and effects on future global climate predictions.

Carbon sinks and sources are investigated across spatial and temporal scales. Assessments at the plot to landscape levels based on data collected from intensive study sites (Figure 1) presenting typical taiga and tundra environments in Northeast European Russia will be upscaled to regional and pan-Arctic levels using GIS and modeling approaches. Investigations will focus on the rate at which critical ecosystem processes take place, including effects of human-induced and natural disturbances.

For this purpose we will reconstruct past changes in climate and environment, monitor and interpret present-day processes, and model future 'transient' and 'equilibrium' ecosystem responses for the next 100 years and beyond. All components of the
regional carbon balance in tundra and taiga ecosystems are studied, including forests and tundra, wetlands, aquatic ecosystems and river export and their interconnections. Results will be integrated through the application of a regional ecosystem model, the calculation of net radiative effects, and an assessment of the sensitivity of climate model predictions to expected ecosystem changes.

Through a comparison of regional carbon budgets under past and recent natural climate variability with future 'transient' and 'equilibrium' responses under global warming, an attribution of the relative importance of anthropogenic climate change and natural variability can be made. The second field season of the project is now going on, and comprehensive results are not yet available.

Satellite image analyses
The aim is to classify the vegetation and allocated biomass in these classes in intensive study sites using QUICKBIRD, ASTER and LandSat images. The field work for the project was started on summer 2007 in tundra region and will continue on 2008 on taiga and tundra regions. Vegetation biomass in the area is analyzed using multiple 1 km long transects, each transect consisting 30 biomass collection points. Vegetation classification of the QUICKBIRD images is done using eCognition software. The information from biomass transects is used as a reference data for the classification, and additional collected ground reference data is used in the accuracy assessment. The classification results of the QUICKBIRD images will be used as training areas for ASTER and LandSat images. These classification results will then in the later phase of the project used to evaluate the available MODIS and other coarser resolution classifications. Especially the amount of the peatlands and water bodies in these coarse resolution classifications can be unreliable, and also other discrepancies are found (Virtanen et al. 2004, Virtanen & Kuhry 2006). Produced classification results will be used in vegetation and soil carbon stock and carbon flux measurement upscaling, and in ecosystem-climate models.

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References

Figure 1. Location of the intensive study sites of the project.
Boreal forests in high latitudes of the NEESPI domain

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Of the total area of ~725 million ha of boreal forests in the NEESPI domain, 98% are situated in Russia (Shvidenko and Apps 2004). Relatively small areas of Northern Eurasian boreal forests are also found in Kazakhstan, North Eastern China and Northern Mongolia. These are situated along the Russian southern boundary and are similar to Russian south taiga mountain forests. Thus, at the continental scale Russian forests could be considered a synonym for boreal forests across the NEESPI domain.

A number of distinctive features define the global importance of Russian forests: (1) the huge scale of this natural phenomenon; Russia comprises ~21% of the worlds forest area and 55% of the worlds growing stock volume of economically important coniferous species; (2) high stability and natural regeneration capacity allow Russian boreal forests to serve as an important environmental stabilizer in high latitudes; these forests have formed under extreme conditions and accumulated distinctive ecological properties; (3) the largest contiguous larch forests over the globe (approximately 260 million ha) represents a unique formation as the most northern forests of the Earth (up to 72°34’ N), forming the northern tree line about 4000 km along the Arctic ocean and growing under an average annual temperature of -15-17°C (the absolute minimum at -70°C); (4) Russia contains 28% of the Earths remaining wilderness landscapes allowing for the functioning of indigenous forest types and untransformed forest landscapes over vast territories; (5) the largest over the globe wetland bog-forest complexes occur in Western Siberia; processes of interaction of forests with wetlands that are observed there are unique; and (6) in many regions, vast territories of the Russian boreal zone are under severe anthropogenic pressure.

Russian forests play a substantial role in global biogeochemical cycling. Recent research within the NEESPI paradigm substantially improved our knowledge on the functioning and productivity of boreal forests. They were found to have accumulated 34 Pg C (or 4.37 kg C m$^{-2}$) in live biomass (Figure 1). The dynamics of live biomass in the European and Asian parts of Russia was substantially different between 1993-2003: from 5.11 to 5.34 kg C m$^{-2}$ and 4.17 to 4.13 kg C m$^{-2}$, respectively. About 150 Pg C is
contained within soil. A new estimate of the Net Primary Production of Russian forest ecosystems is 2.31 Pg C yr\(^{-1}\) (or 291 g C m\(^{-2}\) yr\(^{-1}\)) (Shvidenko et al. 2008a) with clear geographical and altitudinal gradients (Figure 2). In spite of the wide distribution of natural and human induced disturbances, Russian forests served as a net sink of carbon during the last decade (on average at the level at 0.5 Pg C yr\(^{-1}\)). Gross growth of Russian forests is estimated to be about 1.6 billion m\(^{3}\) per year. Under rational forest management and implementation of proper programs of carbon management, Russian forests have a tremendous potential for increasing their Carbon sink in the future for a period comparable with the life span of major Russian forest tree species (up to 150-200 years and more).

However, Russian forests are not managed sustainably: unsatisfactory governance of forests and widespread natural and human-induced disturbances generate serious threats taking into account that the most dramatic climate change expected over the globe is predicted for the continental territories of Northern Eurasia. Over 500 million m\(^{3}\) of wood per year have been lost due to stand-replacing disturbances (fire, insects, etc.) between 1993 and 2003. The forest industry creates negative ecological impacts on the environment and forest ecosystems that result in atmospheric pollution, soil and water contamination, physical destruction of natural landscapes, etc. Boreal landscapes and ecosystems are very vulnerable to global change, however the impacts of global change on boreal forests are complicated; their buffer capacity and feedbacks are poorly understood. Large scale changes to the area of boreal forests substantially impact albedo, in turn affecting the surface energy budget. According to some analyses, warming trends have been increasing the productivity of boreal forests approximately 20% during 1960-2000s. However, negative consequences are expected to be much more serious. Thawing of permafrost will change hydrological regimes over vast territories that will substantially impact the distribution and functioning of these forests. This development very likely will be accelerated by a dramatic increase in the extent and severity of catastrophic disturbances, such as fires and insect outbreaks. Experiences of the last decade have clearly demonstrated the possible consequences of global change: the total area of forest fires in 1997-2006 exceeded 10 million ha yr\(^{-1}\), and outbreaks of dangerous insects for some years amounted to 10-12 million ha, particularly in the northern regions where previously such phenomena has never been observed.

The central, most typical and most vulnerable part of the Russian boreal zone, Siberia, is considered to be one of the ecological hot spots in the contemporary world.
Substantial acceleration of warming and changes in functioning of the regional Earth system are very likely there. It will impact the condition and vitality of both aquatic and terrestrial ecosystems, the functioning of wetlands and arid landscapes, agricultural and urban territories. The most important issues affecting the stability of the environment and ecosystems, generating potential risks and uncontrolled fluctuations of both the current state and future trajectories of development of natural landscapes and ecosystems in the region are: (1) potential threat to infrastructure originating from the thawing of permafrost in major regions of oil and gas extraction and exploration; (2) increased variability of regional climate that negatively impacts the terrestrial ecosystems in different ways; (3) increased risks of catastrophic wild vegetation (particularly forest) fire and outbreaks of pestilent forest insects; (4) destructive impacts of the regions industry on environment and forest ecosystems; (5) lack of knowledge of potential boundaries of stability, buffering capacity, responses and feedbacks of ecosystems due to climate change and increasing anthropogenic pressure; (6) impact of predicted global change on health and living standard of the regional population; and (7) need of cognition of future developments of the changing world as a complex combined ecological, economic and social system. This region may function as a generator of small changes in the regional system potentially leading to profound changes in the ways in which the Earth System operates. The process of “green desertification” (i.e. potentially irreversible replacement of forests by grassy glades and bogs) has already been observed over tens of millions of hectares of previously forested land. The overall impacts of global change on the regional environment and ecosystems may be dramatic and exceed the buffering capacity and resilience of the terrestrial biota.

The future fate of Russian forests is strongly dependent upon the relevant anticipatory adaptation of forest management in the framework of the sustainable development paradigm. It requires a clear understanding of the way a changing environment and human intervention impacts structure, functioning and stability of Russian boreal forests, and where the threshold of these impacts lies. Needs for urgent development of anticipatory strategies of adaptation and mitigation of Russian boreal landscapes and ecosystems to the expected negative impacts and consequences of global change are evident.
References

Figure 1. Live biomass in Russian forests, kg C m\(^{-2}\).
Figure 2. Net primary production in Russian forests, g C m$^2$ yr$^{-1}$.
Large-scale Vegetation Cover Dynamics under Disturbances and Climatic Changes

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The individual-based gap model FAREAST (Yan and Shugart 2005) was developed to simulate forest dynamics of Changbai Mountain in China, and then applied to 31 sites in Siberia and the Russian Far East. Using meteorological (Razuvaev et al. 1993) and soil data (Stolbovoi and McCallum, 2002), we expanded simulation of the species composition and expected biomass (tCha⁻¹) of mature forest landscapes to 223 sites across Russia (Shugart et al., 2006). In this paper we briefly report on the further testing of this model against more detailed forest structure data from Russia. The apparent capacity of the model to simulate large area patterns in such summary features as leaf area and biomass of forest that we have already reported (Shugart et al., 2006) are augmented by the model's capability to project the dynamic changes in forest structure over time. These latter findings are briefly illustrated below. Simulation of forest structural dynamics has significant implications for applications involving land-cover change in response to climate change. We will illustrate one of these applications involving the conservation of the Amur tiger (Panthera tigris altaica).

In our initial exploration (Shugart et al., 2006), we reported species composition and biomass of mature forest stands at the locations associated with 223 meteorological stations. At each site, 200 independent plots of a twelfth hectare were simulated and then averaged for each year. On each of the plots, 100 to 700 individual trees were simulated for 500 years with climate drawn from a statistical distribution of local temperature and precipitation.

To evaluate the ability of the model to capture the dynamic responses of forests to natural disturbances, we inspected the capacity of the model to simulate the features of different forests at different ages (or stages of recovery). Biomass values produced by
the model were validated at 46 of the 223 model sites (Shuman-unpublished) using independent, field-collected inventory data from 43 Russian forests (Krankina et al. 2005). Inventory data for total aboveground biomass of age cohorts within stands dominated by *Abies, Betula, Larix, Picea, Pinus,* and *Populus* were used in linear regression comparisons to model data based on geographic proximity between inventory and model sites, and by age and species. Correlations of model biomass to forest inventory biomass are strong for multiple species suggesting that the model is accurately simulating species biomass in response to forest successional dynamics across the Russian region. For example, the Irkutsk model site (Figure 1A) predicts only slightly lower *Larix* biomass compared to the field collected Goloustovskij forest inventory data from the area (Figure 1B). The correlation between the biomass of *Larix* from the model site of Irkutsk and the Goloustovskij forest illustrated in Figure 1C is 0.9629 (p < 0.001). The variations in model output must now be assessed by geographic location for changes in response due to changes in geographic site parameters or species dynamics. The strength of the validation of model simulated biomass with independent forest inventory data confirms that FAREAST is a robust model of Russian forest dynamics and therefore appropriate for use across the Russian region.

One application of the model that is currently being developed by our research group involves the prediction of climate change effects on forests in its action of alteration of wildfire likelihood. One of our foci in these studies is the Amur tiger. The unprecedented rate of climate warming observed in the last half century strongly influences boreal forests of the Northern Hemisphere (Barber et al. 2000, Soja et al. 2006). In Russia, the impact of natural changes induced by warmer temperatures is amplified by economic changes associated with the collapse of the Soviet Union and the sharp increase in the demand for natural resources. These factors combined put the forests of the Russian Far East (RFE) under severe pressure. Some of the most biologically diverse temperate forests in the world are found in the RFE. These forests support a large number of endemic plant and animal species and subspecies. Two of these endemic animals – the Amur tiger (*Panthera tigris altaica*) and the Amur leopard (*Panthera pardus orientalis*) - are recognized by the World Conservation Unit (IUCN) as critically endangered (IUCN 2004). Over 90% of the Amur tigers remaining in the wild are found within the RFE (Miquelle and Pikunov 2003) and the Amur, or Far Eastern, leopards, of which only 25 – 44 remain are confined to an isolated population along the Russian-Chinese border (Miquelle and Murzin 2001).
We are using satellite remote sensing to determine environmental conditions associated with fire occurrence over this area (Loboda et al. 2007, Lododa in press). These results can be combined with the FAREAST simulator to project the expected changes in forest composition over the region. We are initially simulating the forest landscape at 1000 points scattered and random points across Primorski Krai (Figure 2) to gain the dynamic equivalent of a regional vegetation map that can change with climate conditions or with an associated change in wildfires. At the same time, fire danger at a regional scale is being statistically modeled using publicly available data sources and global satellite imaging. This model is based on a fuzzy logic-driven fire danger model developed for the Russian Far East using remotely sensed data. Fire occurrence recorded by the MODIS active fire product was analyzed during 2001-2005 as a function of various parameters and model performance was evaluated during 2006. Fire danger was evaluated within the model using the ordered weighted averaging approach with fuzzification. The model outputs three scenarios. All output model scenarios present a meaningful representation of fire danger levels in the region with the “trade-off” scenario being the most applicable to mapping fire danger during low fire activity seasons.

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Figure 1. a) Biomass in tCha⁻¹ simulated by the FAREAST model for sites with soils and climate conditions appropriate to Irkutsk. b) Goloustovskij forest inventory data from the area near Irkutsk. c) Correlation between FAREAST simulated data and Goloustovskij forest inventory data paired by stand age.
Figure 2. 1000 sample points distributed across Primorski Krai in the Russian Far East. For each of these points we have calculated slope, aspect, interpolated climate conditions and soil conditions. Forest simulations across this area will be computed for different fire regimes and under climate change conditions to assess the change in potential habitat for the Amur tiger.
Recent changes in boreal and arctic vegetation and their feedbacks to the climate system

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The warming observed at high latitudes in the last 50 years exceeds the global average by as much as a factor 5, that is, 2-3°C in Alaska and Siberia versus 0.53°C global mean (from 2001-2005 relative to 1951-1980 baseline) (ACIA 2004; Hansen et al. 2006). Such a dramatic change in climate influences the partitioning of energy throughout ecosystems, and results in changes in the output of energy from ecosystems back to the climate system, either amplifying the initial changes (positive feedback) or dampening them (negative feedback).

High latitude warming is associated with greater growth and density of shrubs (Tape et al. 2006), latitudinal and elevational forest expansion (Lloyd 2005), and a range of other vegetation responses (Walker et al. 2006). The accumulation of biomass associated with increased productivity is a negative feedback in that it reflects a net removal of carbon (CO₂) from the atmosphere, but can also act as a positive feedback by decreasing the amount of solar energy reflected back to space (albedo) and thus increasing the thermal absorption of energy at the surface. In the arctic environment, shrubs increase snow depth by trapping drifting snow and decreasing sublimation (Sturm et al. 2002), and the greater snow depth delays spring snow melt and albedo (Chapin et al. 2005) and promotes winter soil decomposition and CO₂ emissions by elevating winter soil temperatures (Nobrega and Grogan 2007). Similarly, warmer summers result in deeper thawing of the active layer and mobilization of previously frozen soil organic carbon, promoting greater microbial CO₂ respiration and anerobic methane (CH₄) production, and increased evapotranspiration of water vapor – all of which are powerful greenhouse gases (Christensen et al. 2004). In addition to the biotic responses and feedbacks to climate at high latitudes, the degradation of permafrost increases heat fluxes to the atmosphere in the absence of a once substantial thermal heat sink.
Similar interactions and directional feedbacks occur in the response of high latitude forest vegetation to warming, with successional changes between deciduous and conifer species altering the trade-offs between productivity, respiration, and albedo related radiative forcing (Randerson et al. 2006, Goetz et al. 2007). Moreover, because warming and drying increases the frequency, intensity and the extent of fire disturbance (Stocks et al. 1998), a multitude of legacy effects result from fire disturbance that influence the directionality and magnitude of feedbacks. For example, fires emit enormous quantities of CO$_2$ into the atmosphere in a short time, and influence regional climate in the following years via changes in spring and summer albedo (Randerson et al. 2006), as well as rates of canopy conductance and associated evapotranspiration (Amiro et al. 2006). Increases in boreal forest fire disturbance thus have the potential of altering the global carbon cycle, not only because these areas store some 78 Pg of carbon in above-ground vegetation that can be rapidly transported to the atmosphere by fire, but also because the majority of the Earth’s soil organic carbon (703 Pg) stored at high latitudes can be mobilized fire as well as by the increased thawing and microbial decomposition that lasts for many years after the fire event (Kasischke and Stocks 2001). Thus large carbon stores in high latitude soil organic matter, resulting from the slow accumulation of peat under cold and wet conditions over millennia, is prone to more rapid decomposition and mobilization in the warmer and drier conditions characteristic of climate change over the next few decades (the so called “carbon bomb”).

The trajectory of forest succession is also strongly influenced by fire, particularly fire severity. The classic paradigm of boreal forest succession following stand replacing fire is of one that moves from early pioneer forb and shrub species to an intermediate phase with deciduous tree species dominating, and finally into a mature coniferous forest after 5 or 6 decades. Changes in climate-induced fire severity, however, change this paradigm because more severe fires consume greater amounts of soil organic matter (peat), which facilitates the establishment and persistence of deciduous trees (Figure 1). There are negative climate feedbacks to the climate system associated with these changes (i.e. mitigating further warming), such as greater net productivity and shortwave albedo. The latter is most pronounced in winter when deciduous forest canopies are leafless and do not absorb as much incident solar radiation as a conifer canopy, but also because deciduous canopies do not impede the shortwave radiation reflected by snow back to space. Over large areas these albedo change have substantial consequences on energy balance and radiative forcing on climate, as the low winter albedo of coniferous boreal forest is replaced by high albedo deciduous
forest (Randerson et al. 2006). Other forcings, such as increased evapotranspiration and lower sensible heat flux, are likely to be reduced under climate change at high latitudes because deciduous trees have higher canopy conductance than coniferous trees (Baldocchi et al. 2000). Together, these negative feedbacks act to offset, to some extent, the short-term positive feedbacks associated with direct carbon emissions from forest fire, but over much longer time scales.

The responses and feedbacks described thus far are well understood in many ways, but the magnitude of the feedbacks under a changing climate and the implications and trade-offs of those are currently poorly constrained. For example, satellite observations of high latitude vegetation indicated a ubiquitous ‘greening’ of areas above 45° N latitude between 1982 and 1991 (Myneni et al. 1997). A number of related studies, both observational and from model simulations, supported this view. More recently, however, satellite observational analyses of North America showed that this overall trend changed after 1990, with tundra continuing to green (increase in productivity) but boreal forest areas declining in productivity (“browning”), even excluding all areas burned in recent decades (Goetz et al. 2005). This decline has been attributed to drought, specifically higher vapor pressure deficit associated with warmer and drier air masses, which limits stomatal conductance and photosynthesis in boreal forests better adapted to cooler conditions. The same trends and patterns were also documented across the circumpolar arctic, with distinctly different responses in tundra versus boreal forest areas (Figure 2).

The vegetation-climate feedbacks described above demonstrate the variety of mechanisms through which changes in terrestrial ecosystems can affect the climate system, resulting in a wide range of vegetation responses and trade-offs between positive and negative feedbacks. The contrasting recent trends in vegetation productivity at high latitude, the variety of feedbacks related to vegetation succession after fire disturbance, and the interacting effects of vegetation and snow cover on albedo radiative forcing illustrate how vegetation-climate feedbacks vary under a changing climate. The temporal dynamics of high-latitude vegetation feedbacks is therefore a critical aspect of understanding its influence on the climate system, and the need to track high latitude ecosystem change has never been greater.
References


Figure 1. Hypothesized effects of fire severity and drainage on post-fire successional trajectories in boreal forests of interior Alaska. Predictions for carbon-energy trade-offs in young, intermediate-aged, and mature forest stands over approximately 100 years are indicated. Two possible successional trajectories are indicated for simplicity; in general stand types are highly variable and span the full range of broadleaf deciduous tree densities described by these two end members. NPP = Net Primary Production, SOC = Soil Organic Carbon (from Goetz et al. 2007).
Figure 2. Trends in satellite observations of vegetation photosynthetic activity derived from a 1982-2005 time series of GIMMS-G AVHRR vegetation indices, with significant positive trends show in yellow and negative trends in red. The trends map is overlaid on a 1 km resolution background mosaic of MODIS imagery and ocean bathymetry derived from several data sources (see www.esri.com/data). From Goetz et al. 2007.
Potential climate-induced vegetation change in Siberia in the 21st century

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Regional studies in Siberia have already registered a change in climate at the end of the 20th century. Additionally, we found that in some regions, warming primarily in winter has already exceeded Atmosphere Ocean General Circulation Model predictions. A mounting body of evidence of the changes in Siberian vegetation and in the forests in particular related to climate warming is available in the literature and summarized in the reviews of Soja et al.(2007) and Tchebakova et al. (2008). At the northern treeline, the forest shifted into tundra and open forests become more stocked. In Evenkia, in the permafrost zone which is dominated by only L. dahurica, undergrowth of Siberian cedar (Pinus sibirica), fir and spruce up to 40 years old was found possibly because of permafrost melting. Upper treeline shifts 40-100 m upslope was registered in the mountains in the south: Altai, Kuznetsky Alatau, West Sayan and even in the north in Putorana Plateau. At the lower treeline, changes in forest structure also occur. In the West Sayan, the Pinus sibirica seed production significantly decreased for 1990-1999, the warmest decade of the last century, presumably because of the cone damage by the moth Dioryctria abietella (Schfft.){ that may produce two generations for a longer vegetation period).

In this study, we examined the potential effect of two climate change scenarios on the spatial vegetation redistribution across Siberia for the 21st century and predicted locations where possible changes in climate would create new habitats for vegetation change. We used our bioclimatic vegetation model for predicting vegetation zones (zonobiomes) across Siberia. Our model is an “envelope-type” model (Box, 1981) that determines a unique vegetation class (unique climatic limits for a vegetation class) from three bioclimatic indices: growing degree-days, base 5°C, representing plant requirements for warmth; negative degree-days, base 0°C, characterizing plant cold tolerance, and AMI characterizing plant drought resistance. Vegetation predicted only
from climatic variables was then corrected for permafrost which is the primary factor controlling the vegetation and tree species distribution over Siberia.

Data from about 1000 Siberian weather stations across the study area (within the Siberian window 60-140° E and 50-75° N) were used to map current climatic variables and indices using Hutchinson’s (2000) thin plate splines on DEM grids (1 km). Future bioclimatic indices were calculated using climatic anomalies for 2020, 2050, and 2080 derived from two climate change scenarios the HadCM3 A1FI and B1 of the Hadley Centre in the U.K. based on the Special Report on Emission Scenarios, SRES (IPCC, 2000). These scenarios reflect opposite ends of the SRES range, the largest temperature increase from the A1FI scenario and the smallest temperature increase from the B1 scenario. Temperature increases across Siberia in both the A1FI and B1 scenarios do not differ much for 2020 but double for 2080, with the A1FI showing greater warming, 8-9°C versus 4-5°C in the B1 scenario.

Our research showed that Siberian vegetation would already be disturbed by 2020 and severely disturbed by 2080. Disturbances for each time slice differ in different scenarios: moderate changes are predicted from the B1 scenario and dramatic - from the A1FI scenario (Figure1). Habitats for northern vegetation classes (tundra, forest-tundra, and taiga) would shrink, habitats for southern vegetation (forest-steppe, steppe and semidesert) would expand (table, fig.1). Biomes and major tree species may shift northwards as far as 600-1000 km. Despite the large predicted warming, permafrost will not thaw deep enough across Siberia to support darkleaf taiga which requires 1-2 m of the active layer depth (ALD). Over the plain of Siberia, the larch (Larix dahurica) taiga withstanding shallow ALD will remain the dominant zonobiome. Because of a predicted dryer climate, forest-steppes and steppes rather than forests would dominate over half of Siberia. These lands would be suitable and may be used for growing both traditional crops in the north and new crops in the south for additional food, forage and biofuel production. In the very south of Siberia, desertification is predicted to occur due to the precipitation decrease along with the large temperature increase. Our model also showed that new habitats for some temperate vegetation (broadleaf forest and forest-steppe) would occur by 2080. Melting permafrost and fire are the principal mechanisms that facilitate equilibrium between the vegetation and the climate across Siberian landscapes.
References


Table 1. Siberian vegetation change (%) in the 21st century predicted from HadCM3 A1FI and B1 climate change scenarios. Blue is an area decrease, red is an area increase.

<table>
<thead>
<tr>
<th>Vegetation zone</th>
<th>Current climate</th>
<th>Scenario HadCM3 B1</th>
<th>Scenario HadCM3 A1FI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2020</td>
<td>2050</td>
</tr>
<tr>
<td>BOREAL:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tundra</td>
<td>18.3</td>
<td>8.2</td>
<td>4.7</td>
</tr>
<tr>
<td>Forest-tundra</td>
<td>8.5</td>
<td>7.1</td>
<td>6.3</td>
</tr>
<tr>
<td>Northern Dark Taiga</td>
<td>0.2</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Light Taiga</td>
<td>13.6</td>
<td>10.6</td>
<td>9.0</td>
</tr>
<tr>
<td>Middle Dark Taiga</td>
<td>4.7</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Light Taiga</td>
<td>17.0</td>
<td>14.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Southern Dark Taiga</td>
<td>7.5</td>
<td>5.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Light Taiga</td>
<td>8.6</td>
<td>11.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Forest-steppe</td>
<td>7.5</td>
<td>17.8</td>
<td>24.4</td>
</tr>
<tr>
<td>Steppe</td>
<td>10.0</td>
<td>12.7</td>
<td>14.2</td>
</tr>
<tr>
<td>Semidesert</td>
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<td>3.9</td>
<td>4.6</td>
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<tr>
<td>TEMPERATE:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broadleaf Forest</td>
<td>0.8</td>
<td>1.8</td>
<td>3.9</td>
</tr>
<tr>
<td>Forest-steppe</td>
<td>0.8</td>
<td>1.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Steppe</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>Semidesert/Desert</td>
<td>1.0</td>
<td>2.8</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Figure 1. Vegetation change from current climate to 2080 in Siberia was mapped by coupling our bioclimatic vegetation model with maps of bioclimatic indices and of the permafrost which drive the model for different time slices and two climate change scenarios.
Hydrologic modeling over NEESPI: Challenges and Progress

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Northern Eurasia encompasses a vast region of the earth’s extratropical land area with a variety of climatic regions and biomes, from deserts in the south to frozen tundra in the north. In addition to its varied climate and ecosystems, it is a region of interest because of its changing hydrology. Discharge has increased by 7% since 1930 [Peterson et al., 2002], active layer thickness has increased in permafrost zones [Romanovsky et al., 2007], and some of the strongest warming over the 20th century occurred in northern Eurasia [IPCC, 2007]. Observations over the region are sparse due to its size and harsh climate, making it difficult to fully understand the hydroclimatology and its changes. Hydrologic modeling can bridge the gap in observations and can be used to simulate hydrologic states and fluxes across a domain continuously in time and space as well as provide hydrologic information for related vegetation and biogeochemical studies.

In order to simulate the land surface hydrology of the high latitudes, a number of processes must be parameterized that may be insignificant in other regions, such as permafrost dynamics, snow sublimation/blowing snow parameterizations, and lakes and wetlands. These processes have been included in the physically-based Variable Infiltration Capacity (VIC) land surface model [Cherkauer and Lettenmaier, 1999; Cherkauer et al., 2003; Liang et al., 1994; Liang et al., 1996], and the model has performed well in high latitude environments [Su et al., 2005; Su et al., 2006]. The inclusion of these processes has an effect on the water budgets, as is shown below with the inclusion of a lake model.

Peatlands cover a significant portion of western Siberia, and lakes and wetlands are critical land cover types to be included in hydrologic modeling across northern Eurasia. Lakes act as storage for runoff, particularly during the spring snowmelt season, capturing runoff and retaining it, rather than allowing it to continue unchecked into the stream channel. This allows the lake to perform two important hydrologic functions: the slowed release of water into the stream channel, reducing the discharge peak, and
providing a free water surface to evaporate into the atmosphere. The VIC land surface model includes a physically-based lake model that includes lake freeze/thaw, inundation, evaporation, and runoff release through a weir equation.

Figure 1 demonstrates the effect that the inclusion of lakes has on model performance for the Iset River at Isetskoje, a small basin (56,000 km²) in the Ob River watershed. The left panel shows the modeled seasonal cycle of runoff (averaged from 1940 to 2000) with and without the lake parameterization (black and blue, respectively). Inclusion of the lake model reduces the April peak runoff by 27% and also reduces the annual runoff totals. The panel on the right shows the effect of lakes on the evaporation budget. Annual evapotranspiration increases from 344 mm/yr without lakes to 407 mm/yr with lakes, an increase of 18%. The difference in modeled evapotranspiration has an effect on modeled streamflow, but it also has an effect on the interactions between the land surface and atmosphere. In regions with significant lake coverage, such as the portions of northern Eurasia, coupled models that use simplified land surface schemes without lake models may be underestimating the evapotranspiration from the land surface, which may then have an effect on other processes.

As the high latitudes of Eurasia receive more attention due to climate change, it is important that the hydrological parameterizations in land surface models are sufficiently accurate that they can be used to attribute land use and land cover change (LULCC) and climate change. The areas where improvements in parameterizations are required include lakes, with which VIC has made progress but other land surface models (LSMs) have not; parameterization of peatlands, which are poorly represented in most models (but they cover a significant portion of western Siberia and other areas across the pan-Arctic); improved modeling of permafrost temperatures that requires modeling of deep soil layers; and the inclusion of a water table for the deep soil layers. Advances in modeling these processes are being made, but progress must continue with robust testing of the parameterizations. NEESPI needs to encourage the intercomparison of LSM parameterizations and to test the ability of LSMs to evaluate anthropogenic influences and test attribution hypotheses. Finally, there is the modeling concern that a scale mismatch exists between the observation scale and the LSM modeling scale. Thus, there is a need to explore the potential of remote sensing to bridge this gap so as to improve our understanding of the water and energy cycles across the NEESPI domain.
References
Romanovsky, V. E., et al. (2007), Past and recent changes in air and permafrost temperatures in eastern Siberia, *Global and Planetary Change*, 56(3-4), 399-413.
Figure 1. The top panel demonstrates the reduction in runoff with the inclusion of the lake model, and the bottom panel shows the effect of including lake processes on the seasonal evapotranspiration budget.
Modeling of CO$_2$ and CH$_4$ Fluxes in the Arctic

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The Arctic stores a one-third of earth surface soil carbon, occupies a half of world wetlands, and is dominated by continuous or discontinuous permafrost. It has experienced unique changes in its atmospheric climate comparing to other regions on Earth in the last half century. Wildfires in its terrestrial ecosystems have been increasingly more active. Consequently, permafrost degradation has been expedited. The fate of its large amount of carbon is uncertain. One speculation is that the release of CO$_2$ and CH$_4$ to the atmosphere will be dramatic due to enhanced soil aerobic and anaerobic decomposition. In turn, these gases will exert a positive feedback to the global climate system.

While the potential increase of soil carbon release is of great concern, the climate will also affect plant growing season length and productivity. The possible enhanced photosynthesis due to warming will alter the net CO$_2$ exchanges between the terrestrial ecosystems and atmosphere in the region. Changes of snow cover, soil hydrology, and nutrient condition, especially nitrogen availability, all will affect plant carbon uptake through photosynthesis. Permafrost stability directly associated with soil hydrology will affect the growing season length and plant productivity. In the meantime, the increase of soil decomposition due to warming may provide more nutrients (e.g., nitrogen) to plant, enhancing photosynthesis. Permafrost degradation will lead to a drier condition for some areas and a wetter one for others. Different soil wetness and drainage conditions will influence plant carbon uptake and affect CO$_2$ and CH$_4$ fluxes, as dry soils tend to be a CO$_2$ source and a CH$_4$ sink, while wet conditions will enhance CH$_4$ production and suppress aerobic decomposition. Fires will lead to a large amount of immediate greenhouse gas emissions. Fire disturbances will decrease plant productivity, change soil decomposition, alter soil nutrient conditions, degrade permafrost, change soil hydrological cycle, and likely lead to a more complex pattern of CO$_2$ and CH$_4$ dynamics in the region.
To quantify the net budget of CO$_2$ and CH$_4$ fluxes, a process-based biogeochemistry model, the Terrestrial Ecosystem Model (TEM), is used. TEM incorporates spatially-explicit data pertaining to climate, vegetation, soil, and elevation to estimate the changes of carbon and nitrogen pool sizes and CO$_2$ and CH$_4$ fluxes. To model CO$_2$ dynamics, the model and parameters have been well documented, and the model was augmented by incorporating the permafrost dynamics, fire disturbances, and more sophisticated hydrological models (Zhuang et al., 2001, 2002, 2003; Euskirchen, 2006; Balshi et al., 2007). In TEM, the net exchange of CO$_2$ between the terrestrial biosphere and atmosphere (NEP) is calculated as the difference between the uptake of atmospheric CO$_2$ associated with photosynthesis (i.e., gross primary production or GPP) and the release of CO$_2$ through autotrophic respiration ($R_A$) associated with plant growth and maintenance and through heterotrophic respiration ($R_H$) associated with decomposition of organic matter. The difference between GPP and $R_A$ is defined as net primary production (NPP). The fluxes GPP, $R_A$ and $R_H$ are influenced by changes in atmospheric CO$_2$, climate variability and change, and the freeze-thaw status of the soil. To model CH$_4$ fluxes, TEM explicitly simulates the processes of CH$_4$ production (methanogenesis) and CH$_4$ oxidation (methanotrophy), as well as the transport of the gas between the soil and the atmosphere. The net CH$_4$ emissions from soils to the atmosphere are the total of the CH$_4$ fluxes at the soil/water-atmosphere boundary via different transport pathways (Zhuang et al., 2004, 2006, 2007). The transport pathways include molecular diffusion, ebullition, and plant-mediated emissions through the stems of vascular plants. CH$_4$ production is modeled as an anaerobic process that occurs in the saturated zone of the soil profile. Soil CH$_4$ production is influenced by carbon substrate availability, soil temperature, soil pH, and the availability of electron acceptors, which is related to redox potentials. Monthly NPP estimates in TEM are used to capture the effect of the spatial and temporal variations in root exudates on methanogenesis. CH$_4$ oxidation, which is modeled as an aerobic process that occurs in the unsaturated zone of the soil profile, is a function of the soil CH$_4$ concentration, soil temperature, soil moisture, and redox potential.

We apply TEM to quantify the current combined CO$_2$ and CH$_4$ budget and to project a set of alternative future budgets associated with various climate change scenarios and alternative assumptions about the importance of CO$_2$ stimulation of plant growth and carbon storage in plants and soils (Zhuang et al., 2006). For our regional simulations, we use gridded (0.5°x0.5°) input data on vegetation distribution, elevation, soil texture, soil-water pH, wetland distribution, and fractional inundation of wetlands. Climate data, including the monthly mean temperature, precipitation, and vapor pressure for each land grid cell in the high northern latitudes are developed using the MIT Integrated Global System Model (IGSM). We conduct a set of TEM simulations with a factorial design considering three plausible climate scenarios, with and without a CO$_2$ fertilization effect on photosynthesis, and three different fire disturbance regimes. In each simulation, TEM estimates the terrestrial CO$_2$ and CH$_4$ dynamics of each 0.5° latitude x 0.5° longitude grid cell from 1860 to 2100. We find that currently the region is a net source of carbon to the atmosphere at 276 Tg C yr$^{-1}$. We project that throughout the 21st century, the region will most likely
continue as a net source of carbon and the source will increase by up to 473 Tg C yr\(^{-1}\) by the end of the century compared to the current emissions. Our simulations show that the arctic wetlands will function as a source of between 4.1 and 5.8 Pg C over the century, mainly as CH\(_4\). By 2100, we project CH\(_4\) emissions from the wetlands of the region would more than double over the century when anthropogenic emissions are high. Using a simulation modeling approach, Gedney and colleagues (Gedney et al., 2004) have also estimated a projected doubling of CH\(_4\) emissions over this century. We calculate the greenhouse gas budget as the difference between net CO\(_2\) and CH\(_4\) exchanges using the measure of global warming potentials (GWP). The calculation shows that the local-scale changes in radiative forcing can be large (Figure 1). However, our coupled carbon and climate model simulations show that these emissions will exert relatively small radiative forcing on the global climate system compared to large amounts of anthropogenic emissions. We estimate that the change in global radiative forcing associated with climate-related biogeochemical changes in the Arctic will be less than +/− 0.1 W m\(^{-2}\) over the course of the 21\(^{st}\) Century.

In doing above analyses, however, we were lack of better information in the following areas at the time: 1) effects of CO\(_2\) fertilization on net primary production and net ecosystem production in the region; 2) the fire history of forests in the region and the controls to the spatial and temporal patterns of this important disturbance; 3) the linkages between dynamic hydrology, lake formation and drainage, and permafrost thawing; and 4) the effects of atmospheric depositions including nitrogen and ozone on plant productivity. In addition, we were not able to consider large potential CH\(_4\) emissions from thawing lakes as indicated by Walter et al., (2007) and the potential increase of emissions of CO\(_2\) and CH\(_4\) due to abundant carbon stored in permafrost (Zimov et al., 2007). Factoring these effects, processes, and sources into our future modeling of CO\(_2\) and CH\(_4\) dynamics will revise our quantification of these greenhouse gases budget in the Arctic.

Reference:


Figure 1. Spatial distribution of net greenhouse gas exchanges simulated with TEM (a) in the 1990s, (b) in the 2090s with CO₂ fertilization effects, and (c) in the 2090s without CO₂ fertilization effects. Positive values indicate greenhouse gas sources to the atmosphere. Negative values indicate greenhouse gas sinks from the atmosphere to terrestrial ecosystems. The CO₂ equivalent of net CH₄ exchanges is calculated as global warming potentials (GWPs) on the 100-year time horizon, i.e., one gram CH₄ is equivalent to 23 g CO₂. The maps are simulation results of the “Reference” climate and atmospheric CO₂ scenario. The MIT Integrated Global Systems Model (IGSM) is used to develop monthly estimates of surface air temperature, precipitation, and vapour pressure for three future climate and atmospheric CO₂ concentration scenarios for input into TEM by mapping the projected zonal-average IGSM changes to latitude and longitude by adjusting observed current climate (Prinn et al., 1999). The annual anthropogenic CO₂ emissions in 2100 for the “Reference” scenario are equivalent to 73 Pg CO₂. The emissions correspond to projected atmospheric CO₂ mole fraction (parts per million, ppm) by 2100 of about 694 ppm. In these maps, the effects of fire disturbances have also been considered (Zhuang et al., 2006).
Hydrological changes across Eurasian Arctic

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²State Hydrological Institute, St. Petersburg, Russia
Correspondence author e-mail: Alex.Shiklomanov@unh.edu

There is increasing evidence pointing to significant changes in the hydrological regime over the North Eurasian region. Understanding these changes due to both global and local influences are important to explore potential signals of climate change and to assess their feedbacks to hydrological systems, the global climate and to their impacts upon humans. Using the extensive collection of hydrometeorological data archived at the University of New Hampshire (UNH) and the State Hydrological Institute (SHI), Russia we examined the hydrological characteristics across the Eurasian pan-Arctic drainage basin.

The discharge data for largest Eurasian Arctic Rivers (Yenisei, Lena, Ob, Severnaya Dvina, Pechora and Kolyma) were used to estimate the long-term discharge variability. All of the rivers, except Kolyma, show significant (p<0.05) increasing trend in annual river discharge over 1936-2006 (Table 1). Mean discharge over 2000-2006 for these six Eurasian rivers was on average ~7 % higher than discharge over 1936-2006 (Richter-Menge et al., 2007). The maximum total discharge of the six largest Eurasian rivers over 1936-2006 was observed in 2002 and it was 25% higher than long-term mean. Thus the contemporary data further confirms the presence of significant increasing trend in the fresh water discharge to the Arctic Ocean from Eurasia documented earlier by Peterson et. al. 2002. These increases could effect the fresh water budget of the Arctic Ocean and which may slow down the North Atlantic thermohaline circulation (e.g. Marotzke, 2000).

Why discharge has increased is not clear. There is some evidence for increased precipitation over the terrestrial Arctic drainage but there are also indications that increased precipitation may be in part balanced by higher evapotranspiration due to a significant rise in air temperature. An analysis of trends (1936-2001) in the water budget components across 56 subbasins of the six Eurasian river systems has been carried out to identify regions where runoff changes are consistent with trends in
precipitation (P) and evapotranspiration (ET). Using the 25 km x 25 km EASE Grid river network from ArcticRIMS (http://RIMS.unh.edu), discharge data from R-ArcticNet (http://R-ArcticNet.sr.unh.edu), precipitation and air temperature from University of Delaware (http://climate.geog.udel.edu/~climate/html_pages/archive.html), the Hamon potential evapotranspiration function (Vorosmarty et al, 1998) we found that changes in runoff have complex spatial distribution with greatest increasing trends in the northern latitudes (Figure 1). Changes in precipitation and runoff across the region are consistent, however the rate of runoff increase is much higher and therefore we cannot explain the discharge increase solely based on precipitation changes. Evapotranspiration has insignificantly increased across the region and the greatest discrepancies between the water budget components are seen in the northern areas underlain by permafrost (Figure 1). This supports, indirectly, the idea that permafrost thawing and a thicker active layer could provide some of the additional water release into the river network to account for these changes.

To analyze the seasonal trends in river discharge we cannot use stream gauges located along the many large rivers because of large-scale impoundments and other human impacts within the basins. While at first the reservoirs appear small, their impact during low flow (winter) could be significant even for gauges located very far from reservoir. An analysis of 97 monthly discharge records longer 50 years for rivers with no significant human impacts has been used to identify seasonal variations and changes in the hydrological regime across the Eurasian pan-Arctic (Walsh et al, 2005). The results showed that from the late 1970s to the beginning of 2000s winter river runoff has increased over most parts of the region. Significant increases (10-50%) in winter and summer-autumn runoff have occurred on rivers located on the north slope of the European Russia. Winter runoff has increased by up to 40-60% in the Irtysh basin and in southeastern Siberia, and up to 15-35% in the northern Siberia.

We also analyzed trends in maximum daily discharge records from a new data set of 139 Russian gauges in the Eurasian Arctic drainage basin with watershed areas from 16.1 to 50 000 km$^2$ (Shiklomanov et al, 2007). These drainage basins were chosen specifically for their long-term records with relatively undisturbed land cover and land use change. For the magnitude of spring maximum daily discharge we found equal numbers of significant positive and negative trends across Russian Arctic drainage basin, which draws into question the hypothesis of an increasing risk of extreme floods. However, analysis of extreme water stages across Russia over 1985-2001 made at
SHI demonstrated a significant increase in flood situations for most of Russia associated with ice dams and intensive rainfalls during summer-fall period.

Significant changes have occurred in the timing of many hydrological events across the Eurasian pan-Arctic. A significant shift to earlier spring discharge peak (about 5 days over 1960-2001) was found by Shiklomanov et al. (2007). This is consistent with documented changes in snowmelt, freeze-thaw dates and freeze-up duration (McDonald et al., 2004).

To project future runoff/discharge changes we used simulations from the UNH Water Balance and Water Transport Models (WBM/WTM) (Wisser et al, 2008) which incorporates irrigation and reservoir effects, along with results from the SHI and UNH pan-Arctic water balance models with improved frozen ground schemes (Georgievsky et al. 2002 and Rawlins et al 2005 respectively). All models were driven with the same climate scenarios from Global Circulation Models (GCM) and demonstrated a general tendency toward increases in river runoff although the changes across Northern Eurasia were not spatially uniform (Figure 2). For our analysis ECHAM5 and HadleyCM3 GCMs were chosen. Simulated changes in seasonal and annual runoff based on ECHAM5 GCM, scenario A1b for the end of XXI century is shown in Figure 2. Most significant annual runoff increases are projected along the Arctic Ocean coastline, in Northern Europe and the Russian Far East. Most significant increases in the Eurasian Arctic Basin rivers are projected during winter and spring months which is likely a result of both higher runoff and earlier spring melt. A decrease in runoff is expected in most southern regions of the NEESPI domain with limited water resources.

These results are consistent with other future runoff projections using different hydrologic models and climate scenarios (Table 2). In general, all hydrological models project a significant runoff increase across the Eurasian pan-Arctic despite the significant uncertainty in future precipitation changes between GCMs (the uncertainty in precipitation increases over time and between the different models averaging 100 mm/yr in year 2000 to 110 mm/yr, 130 mm/yr, and 150 mm/yr in 2025, 2050, and 2099, respectively).

The Eurasian pan-Arctic represents an extreme environment presenting challenges to detailed hydrological studies due to severe climate, specific conditions of runoff formation associated with permafrost, sparse hydrological networks, a declining number of observational stations, vast areas with no gauges at all, lower data quality,
and the absence of reliable field experiments. There are large data sets available reflecting the long history and importance of scientific research in Russia, and we believe that our collaboration with Russian partners under several NEESPI projects will help in better understanding of regional hydrological processes and the changes now being observed.

References
R-ArcticNET - Regional Hydrographic Network for the Arctic Region, on CD-ROM from National Snow and Ice Data Center, Boulder, Co, USA or http://www.R-ArcticNet.sr.unh.edu
Table 1. Characteristics of annual discharge for large Eurasian Arctic rivers. Period of observations 1936-2006.

<table>
<thead>
<tr>
<th>River</th>
<th>Drainage area (km²)</th>
<th>Mean discharge for the period (km³ yr⁻¹)</th>
<th>Change over observational period*</th>
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<tr>
<td></td>
<td></td>
<td>Entire observational period</td>
<td>1936-1999</td>
</tr>
<tr>
<td>Yenisey at Igarka</td>
<td>2440000</td>
<td>585</td>
<td>580</td>
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<tr>
<td>Lena at Kusur</td>
<td>2430000</td>
<td>530</td>
<td>526</td>
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<tr>
<td>Ob at Salekhard</td>
<td>2950000</td>
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<td>398</td>
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<td>Pechora at Ust-Tsilma</td>
<td>248000</td>
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<td>Severnaya Dvina at Ust-Pinega</td>
<td>348000</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Kolyma at Srednekolymsk</td>
<td>361000</td>
<td>70</td>
<td>70</td>
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<tr>
<td>Total</td>
<td>8777000</td>
<td>1795</td>
<td>1783</td>
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Note: *Computed based on a slope of linear trend line.
Table 2. Expected changes in the discharges of the largest Eurasian Arctic rivers as a result of global climate change according to different authors.

<table>
<thead>
<tr>
<th>Publication</th>
<th>Climate scenario</th>
<th>River basin</th>
<th>Annual discharge change (%)</th>
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<tr>
<td>Aroa &amp; Bayer, 2001</td>
<td>CGCM By 2050</td>
<td>Yenisey</td>
<td>18</td>
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<td></td>
<td></td>
<td>Lena</td>
<td>19</td>
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<tr>
<td></td>
<td></td>
<td>Ob</td>
<td>-12</td>
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<td>Mokhov et al, 2003</td>
<td>HadCM3</td>
<td>Yenisey</td>
<td>8</td>
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<td></td>
<td>ECHAM4</td>
<td>Lena</td>
<td>22-24</td>
</tr>
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<td></td>
<td></td>
<td>Ob</td>
<td>3-4</td>
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<td>Georgievsky et al., 2002</td>
<td>HadCM3</td>
<td>Lena</td>
<td>12</td>
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<tr>
<td>Manabe &amp; Wetherold, 2003</td>
<td>IS92a by 2035-2065</td>
<td>Yenisey</td>
<td>13</td>
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<tr>
<td></td>
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<td>Lena</td>
<td>12</td>
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<tr>
<td></td>
<td></td>
<td>Ob</td>
<td>21</td>
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<tr>
<td>Arnell, 2004</td>
<td>Ensemble of 6 models by 2080</td>
<td>Total inflow to the Arctic Ocean</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A2 emission</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B2 emission</td>
<td></td>
</tr>
<tr>
<td>Nohara et al., 2006</td>
<td>Ensemble of 19 models by 2081-2100 for A1b emission</td>
<td>Yenisey</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lena</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ob</td>
<td>10</td>
</tr>
</tbody>
</table>
Figure 1. Annual changes in major components of water balance over 1936-2000 for subbasins located across the six largest Eurasian Arctic rivers computed based on a slope of linear trend line.
Figure 2. Map showing changes in runoff by 2080-2100 using ECHAM5 A1b scenario and UNH WBMPPlus simulations. The change in seasonal discharge for several medium size watersheds (highlighted) located in different climatic and land cover zones is presented on the bar graphs.
Coupling satellite data with snow pack modeling for estimating the continuous fields of snow cover characteristics

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Introduction
Despite a significant enhancement of observing capabilities of satellite instruments, snow datasets derived from satellites still do not completely satisfy the needs of the hydrological modeling community. The largest errors in satellite snow datasets are common in the forest areas. A promising solution to improve representation of snow cover consists of coupling satellite observations with physically-based snow pack models and ground–based measurements. Such an approach ensures consistency of estimates of different physical properties of the snow pack and permits more frequent and timely product generation. The runoff generation models can be used for improving (calibration) of the procedures of estimating snow fields and implementing them in hydrological predictions. The research carried out had the following major goals:

← To assess potentials for improving characterization of snow pack properties using satellite snow retrievals coupled with a snow cover model and ground-based data.
← To use the snowmelt runoff generation model for testing the snow characterization.
← To demonstrate benefits of using satellite-derived information on the snow cover in river runoff and snowmelt runoff simulations.

The study was carried out for the region within the NEESPI area with the size of approximately 240 000 km² (56°N to 60°N, and 48°E to 54°E) including the Vyatka River basin (124,000 km²).

Simulating fields of snow characteristics by the physically based model of snow pack using combined MODIS and AMSR-E data

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The physically based model of snow cover that was used (Kuchment and Gelfan, 1996; Gelfan et al., 2004) simulates snow depth and density, snow metamorphism, melt, sublimation and refreezing of melt water, changes of ice and liquid water content in snowpack, snow interception by the canopy, sublimation of intercepted snow and the canopy effect on sub-canopy radiation and turbulent fluxes. The input to the model includes the air temperature, air humidity, precipitation, wind speed, and cloud cover measured at six-hour intervals. For snow modeling we also used the following satellite products: (1) pre-melt daily snow water equivalent (SWE) for open areas derived from Advanced Microwave Scanning Radiometer for EOS satellites (AMSR-E) onboard AQUA satellite (for forested areas this information is considered as unreliable); (2) MODIS swath-based daily land surface temperature maps MOD11_L2 (MODIS Terra) and MYD11_L2 (MODIS Aqua). (3) MODIS-based broadband land surface albedo MOD043C1 (MODIS Terra); (4) land cover classes derived from MODIS data by USGS. The meteorological data measured at 19 meteorological stations within the region under consideration were interpolated to the latitude-longitude projection with a 0.01° (or about 1 km) grid cell size, and the same was done for the satellite products that were acquired for the spring snowmelt period from March 1 to May 31 of 2002-2005. The interpolated values of SWE for the forested pixels had been corrected by using the regional ratios of pre-melt SWE in the forest to the corresponding SWE at the open sites. These ratios depend on the type and the density of the forest and we obtained them on the basis of modeling snow accumulation in both the open areas and the different types of the forests.

Using AMSR-derived values of SWE on March 1, for the open areas and the estimated values of SWE for the forested areas as the initial conditions for the model, as well as the acquired ground-based meteorological data and satellite data as the model inputs, we simulated fields of snow characteristics over the whole region for the spring seasons of 2002-2005. As an example, maps of simulated distribution of SWE for a few successive dates during the melt season of 2005 are shown in Figure 1 and compared with the corresponding MODIS-based maps. One can see from this illustration that only one of four satellite images is almost free of cloudiness and allows one to estimate snow distribution for the most of the region. Also, according to the satellite images, the region is almost free of snow at the end of the period presented in the Figure 1 but according to the model simulations snow is absent only for the open (southern and central) parts of the region and covers the forested (northern) part. Thus, there are significant differences in the calculated and satellite-derived snow fields. To compare reliability of both these fields, we used them to simulate the runoff generation and
calculate the hydrographs of the Vyatka River through the system of physically based models of hydrological processes developed in the Water Problems Institute of RAS (Kuchment et al., 1983, Kuchment et al., 2000). This model of the runoff generation is based on a finite-element schematization of the catchment area and includes simulation of the following processes: snow cover formation and snowmelt, freezing and thawing of soil, vertical moisture transfer and evaporation, surface water detention, overland, subsurface and channel flow.

The model was calibrated by comparison of the observed and simulated hydrographs of 17 snowmelt floods and validated using 20 floods which had not been applied for calibration. A technique for assimilating satellite snow cover products in snowmelt runoff modeling was applied to the data of snowmelt seasons of 2002-2005. Satisfactory accuracy in calculating hydrographs has been obtained. The largest errors of runoff prediction in the outlet gauge occurred in 2003: the snowmelt volume and the flood peak discharge were underestimated by 19%. For other seasons, the obtained deviations did not exceed 13%. Figure 2 illustrates the comparison of the calculated hydrographs with the observed ones for the spring floods of 2003 and 2005. As one can see from this Figure 2, the proposed correction of the initial SWE fields gave better results of the hydrograph simulation than the AMSR-derived SWE fields (in the latter case the runoff discharges turned out to be underestimated).

References
Figure 1. Daily snow cover maps simulated by the model (left) and the corresponding MODIS-based maps (right) for the period from 20 (top) to 23 (bottom) April, 2005. White color represents the snow, green color represents the ground, and gray color represents the cloudiness.
Figure 2. Comparison of the observed hydrographs (points) for the springs of 2003 (left) and 2005 (right) with the hydrographs calculated using the AMSR-derived initial SWE values (thin line) and the hydrographs calculated using improvement of the initial SWE values for the forested areas. From top to bottom: Kirov (catchment area $F=44380$ km$^2$); Kotelnic (F=94900 km$^2$); Vyatskie Polyany (F=124000 km$^2$).
Northeastern Asia: projection of mountain glacier systems based on AOGCM scenario

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In this study we consider contrasting continental (Orulgan, Suntar-Khayata and Chersky ranges located in the Pole of Cold Area at the contact of Atlantic and Pacific influences in Siberia) and maritime (Kamchatka under the Pacific influence) Russian glacier systems.

Our purpose is to present a simple method for the projection of change of the main parameters of these glacier systems with climate change. To achieve this aim, reconstructed vertical profiles of mass balance (accumulation and ablation) based both on meteorological observations for the mid to late 20th century and an ECHAM4 GCM scenario for 2040–2069. The observations and scenario were used for defining the recent and future equilibrium line altitude (ELA) for each glacier system. The altitudinal distributions of the areas covered with glacier ice were determined for present and future states of the glacier systems, taking into account the correlation of the change of the ELA and glacier-termini levels. We also give estimates of the possible changes of the areas and morphological structure of North-eastern Asia glacier systems and their mass balance characteristics from the ECHAM4 scenario. Finally, we compare characteristics of the continental and maritime glacier systems stability under conditions of global warming.

Our approach involves 1) the projection of the ELA because on this level it is possible to reconstruct accumulation by calculated ablation due to their equity here, and 2) the glacier termini level because it is correlated to the ELA change. The projected ELA can be obtained as a value of the balance profiles cross-section for glacier systems.

The projection of glacier change, not only for individual glaciers but also for groups of them (glacier systems), is a very important goal of global environmental change studies (e.g. Dowdeswell and Hagen 2004). The term “glacier system” is considered as a set of glaciers united by the joint links with the environment: the same mountain system or
archipelago and similar atmospheric circulation patterns; the glaciers are related to
each other usually by parallel links from atmospheric inputs and topographical forms to
hydrological and topographical outputs, and demonstrate common spatial regularities
of the regime and other features. In this paper we present a simple method for
prognosis of change in glacier systems’ parameters and the application of this method
for the region of Northeast Asia. From the glacier systems of NE Asia we have chosen
to study the continental glacier systems of North-eastern Siberia – Orulgan (a part of
Verkhonyansk Range in Figure 1), Suntar-Khayata and Chersky ranges – and the
marine glacier systems of Kamchatka – Sredinniy, Kronotsky ranges, Kluchevskaya,
Tolbechek, Chiveluch volcano groups, etc (Figure 1, Table 1). Observations of both
these glacier regimes are available only for one or two benchmark glaciers, so we used
the data from The USSR Glacier Inventory (1965–1982), which was based on remote
sensing data of these regions’ glaciers (Orulgan Range – 1958, 1963; Suntar-Khayata
Northeastern Siberia has undergone both winter and, to a lesser extent, summer
warming since around 1960 until present, as well as the intensification of cyclonicity
and precipitation (Ananicheva et al., 2003; IPCC, 1995). Due to these climatic
tendencies the proportion (and amount) of solid precipitation here is increasing
(Ananicheva and Krenke, 2005). Significant warming is also observed in Kamchatka
(Shmakin and Popova, 2006).

As a result of the ECHAM4 scenario, we obtained the following projected assessments
of the ELA change. The shift upward of the ELA altitude, \(\Delta H_{ela}\), is less in northern
parts of Northeastern Siberia than in the south (230m as against 500m in the south). In
Kamchatka \(\Delta H_{ela}\) as a rule is more significant and depends on precipitation rate. The
largest \(\Delta H_{ela}\) (up to 1210 m) was found in the south of Ichinskiy Volcano, located in the
“rain shadow” of the Sredinniy Range (Table 1). The change in glaciated area is
anticipated to range from a complete disappearance of some minor glacier systems, to
the preservation of 70% of the present area (Kluchevskaya volcano group) and 50% of
contemporary glaciated area (Shiveluch and Tolbachek volcanoes). Under the warming
scenario as calculated by our approach, glaciers will not be present in southern
systems of Northeastern Siberia – southern knots of Orulgan glaciation and the Suntar-
Khayata Mountains, on the Sredinniy Range of Kamchatka and around Ichinskiy
Volcano. Those glaciers covering the volcanoes of southeast Kamchatka and receiving
intensive nourishment due to the elevation of the peaks and proximity of the Pacific
Ocean would preserve more than 40% of their area.
As for the intensity of mass exchange at the ELA, we can expect the following changes in ablation and accumulation during the projected period compared with the baseline period. $\Delta A,C$ at the ELA is greater for Northeastern Siberia on the north of the Orulgan, Chersky, and Suntar-Khayata ridges, where precipitation due to warming will grow (Orulgan derives moisture from the Atlantic; the Chersky, while Suntar-Khayata ridges also receive moisture from the Pacific Ocean) – from 200 to almost 500mm (accumulation=ablation at the ELA). In glacier systems of Kamchatka only the Kronotsky Range and volcanoes of the South-east part of the peninsula are characterized by high $A,C$ at the ELA – from 200 to 450mm (these are areas of plentiful precipitation, and despite the solid precipitation portion being reduced during warming, it would still be a large absolute value). In the rest of the Kamchatka systems $\Delta A,C$ will range from 30 to 150mm as a result of reduced snow nourishment because of strong warming. The glaciers of the Shiveluch Volcano attain negative $A,C$ values at the ELA due to a rather abrupt decrease of the solid-precipitation fraction.

Judging from the glacier-balance averages both for the baseline and projected periods, the glacier systems have different sensitivities to current climatic conditions and predicted future climate change. Under a constant climate, when glacier mass balance is close to zero, the glacier will not change; but assuming the same constant climate, if mass balance is positive the glacier will expand, while if it is negative it will shrink. The balance trend, stability or change, and its sign are controlled by climatic conditions. A glacier can “keep up” with climate change – in this case its balance also remains near zero as well as consistent with climate. Among the glaciations considered, only that of the Chersky Range has been in this state during the baseline period. Glaciers of the Orulgan, the western slope of Sredinniy Range, the Kluchevskya Volcano group and Tolbachev in Kamchatka were growing at that time. The rest have already retreated.

For the 2040–2069 period the northern knot of Orulgan glaciers and glacier of the Kluchevskya and Tolbachev volcanoes are predicted to come into equilibrium with climate. Despite the intensive warming scenario, the Chersky glaciers will still be consistent with climate: this is due to a combination of elevation, relief forms and corresponding glacier morphology and regime, leading to their quite slow movement and change. Glaciers of the Sredinniy and Kronotsky ranges, Shiveluch and southeast Kamchatka volcanoes will undergo accelerated retreat and provide evidence of a time lag when compared with the warming rate.
References
Table 1. Change of glacier systems characteristics in NE Siberia and Kamchatka up to the mid 21st century (2040-2069).

<table>
<thead>
<tr>
<th>Glacier system</th>
<th>The shift of $\Delta H_{\text{ela}}$ (from basic to projected period), m</th>
<th>The elevation range of the glacier system, m</th>
<th>Glaciated area, km$^2$, %</th>
<th>Ablation and accumulation at the $H_{\text{ela}}$, mm</th>
<th>Balance, cm yr$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic period Projected period</td>
<td>Basic period, km$^2$ Projected period, km$^2$</td>
<td>Basic period (%)</td>
<td>Projected period (%)</td>
<td>Projected period</td>
</tr>
<tr>
<td>NE Siberia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orulgan Northern Knot</td>
<td>250</td>
<td>750</td>
<td>400</td>
<td>7</td>
<td>2(27)</td>
</tr>
<tr>
<td>Orulgan Southern Knot</td>
<td>500</td>
<td>760</td>
<td>0</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Cherskiy –Erikit knot</td>
<td>320</td>
<td>700</td>
<td>200</td>
<td>7</td>
<td>1 (10)</td>
</tr>
<tr>
<td>Cherskiy-Buordakh</td>
<td>300</td>
<td>1640</td>
<td>1280</td>
<td>63</td>
<td>18(29)</td>
</tr>
<tr>
<td>Cerskiy-Terentykh</td>
<td>300</td>
<td>1520</td>
<td>1180</td>
<td>28</td>
<td>8 (29)</td>
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<td>Suntar-Khayata, North</td>
<td>350</td>
<td>1080</td>
<td>520</td>
<td>111</td>
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<td>Suntar-Khayata, South</td>
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<td>1110</td>
<td>60</td>
<td>22</td>
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<td>Kamchatka</td>
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<td></td>
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<tr>
<td>Sredinny Range Eastern Slope</td>
<td>600</td>
<td>2850</td>
<td>2160</td>
<td>124</td>
<td>24(20)</td>
</tr>
<tr>
<td>Sredinny Range Western Slope</td>
<td>570</td>
<td>1900</td>
<td>1330</td>
<td>264</td>
<td>55(21)</td>
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<tr>
<td>Shiveluch Volcano</td>
<td>600</td>
<td>3240</td>
<td>2720</td>
<td>30</td>
<td>16(52)</td>
</tr>
<tr>
<td>Kluchevskaya Group</td>
<td>420</td>
<td>3950</td>
<td>3660</td>
<td>124</td>
<td>85(69)</td>
</tr>
<tr>
<td>Tolbachev Volcano</td>
<td>580</td>
<td>3085</td>
<td>2680</td>
<td>70</td>
<td>33(47)</td>
</tr>
<tr>
<td>Tumrok and Gemchen ranges</td>
<td>430</td>
<td>1020</td>
<td>0</td>
<td>11</td>
<td>0</td>
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<tr>
<td>Khronotskiy Range</td>
<td>510</td>
<td>1150</td>
<td>260</td>
<td>91</td>
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<td>Valaginskiy Range</td>
<td>610</td>
<td>1000</td>
<td>0</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Volcanows of South-Eastern Kamchatka</td>
<td>300</td>
<td>2660</td>
<td>2340</td>
<td>34</td>
<td>14(41)</td>
</tr>
<tr>
<td>Ichinskiy Volcano</td>
<td>740</td>
<td>2080</td>
<td>780</td>
<td>29</td>
<td>6(22)</td>
</tr>
<tr>
<td>Ichinskiy Volcano (with account of blowout from the slopes)</td>
<td>1210*</td>
<td>2080</td>
<td>0</td>
<td>29</td>
<td>0</td>
</tr>
</tbody>
</table>

* The projected elevations are higher than the real topography, so the glaciation in these cases will not exist under the scenario used.
Figure 1. The map of the region studied.
Investigations of atmospheric aerosol based on the polarization measurements of the twilight sky

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Optical measurements of the sky background during the twilight period are an effective tool for the detection and investigations of aerosol in the different layers of the atmosphere. Ascension of Earth’s shadow above the observer with the depression of Sun leads to the increase of the effective altitude of the solar emission scattering in the atmosphere [1]. Having conducted the sky background measurements during the whole twilight period, we made the vertical scan of the atmosphere and built the profile of trace gases and atmospheric aerosol from the troposphere to mesosphere.

The basic problem of the twilight method of atmosphere investigations is the large contribution of multiple scattering [2]. This value was difficult to estimate through the whole 20th century. The exact mathematical models have appeared just recently [3].

The possibilities of using the twilight method expand significantly if the sky background polarization is also measured. First, it helps to separate the multiple scattering due to the difference of polarization properties of this component. The idea of the method was suggested in [4] and was developed in [5,6]. The results were in good agreement with the numerical calculations for standard aerosol models in the troposphere [7]. Second, polarization data expand the information about the atmospheric aerosol and allow the investigation of its microphysical properties. The idea was applied to the dense and variable tropospheric aerosol in [8].

The background level of stratospheric aerosol is usually low. In the polar regions polar stratospheric clouds (PSC) can appear. In other locations an increased level of stratospheric aerosol is observed after strong volcanic eruptions when a large amount of sulfur dioxide (SO₂) reaches the stratosphere, oxidizes to sulfuric acid (H₂SO₄), and condenses to sulfate aerosol particles. The most powerful volcanic eruption in recent decades was the Pinatubo eruption in 1991. During the following 3-4 years the
stratosphere was globally polluted, but after that the clear stratosphere period had started.

Figure 1 contains the dependencies of the twilight background polarization in the zenith on the solar zenith angle or effective scattering altitude for different years (2000-2003) and seasons in the clear stratosphere period. These dependencies are obtained from the wide-angle CCD-measurements in Crimea using a wide spectral band with an effective wavelength 525 nm. The graph also contains the results of numerical simulations for the gaseous atmosphere and three standard tropospheric aerosol models with the background stratospheric aerosol. We see that for solar zenith angles greater than 90-91 degrees, when the effective single scattering occurs above the troposphere, all observational and theoretical curves are just shifted one from another as a whole. Variations of twilight sky polarization are the same in the light and dark stage of twilight, when multiple scattering dominates. Depolarization caused by the stratospheric aerosol is not observed.

In October, 2006, the eruption of Rabaul volcano in New Guinea had begun. The eruption products reached the stratosphere and began to expand there. An increased level of stratospheric aerosol was detected by the lidar station in Tomsk, Russia, shortly thereafter [9]. Figure 2 shows the dependencies of moonless sky polarization in December, 2006, compared with the observations in the same season in 2002. We see that the polarization is almost the same in the light and dark twilight, but there is the depolarization effect when the effective scattering occurs in the stratosphere. Analysis of observable parameters (intensity, polarization and their gradients along the solar verticals) shows that the effect is related with the additional scattering component in the stratosphere. The method developed in [10] gives the polarization value of stratospheric aerosol scattering by the angle 90 degrees of 0.28 ± 0.03, with the ratio of aerosol and molecular scattering in the stratosphere varying from 0.1 to 0.2. The last value is in good agreement with the lidar backscattering data [9].

The same analysis can be used to detect the dust and aerosol in the mesosphere. This atmospheric layer may contain noctilucent clouds and be bombarded by meteoric dust. The strongest meteor shower in the recent years was Leonids which produced outbursts from 1998 until 2002 after the perihelion of parent comet 55P/Temple-Tuttle in 1998. The last double-peaked storm was predicted in [11] and observed beginning on November, 19, 2002. During the first maximum (with Zenithal Hourly Rate about 2500) the shower radiant was high above the horizon at the observation place in
Crimea, providing the good conditions for the meteoric dust inflow to the mesosphere [12].

Figure 3 shows the same dependencies of the twilight sky polarization on the solar zenith angle for the period of late November and early December 2002, where the moonlight scattering and multiple scattering variability are reduced. We see the effect of twilight sky depolarization on November, 21, 2002, for the scattering altitudes above 90 km. The effect is related with the meteoric dust in the mesosphere.

A way to improve the twilight investigations of the atmosphere is the idea of providing network installations for the twilight photometric and polarization measurements. Aerosol remote sounding above the large territories will make possible the dynamic investigations of production, transportation and destruction of different kinds of aerosol in the atmosphere.

References


Figure 1. Theoretical and observational dependencies of zenith twilight sky polarization on the solar zenith angle (525 nm, clear stratosphere period).
Figure 2. Dependency of zenith twilight sky polarization on the solar zenith angle with the effect of stratosphere depolarization in December, 2006.

Figure 3. Dependency of zenith twilight sky polarization on the solar zenith angle with the effect of meteoric dust in November, 2002.
Permafrost Active Layer Observations in the North Eurasia

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Permafrost has profound effects on the ecology, hydrology, geomorphology, and human occupation of North Eurasian environments. The presence of large quantities of near-surface ground ice forms a relatively impermeable layer that determines the depths at which groundwater can circulate and to which plants can extend their roots. Thaw of ice-rich permafrost can lead to settlement and irregular subsidence of the ground surface (thermokarst) that, in turn, disrupts drainage patterns and can cause severe damage to buildings and transportation facilities (Nelson et al., 2001 and 2002). Near-surface permafrost sequesters substantial amounts of organic carbon that, if released to the atmosphere, could amplify greenhouse warming (e.g. Bockheim and Hinkle, 2007).

Permafrost regions occupy more than half of the Northern Eurasian terrestrial surface. Everywhere in this vast frozen domain, a relatively thin layer of earth materials between the ground surface and the top of the permafrost undergoes an annual cycle of freezing and thawing. The importance of this active layer is much greater than its limited vertical extent suggests, because it is here that most biological, geomorphic, and hydrological activity in the permafrost regions occurs (Kane et al., 1991). A systematic and widespread increase in the thickness of this layer over the last decade was reported for several characteristic Northern Eurasian regions (Fedorov-Davudov et al., 2004; Mazhtova and Koverin, 2008; Akerman and Johansson, 2008). Preliminary study also indicates that the progressive thaw penetration into ice-reach permafrost layers in some East Siberian landscapes can contribute to significant increases in stream discharge (Davudov et al., 2008).

Increasing recognition of the active layer’s importance in the context of global climate change (e.g., Kane et al. 1991) provided much of the impetus for creating a long-term monitoring program focused on the active layer and shallow permafrost. The Circumpolar Active Layer Monitoring (CALM) program is a network of sites at which data about active-layer thickness (ALT) and dynamics are collected. CALM was established in the 1990s to observe and detect the long-term response of the active layer and near-surface permafrost to changes in climate. CALM is among the international permafrost community’s first large-scale efforts to construct a coordinated monitoring program capable of producing data sets suitable for evaluating the effects of climate change. Together with the IPA’s Thermal State of Permafrost program, CALM comprises GTN-P, the Global Terrestrial Network for Permafrost. The CALM network’s history and organizational structure are reported in Brown et.al (2000). This report provides short description of CALM network over Northern Eurasia. Scientific results are presented regularly at national and international meetings, and have been published widely in international scientific journals and symposia proceedings. Several edited volumes focused on the CALM program have been published to date (Brown et al., 2000; Nelson ed.; 2004a, 2004b).
The distribution of CALM observational sites in the Northern Hemisphere is shown in Figure 1. The CALM network incorporates 168 sites in Arctic, sub-Arctic, and mountainous regions. Several sites constitute longitudinal and latitudinal transects across northwestern North America, Europe and the Nordic region, and northeastern and northwestern Russia. Sites in Europe, China, Mongolia, and Kazakhstan provide high-elevation locations. The majority of sites (87) are located in the Northern Eurasia. About 70% of the sites are located in Arctic and Subarctic lowlands underlain by continuous permafrost. Discontinuous and mountainous permafrost areas contain respectively 20% and 11% of sites. The distribution of sites is not uniform, a circumstance attributable to historical circumstances and logistical constraints. The sites were established in regions of extensive economic activity and/or in areas of long-term climatic, permafrost, and ecosystem research. This logistically driven approach to site selection was adopted to insure regularity and periodicity of measurements.

Three methods are used to determine the thickness of the active layer: 1) mechanical probing using a graduated metal rod; 2) temperature measurements; 3) frost/thaw tubes. With exception of mountain environments at all North Eurasia sites the active layer is measured by mechanical probing on regular grids of sampling points ranging from 10×10 m to 1000×1000 m. The time of probing varies from mid-August to the end of September, i.e., when thaw depth is at or near the maximum. More frequent measurements are made at some sites and in some years. The gridded sampling design allows for analysis of intra- and inter-site spatial variability and yields information useful for examining interrelations between physical and biological parameters. Grids are established at undisturbed locations, characteristic of dominant environmental conditions. Their size varies depending on site geometry, and the level of natural variability of surface and subsurface conditions. In general, 10×10 m to 100×100m size grids are established within relatively homogeneous landscape units. Several sites contain a number of grids representing various landscape units within the area. The 100×100 m to 1000× 1000 m grids usually encompass several characteristic landscapes within the area. CALM adopts a systematic sampling scheme for thaw depth measurements on most grids. The systematic sampling design involves annual replicate measurement at regularly spaced grid nodes. With a few exceptions, each 10, 100, and 1000 m -side grid contains 121 nodes distributed evenly at 1, 10, and 100 m spacing respectively. All grids have data loggers for monitoring air and soil temperatures at various depths. Several sites have installations for continuous monitoring of soil moisture. Detailed spatial characterization of topography and surface and subsurface conditions are available for each grid. These include DEMs, vegetation, soil, and landform characterization, and organic layer thickness. In addition, several spatially oriented monitoring of frost heave and thaw subsidence using optical leveling is conducted at five representative sites in Russian Arctic.

Several regions with large assemblages of sites and representative of high-latitude climatic/landscape gradients are suitable for spatial data integration. Examples of such regions in Northern Eurasia are the North West Siberia region (Yamal-Gydan Peninsulas), and the Lower Kolyma River region. Each of these regions has been the subject of extensive geocryological research and contains information sufficient to facilitate regional-scale mapping. At present, the CALM North-Eurasian database contains regional compilation of site observations in the form of a detailed digital landscape and active-layer map of northern West Siberia. The map was compiled in cooperation with the Earth Cryosphere Institute (Russia) and depicts a hierarchy of landscapes units, organic layer thickness, lithology, and the landscape-specific characteristic values of active-layer thickness (Figure 2). At present, the map is being refined and extended.
One of CALM’s primary objectives is to develop coherent, quality-controlled datasets of long-term observations on the active layer and upper permafrost, suitable for assessing changes in polar terrestrial ecosystems. At present, the CALM database consists of annual submissions from 168 sites, and includes active-layer thickness (ALT), soil temperature and moisture (where available), and heave/subsidence data (where available). The majority of available data are distributed through the CALM website maintained by the University of Delaware’s Department of Geography. (www.udel.edu/Geography/calm). The web-based summary table contains average ALT at all stations for all years, and is linked to metadata and individual data sets.

Active-layer observations and auxiliary information from the CALM network provide an extensive circumpolar database, which has been used extensively to validate process-based geocryological (e.g., Oelke and Zhang, 2003; Shiklomanov et al., 2007) and hydrological (Rawlins et al., 2003) models. Although the CALM network continues to grow in terms of the number of participating sites and the quantity and quality of observations, two outstanding data issues remain to be resolved. 1) Continuation of periodic measurements: This problem relates to difficulties associated with unattended operation of scientific equipment at remote locations and periodic accessibility of sites. For example, approximately one-fourth of Russian sites were discontinued during the last five years due to substantial increases in logistical costs. A large number of sites have suffered from equipment malfunction and vandalism. 2) The methodology of simple sharing of basic data, adopted by CALM in the late 1990s, does not entirely satisfy the growing needs of the increasingly international and interdisciplinary scientific community and general public. Newly developed web-based database and mapping applications provide more advanced and user-friendly vehicles for presenting and sharing geographically referenced information.

References


![Figure 1. Permafrost distribution and location of CALM sites in the Northern Hemisphere. Sites are grouped according to active-layer monitoring methods.](image_url)
Figure 2. Map the characteristic active layer thickness in Northern West Siberia.
NOAA approach to a new climatological observatory in Tiksi, Russia

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Tiksi, Russia has been recognized as a key location in the Siberian Arctic that would be an ideal location for a permanent, intensive, climate observatory (Uttal, et al. 2007). The location would bridge a significant gap in the existing network of atmospheric measurements in the Arctic (Figure 1). More specific scientific motivations for choosing the Tiksi site have been described in a separate document entitled “Proposal for a Joint U.S. - Russian Atmospheric Climate Observatory”. Rational for establishing the intensive atmospheric observations in Tiksi, Russia is driven by the question on HOW the climate is changing. In order to answer this question a long term monitoring program needs to be established. NOAA collaborates with multiple international programs such as GAW, NDACC, etc. These programs have well established requirements for the quality control of the measurements. After the QA/QC procedures are established, the site can serve as a “truth” for the satellite validation. However, the climate monitoring program also needs to have emphasis on WHY the climate is changing. In order to fulfill this task the process studies are required. The model support to the data collection has to be established. The full monitoring site can also address the fast response issues to the NOW issues that are defined as sudden events.

NOAA approach to the development of the climate monitoring station in Tiksi has been an active partnership between the National Science Foundation, Roshydromet, NOAA, Finnish Meteorological Institute, the Polar Foundation, and VECO Polar. NOAA responsibilities lay with provision of the instruments and other support to Tiksi Observatory. Otherwise, NOAA will look to Roshydromet to determine priorities and schedules. Tiksi is an integral component of the International Arctic Systems for Observing the Atmosphere (IASOA) network (see Figure1, and the LASOA web site at ftp://www.iasoa.org, and contact Lisa.Darby@noaa.gov for further inquiries).

Existing components of the Tiksi stations are comprised of the NSF infrastructure contributions, NOAA project coordination and long-term design, and NSF funding of science projects. The Saha Republic (Russia) government provides support for the road and power improvements at the Tiksi station. Roshydromet is responsible for the weather station upgrades and met-observation programs. NOAA, NASA and FMI are also strongly engaged in the Tiksi observation programs.

The most recent Tiksi station upgrades include a new weather station building. It has been completed and is currently available for installation of instruments. A Clean Air Facility (CAF) is in the process of construction. It will be suitable for aerosol, chemistry, pollutant, greenhouse gas, fluxes and radiation measurements. It is expected to be completed by the end of the summer of 2008. The real-time continuous measurements of surface ozone at the Tiksi station have recently been implemented since Spring of 2008. Black carbon samples from snow were recently collected in the vicinity of Tiksi station by FMI scientists. Flasks for carbon cycle gas measurements for the new Tiksi
station are awaiting shipping from Boulder, CO. Moreover, the CH₄ and CO₂ measurements, similar to those planned for Cherskii station in Russia, are in the planning stages for Tiksi. These upgrades are a result of a partnership between the U.S. National Science Foundation (NSF), the Russian Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), the National Oceanic and Atmospheric Administration (NOAA) and the Finnish Meteorological Institute (FMI).

In addition to the Tiksi station, Cherskii station in Russia is expected to undergo several upgrades. The University of Alaska Fairbanks (UAF) and the National Oceanic and Atmospheric Administration (NOAA) are collaborating on measurements of CO₂ and CH₄ from 3 levels on a tower. The CH₄ measurements will be combined with new modeling methods developed at NOAA to infer regional-scale CH₄ fluxes. These estimates will complement CH₄ fluxes determined by UAF using a flux gradient method. Installation of instruments is scheduled for summer 2008. This work is timely and important due to the large carbon stores, mostly CH₄ that could be released in response to climate change.

Current instrumentation planned for Tiksi stations includes Ozone meter (already installed in Tiksi, see Figure 2), black carbon sampler (ready to ship), USCRN (ready to ship with 2 months notice). In addition the carbon cycle gas sampler is planned for the station, but the issues with sample shipping have to be resolved before the installation. Black Carbon samples were collected in snow by FMI team that was on site in April, 2008. Atmospheric Radiation sensors are partially purchased, while Micrometeorology Flux sensors and aerosol sensors are not yet purchased. There is a possibility for the UV sensors to be purchased through the NSF contribution. The FMI contribution is in the supplies of the methane samplers.

References


Figure 1. The schematic of the International Arctic Systems for Observing the Atmosphere (IASOA) network.
Figure 2. Ozone surface detector (contact is S. Oltmans and NOAA/ESRL, Boulder, CO) and picture of the room in the hydrometeorology observatory building in Tiksi, Russia showing the installed and active Ozone Sampler instrument.
The NOAA National Climatic Data Center: Data Availability, WDC-A, and GCOS Data Sets

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Abstract

This paper presents an overview of climatic data offered by the NOAA National Climatic Data Center and the World Data Center for Meteorology – Asheville. Specific emphasis is placed on data that has coverage of or relevance to the NEESPI research region. Datasets include surface and upper air data, and are constructed by incorporating data that has been exchanged between the United States and the Russian Federation during a data exchange agreement that has been in place since the 1970s.

Introduction

The National Oceanic and Atmospheric Administration’s (NOAA) National Climatic Data Center (NCDC) is among the world’s largest repositories of climate and environmental data. Located in Asheville, North Carolina, NCDC is one of the UNESCO World Data Centers. In addition, NCDC is the home of the World Data Center for Meteorology – Asheville (WDC-A), which is one of three WDCs for Meteorology – the others being at the All Russian Institute for Hydrometeorological Information (RIHMI) in Obninsk, Russia and at the China Meteorological Administration (CMA) in Beijing, China.

NCDC and the World Data Centers (especially WDC-A and RIHMI-WDC) provide access to a wealth of climate data and information for the Arctic as a whole and, more specifically, for the research regions of the Northern Eurasia Earth Sciences Partnership Initiative (NEESPI). Both in situ and remotely sensed climatic data are archived and data coverage includes a number of variables from the surface and subsurface as well as the atmospheric column well into the lower stratosphere.

A number of these data sets are the result of efforts between the United States and the Russian Federation (formerly USSR) to exchange environmental data that was deemed important to understanding the Earth’s environmental systems. These exchanged data have been incorporated into several comprehensive global surface and upper air data sets covering such variables as snow cover, soil temperature, precipitation, and air temperature.

All of the data archived at NCDC is available for access, and many of the data sets relevant to NEESPI research are available via the Internet, either from NCDC directly (http://www.ncdc.noaa.gov/) or through the World Data Centers (http://wdca-meteorology.org). Most of these data sets are also incorporated in the Global Climate Observing System (GCOS), which can be accessed via the Global Observing Systems Information Center (GOSIC) Web portal.
Data Exchange and Products

On of the primary sources for the environmental data and information for northern Eurasia that is provided by NCDC and the WDC is the aforementioned data exchange activity between NOAA and Roshydromet (Russia). This exchange was begun in the 1970s as a means to gain a more complete global understanding of the environment. Since that time, the exchange activities have included not only the transfer of valuable environmental data, but have fostered a number of collaborative international research projects, especially in the Arctic. Research activities and data exchanges have taken place at many institutions in both Russia and the United States, including several universities (e.g., St. Petersburg State University, University of Alaska, and University of Maryland) in addition to a number of governmental institutions in both countries (e.g., Russian Academy of Science, Main Geophysical Observatory, University Consortium for Atmospheric Research).

Exchanges of data for the Arctic and northern Eurasia have included oceanographic data collected by US and Russian research vessels (e.g., water temperature, ice thickness, salinity), terrestrial data such as soil temperatures, state of the ground (i.e., frozen, unfrozen), and snow cover extent, and atmospheric data that include meteorological measurements for several thousand surface stations (many in the NEESPI region) and hundreds of upper-air radiosonde balloons, and extensive satellite coverage.

Surface (land and sea) atmospheric measurements that are available for locations within the NEESPI research domain include air temperature, precipitation, solar radiation, wind speed and direction, air pressure, and trace gasses such as Carbon Dioxide and Ozone. Most of these data are available at either daily or monthly time scales, while a few (e.g., air temperature) are available at synoptic (hourly or 3-hourly) scales, and most of these data sets receive regular and timely updates via the Global Telecommunications System (GTS) or via FTP from their respective originating organizations. In this way, data users are ensured of having the most up-to-date data through the present. Although the exchanges have been ongoing, new datasets continue to become available. For example, as part of a data rescue effort by Roshydromet, a data set of monthly mean air temperatures from the Russian Empire between 1743 and 1928 is now available as NCDC Dataset DSI-9809.

Data Access

In the United States, all exchanged atmospheric data is archived at NCDC and the WDC-A, with the exception of some trace gas data that is housed at the Carbon Dioxide Information and Analysis Center (CDIAC) in Oak Ridge, Tennessee (http://cdiac.ornl.gov). In Russia, these data are available from RIHMI-WDC (http://meteo.ru/english/). These data are primarily available as part of larger, global-coverage datasets such as the Global Historical Climate Network (GHCN) for daily and monthly surface data, and the Integrated Global Radiosonde Archive (IGRA) for daily upper air data.

In addition, there are numerous data sets that are available from the WDC through at least 28 major international research projects (e.g., International Polar Year) and programs (e.g., Global Climate Observing System). These and other data are nearly all on-line and can usually be accessed via NCDC’s Web interface (see Figure 1) or through the World Data Centers. In addition, and for data that is not available via the Internet, fax, telephone and postal mail orders also are accepted and processed.
To better identify and link to data that may not be held at NCDC, Web portals, such as GOSIC (http://www.gosic.org/ - see Figure 2) or the Global Change Master Directory (GCMD – http://gcmd.nasa.gov) may be helpful. These portals provide access to a searchable metadata directory that directs the seeker to relevant data sets and provides information regarding data access and restrictions.

While current Web-based methods provide the most expedient access to these data, there are ways in which access can be improved. Currently, NCDC offers some spatial and temporal search capabilities via its Web map server and Climate Data Online (CDO). However, the ability to efficiently subset data products has been a shortcoming in the current system (most data reside in flat files that must be completely downloaded and then parsed by the user). Search interfaces that can be tied to relational databases present some promise in giving the data requestor the ability to request specific subsets of data. Such technology may also more easily facilitate the searching of multiple data sets with disparate data (and from diverse sources), and the retrieval of an integrated data product tailored to the individual user's requirements (i.e., variables, formats, spatial and temporal extent). At the present time, NCDC and the WDC are evaluating methods that might make such search and retrieval a possibility.

Figure 1. Home page of NOAA’s National Climatic Data Center.
Figure 2. Home page of the Global Observing Systems Information Center (GOSIC).
Climatic data serve the basis for studying climate and its variability. The study of regional features of climate variability is of increasing importance against the background of global warming.

RIHMI-WDC has the State Hydrometeorological Data Holding. A sufficiently dense network of meteorological stations is located on the Russian territory (Figure 1). Northern regions have fewer stations and more problems. The variation in the number of the stations is shown in Figure 2. The maximum number of the stations was recorded in the 1980-s. Currently, there are about 1500 active stations in Russia.

Meteorological data arrive to 25 regional centers. Data processing and data input are performed by Climatic Data Base Management Systems. The regional centers make the data available to RIHMI-WDC. Data are recorded on advanced machine-readable carriers.

Data quality control is important problem. In creating historical meteorological series, particular attention is to be given to data quality control and elimination of data inhomogeneity. There are different reasons for data inhomogeneity in Russia. On the one hand, this is due to the change in the observation procedure (change in observation frequency). Before 1936, observations were made three times a day, from 1936 to 1965, four times a day, and since 1966 observations have been made every three hours. Therefore, meteorological data archives for different periods are of different structure and in different formats (Table 1).

Data homogeneity is also disturbed by the replacement of instruments (type of the rain-gauge, anemometer), the change in meteorological data processing procedures (e.g. introduction of wetting corrections into precipitation observations, changes in codes of visibility (Table 2) and displacement of meteorological stations.

It seems impossible to solve the problem of obtaining high-quality meteorological data at the same time for the whole meteorological information available. The amount of data, their organization and the existing problems make it impossible to do. Therefore, the first stage in implementing any climate research project is to create the required database. The historical database creation includes the following:

- Formation of metadata sets of the appropriate stations.
- Elimination of inhomogeneity in meteorological data series that is caused by the change in observation and processing procedures, instrumental change, etc.
- Ensuring the opportunity of regular updating of data sets with current data.

Apart from recovery and preservation of data in the Holding’s data archives, we consider it vital to make meteorological data of Russia accessible to the world scientific communities. International projects and bilateral cooperation contribute to the solution
of this problem. The following data sets can be used as an example of specialized climatic databases:

← Data set of snow characteristics for 223 Russian stations and data on route snow surveys (1200) which are created in implementing the project INTAS-Snow Cover Changes Over Northern Eurasia During the Last Century: Circulation Consideration and Hydrological Consequences (SCONE).

← Daily precipitation data set for stations in the former USSR (TD-9813) created within the framework of bilateral cooperation (between RIHMI-WDC and NCDC).

← Data set Daily Temperature and Precipitation under the project European Climate Assessment (ECA), 2000.

Special attention should be paid for preparation of the specialized data sets for NEESPI purposes.

Table 1. Change in observation frequency.

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<tr>
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<td>Four (1, 7, 13, 19 LT)</td>
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<tr>
<td>1966 - 1976</td>
<td>Eight (3, 6, 9… Moscow Time)</td>
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<tr>
<td>1977 - 1984</td>
<td>Eight (3, 6, 9… Moscow Time)</td>
</tr>
<tr>
<td>1985 - 1992</td>
<td>Eight (3, 6, 9… Moscow Time)</td>
</tr>
<tr>
<td>1993 - now</td>
<td>Eight (3, 6, 9… Greenwich Time)</td>
</tr>
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Table 2. Changes in codes of visibility (an example).

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<td>1947-1949</td>
</tr>
<tr>
<td>X0</td>
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</tr>
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</table>
Figure 1. Russian meteorological stations.

Figure 2. Variation in the number of the Russian stations in digital archives.
The Irkutsk Regional Information System for Environmental Protection (IRIS)

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The Irkutsk Province is political important since its development represents the economic and sustainable growth in the vast rural territories of Siberia. The many years of human impact culminated in heavy industrial development during Soviet times. Large areas are under intensive anthropogenic press, which intends to be substantially increased. Atmospheric pollution by large industrial zones, contamination by untreated waste water effluents and timber logging are pointed out as region’s most apparent man-made environmental risks. The high value forests of the Irkutsk Province are also affected by this development and since then information provision for forest protection with respect to natural and human-induced disturbances is needed. Due to common forest fire events as well as intensive human activities such as clear cutting and cultivation the Irkutsk Province is characterized by intensive large area changes of forests.

However, the controlling of forest resources and their active involvement into the economic cycle do not provide the region with proper sustainability and qualitative economic growth. Irkutsk Province, as a typical resource-rich Russian Federation administrative region, suffers much of these capacities and material inputs and, accordingly, reaches only low levels of added values and low labor productivity in comparison to developed countries. Moreover, the big number of industrial facilities in the territory has resulted in serious ecological consequences: high and very high levels of pollution of the natural environments are stably verifiable in 42 % of Irkutsk Provinces’ settlements, which frequently exceed average over Russian Federation indicators (Oblmashinform 2005). Under these conditions, the formation of a qualitative economic growth is not ensured.

The evaluation of the influence of specific industrial branches onto the economic well-being of the society takes a center stage by economists for more than a decade. There are a lot of disputes on how to better determine and compare levels of public welfare of various regions, areas, countries. In 1946 and for the first time, it was offered by Hicks to solve this problem with the help of the net national product parameter. New approaches, such as the estimation of an environmentally-adjusted net domestic product (Bartelmus 2001) dealing with the social costs of environmental impacts. Thereby, the Gross Regional Product (GRP) has been chosen as the major indicator, characterizing the efficiency of the economy functioning. To measure the GRP, econometric models have been applied. Such models usually consist of two parts, estimation equations and defined equations as that the GRP is composed of consumption, investment, and export off import. The most important statistical method to get the estimation equation is regression analysis. Within the concept of IRIS, the authors undertake an attempt to estimate quantitatively the contribution of the Lumber Industry Complex into the economy of Irkutsk Province and to determine how essential is the factor of environmental degradation while estimating and forecasting the GRP. Alongside, multiscale datasets on pollution sources (e.g. disturbed, abandoned, remediated lands, ha; place of location; amount; substances) and stress factors in the
region (e.g. birth and death rates, diseases, sanitary-epidemiologic conditions) were collected and incorporated in the econometrics approach by the Department of Regional and Social Problems, Irkutsk Science Center.

For the above mentioned integrated management methodical designs are necessary which refer to the complexity of the resources to be managed and the difficulty to monitor them. A recent, sophisticated approach is to understand landscapes consists in modelling their structures as a fuzzy system composed of complicated, dynamic, stochastic processes. This methodology supports specifically landscape-ecosystem based approaches in which ecosystems of different scales are regarded as primary units for quantification and modelling (Seppelt and Voinov 2002). Satellite-based Earth Observation (EO) platforms are herein the primary data source from which the above mentioned landscape patterns can be assessed (Bunn et al. 2006, Huettich et al. 2006). Without a priori information about these patterns, observations made by remote sensing sensors supply an independent and unbiased framework to analyze the land cover at multiple scales (Hay et al. 2003). IRIS’ strategy follows this approach that considers spatial, spectral and temporal resolution demands by combining a variety of EO products and is thus in agreement with the suggested key issues by latest landscape research: data acquisition and scaling (Wu and Hobbs 2002).

IRIS is a follow-on activity to SIBERIA-II, which was a joint Russian-European remote sensing project that improved greenhouse gas accounting over a 300 Million ha area in the central Siberian region including the Irkutsk Province. The products which have been generated include regional maps of land cover, fire induced disturbances, phenology, snow depth, snow melt date, onset and duration of freeze and thaw, LAI and others. Most of these products are available for several years and cover the entire Irkutsk region. Other data used are provided by the TerraNorte Information System by the Russian Academy of Science’s Space Research Institute (Bartalev 2005). The GIS database already developed for the Irkutsk region by the Institute for Applied Systems Analysis (IIASA) together with a number of Russian institutions includes a number of layers (landscape, soil, vegetation, forests, utilities), which are effectively used for the goals of the regional information system on environmental protection and anthropogenically-driven risk assessment. However, in order to serve as a basis of IRIS, the GIS is required to be adapted to recent technological standards such as web map services (WMS) and web feature services (WFS).

IRIS also aims to efficiently share up-to-date and long-term EO data and environmental-related information of regional branch systems analysis within earth science and land management communities to identify environmental parameters that are responsible for region’s economy functioning. However, until now, traditional Geographic Information Systems in use by public administrations have scarcely integrated with scientific data, e.g. products stemming from Earth Observation, that are of great importance, for example, in scenarios of environmental risk. Likewise, real-time or near real-time applications, typical of monitoring and security scenarios, have been hindered by the quality of service of communication infrastructures, or by the available computational power.

IRIS comprises a catalogue holding metadata of all data products. The catalogue will be part of the SIB-ESS-C catalog (Bigagli & Gerlach 2008), which is implemented onto an RDBMS, that users can query through a web interface IRIS service infrastructure. The catalogue has been implemented as a federated catalogue service complying to the ISO 19115/19139 standards. Thus enabling users to perform queries on external catalogues such as the NEESPI instance of Giovanni and in turn allowing other
registries to harvest information about IRIS data holdings and services. Access to IRIS data products is provided through OGC Web Coverage, Feature, and Map Services, allowing users to directly integrate the data into their application or retrieve a file of the requested data product. Following the principle of interoperability IRIS is planned to become part of a distributed network of similar systems where not only data is being distributed and shared, but also applications are being offered and used throughout the network.

References


Figure 1. IRIS' Contribution to Standards: Interoperability by WebGIS Technologies.
Regional Integrated Monitoring System for the Pan-Arctic (RIMS)

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The Regional Integrated Monitoring System framework (ArcticRIMS) was developed at University of New Hampshire for acquiring near-real time data and producing "quick-look" outputs that characterize terrestrial and aerological water budgets across the pan-Arctic drainage region. ArcticRIMS is not only a data depositary but is also a data evaluation system for systematic detection of hydrological change over the pan-Arctic land-atmosphere domain. RIMS has several analysis tools (web-based interface, database engine, data explorer and visualization tools, hydrometeorological data “mining”, and archiving (download/upload)); (http://RIMS.unh.edu) and integrates a broad suite of data: station precipitation, observed runoff and discharge, satellite data, hydrologic and thermal modeling; and output from reanalysis fields with the UNH Pan-Arctic Water Balance Model (PWBM) to compute spatially-varying daily outputs of soil moisture, evapotranspiration, shallow groundwater storage, runoff, and river discharge routed along simulated river networks. Fields (25 km resolution under NSIDC EASE-Grid) are updated monthly for precipitation, air temperature, moisture flux convergence, permafrost active layer thickness, snow water equivalent and near-surface freeze-thaw status.

RIMS is a collaborative effort between the University of New Hampshire (UNH) the University of Colorado and the Ohio State University. UNH is responsible for maintaining the ArcticRIMS web site. ArcticRIMS contains background material, a tutorial for site navigation and a suite of visualization and analysis tools. Part of the web site maintenance includes periodic updating of records provided by the different institutions (e.g., P-E, precipitation, a suite of reanalysis fields, near-real time discharge). One of the most important components of the ArcticRIMS is the collection of near real time river gauge data for the Eurasian part of the Arctic Ocean drainage. Obtaining near real time data from Russian hydrometeorological services is more complicated due to the non-automated hydrometric network data collection methods. Russian hydrographic data is currently collected at individual discharge stations and sent to regional offices of Roshydromet (the Russian hydrometeorological observation and research service). Hydrological information is then transmitted to the central office in Moscow and to the Arctic and Antarctic Research Institute (AARI) in St. Petersburg for processing and assembly. In close collaboration with AARI, UNH obtains data from the AARI servers and harmonizes them with RIMS. Currently, ArcticRIMS compiles information in near real time for 56 Russian gauges in the Eurasian pan-Arctic. An example of a single Russian monitoring station in ArcticRIMS is shown in Figure 1.

Gridded data in ArcticRIMS is organized based on watershed hydrology and all components of the analysis and data storage are built around the drainage basin framework. Within the website, a user is able to explore and obtain data at a variety of time and space scales where the spatial component is constructed of i) grid cells, ii) drainage basins, iii) hydrologically consistent aggregations of watersheds as defined by sea basins, iv) continental aggregations, and v) the entire pan-Arctic. The online structure of the main page for the ArcticRIMS explorer with highlighted Eurasian pan-Arctic is given on Figure 2. We are planning to extend the website functionality by
including human dimensions data into the online ArcticRIMS biogeophysical data repository and exploration tool. As a first step in this direction we recently incorporated a new aggregation framework based on a hierarchy of political divisions for which most of human dimension data are available.

The next step in our online development will be the creation of a data analysis framework in the RIMS mode for the NEESPI domain to unite several of our existing capabilities in remote sensing, land cover change analysis, high northern hydrology, and Earth System modeling.

Figure 1. Example of webpage for an operational (near real time) river gauge, Lena at Kusur. Daily river discharge data are shown on the graph. Each time series is updated approximately weekly, and extends to within a few days of the present. Current conditions can be assessed as anomalies relative to climate means using the R-ArcticNet compendium of >5500 stations.
Figure 2. View of current Arctic-RIMS online data explorer through which the community can access, manipulate, and download hydrometeorological information. A water budgeting/hydrologic modeling scheme links multiple time and space scales of land-based hydrological information for summary calculations to individual river courses, water bodies, and sub-basins. Linkage across the full domain of the hydrological cycle facilitates identification of inconsistencies among modeled and observed variables as well as systematic and random errors in water budget closure. Shown is just one of the pan-arctic hydrometeorological fields (precipitation) with red circles representing regularly updated near real-time river gauges.
Giovanni Services for the NEESPI Domain

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Introduction

One of the key objectives of the NEESPI project is creating an integrated observational knowledge database to facilitate environmental studies in Northern Eurasia. The database incorporates ground observations, validated remote sensing products, and model data. NASA NEESPI Data Center collects remote sensing data, provides tools, information, and services in support of NEESPI scientific objectives (Leptoukh, et al., 2007). A specific focus of this work is on providing online data access through advanced data management system, reformatting data into common projection and format, preprocessing data to same spatial and temporal resolution that enables inter-comparison or relationship studies, providing parameter and spatial data subsetting, as well as providing online data visualization and analysis tools.

The Goddard Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) is a Web-based Earth science data tool developed by the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science data without having to download the original data (Acker and Leptoukh, 2007). The Giovanni system has convenient user Web interfaces, back-end data processing software, and image renderers. A configuration tool has been developed to easily create Giovanni instances based on particular scientific needs by selecting desired analysis functions and parameters from one or more satellite sensors or numerical models from Giovanni database.

Giovanni has been widely used to explore data and conduct initial studies, for example, dust and aerosol (Alpert, et al. 2005, Ramachandran and Cherian 2008); ocean color (Acker, et al. 2008, Shen et al., 2008); and precipitation (Huffman, et al., 2007). This paper describes basic features of the Giovanni instance designed for the NEESPI project and presents the results of its application.

Features of Giovanni-NEESPI

Giovanni-NEESPI is a customized Giovanni instance built to support the NEESPI program. It integrates atmospheric, land surface and cryospheric data from a number of sensors and models within the boundaries of Northern Eurasia. This instance helps to visualize parameters through various plot functions, like lat-lon area maps, animations, time-series, and cross-section (Latitude/Longitude–Time and Height-Latitude/Longitude). It allows to compare or to study relationship between parameters through several functions, such as scatter plot, correlation coefficient map,
difference, and overlays. Other capabilities of the Giovanni-NEESPI instance include downloading original full spatial coverage or intermediate subsetted data for the region of interest in different formats (ASCII, HDF, netCDF); recording products lineage presented by a brief descriptions of how images and data were processed to obtain the end result; and providing images in KMZ format that can be viewed through Google Earth. Giovanni-NEESPI can be accessed in a machine-to-machine way via WMS and WCS protocols. It can act as WMS or WCS server, thus allowing any GIS clients to add layers or get subsetted data from the system. It can also act as client by getting remotely located data via WCS.

Current available products in Giovanni-NEESPI system are monthly 1°x1° resolution data from MODIS Terra, MODIS Aqua, AMSR-E, and multisensor data from the NESDIS/IMS system. Daily products of the same resolution from the above instruments plus Aura OMI and AIRS are in testing phase. We are working on higher resolution daily or 8-day products to better satisfy the needs of regional studies. Table 1 lists parameters, instrument name, temporal coverage and the status of products in Giovanni-NEESPI.

Sample Application

We have used Giovanni to understand (or improve understanding) of the role of lagged effects of ecological processes on catastrophic fire occurrence in various regions of Northern Eurasia. Our previous analysis of fire and related data within the Giovanni system demonstrated that similar environmental conditions may lead to vastly different fire seasons within different ecosystems (Leptoukh et al., 2007). For example, in temperate forests a considerable increase in spring precipitation has little impact on the overall vegetation growth but reduces the wildland fire occurrence. At the same time, increased spring precipitation in the grasslands leads to an increase in biomass availability that can support large fire events during the dry period of the year.

The NEESPI-Giovanni system can be applied to identify large trends in environmental conditions which may serve as early-warning signs of potentially severe wildland fire seasons within a single ecosystem.

Summer monsoon dominated climate of the temperate forests in the Far East (an area 45 - 50° N and 136° - 140° E) limits large fire occurrence during the summer months (Loboda, in press). However, a large number of fires were detected in July of 2003 — a nearly 200-time increase in fire detections compared to other years during 2001-2006. The analysis (Figure 1) showed that traditional vegetation indices (NDVI and EVI), frequently included in operational fire danger assessment (San-Miguel-Ayanz et al., 2003), provide little information on the fuel state in this ecosystem pre- or post-fire.

Furthermore, no considerable differences in surface temperature and soil moisture in July were observed between the catastrophic year of 2003 and the two subsequent years of low summer fire occurrence of 2004 and 2005. However, the temporal analysis shown in Figure 2 indicates that dry spring conditions in 2003 (detected through low soil moisture measurements in April and May) may have lead to stressed vegetative state and created conditions conducive to catastrophic fire occurrence.

Acknowledgement

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Relevant Links
The NASA NEESPI Data Center: http://neespi.gsfc.nasa.gov/

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variations of chlorophyll a concentration in the Northern South China Sea. *IEEE

Table 1. Parameters in Giovanni-NEESPI system

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<td>Year</td>
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Figure 1. Time-series of fire counts, EVI, NDVI, surface temperature (day and nighttime), and soil moisture for 2001 – 2007 in the Russian Far East. The black circles indicate the time frame corresponding to the peak in fire occurrence of July 2003; the red circle indicates the potential early warning sign for favorable conditions for fire during the summer.
Figure 2. Snapshots of soil moisture and fire counts for May and July of 2003, 2004, and 2005.
IIASA FOR environmental data holdings for Northern Eurasia

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The Forestry Program of the International Institute for Applied Systems Analysis (IIASA FOR) has a long history in collecting, analysis and application of environmental, ecological and socio-economic data for Northern Eurasia. Since the early 1990s, together with a number of Russian and western partners, FOR carried out several large-scale projects devoted to study the regional terrestrial biota (with a special emphasis to forests) and its sustainable development in a changing world. These projects required development of extensive and diverse environmental databases describing natural landscapes in all ramifications – their structure, condition, dynamics, functioning, anthropogenic impacts, human impacts and transformation etc.

The overall requirements for organizing the information have been basically defined by information needs of the verified terrestrial biota full greenhouse gas account (FGGA) for large regions (national to continental scales). By definition, the FGGA (1) includes all ecosystems and all processes continuously in time and (2) supposes that uncertainties are assessed in a reliable and comprehensive way for all modules and stages of the account. The fuzzy character of the FGGA predetermines the need for system integration of all information sources and methods of different nature using the landscape-ecosystem approach as a methodological background (Shvidenko and Nilsson 2003, Nilsson et al. 2007). The Integrated Land Information System (ILIS) serves as the information basis for such integration. The ILIS is represented by a multi-layer GIS at different scales (Figure 1) with corresponding attributive databases and datasets. The hierarchical structure of the land cover classification, as well as spatial and temporal resolution of the data, are defined by the specifics of vegetation classes and their role in the major biogeochemical cycles (carbon and nitrogen). Major principles of development of the ILIS include: (1) usage of a unified topographic base at an appropriate scale; (2) selection of relevant cartographical sources of information, possible modification of those, and GIS representation; (3) selection of appropriate remote sensing imagery and products within a multi-sensor remote sensing concept; (4) development of corresponding attributive databases; (5) implementing of all relevant sources of ground information (data of land account; forest inventories; official statistics; data of different surveys; data of different types of monitoring; etc.) in the ILIS; (6) integration and multiple constraints of all information related to land-cover, condition and functioning of terrestrial vegetation; (6) development of a hybrid land cover dataset; (7) spatially and temporarily (to the extent possible) explicit representation of major pools and fluxes considered in the FGGA; and (8) defining ways for future updating of the system.

Environmental data included in a current prototype of the ILIS for the NEESPI domain contain a comprehensive description of natural landscapes and vegetation as of 2005 (Figure 2). The “background” layers of the ILIS comprise historical and relatively stable information sources like administrative divisions of Russia, digitized versions of different geographical maps (landscape map, edited by I. Goudilin, 1990, scale 1:2.5 Mio; soil map, edited by V. Fridland, 1990, 1:2.5 Mio; vegetation map, edited by T. Isachenko, 1990, 1:2.5 Mio; land use – land-cover map, edited by M. Zvonareva, 1990, 1:4 Mio; et al.). Attributive DBs have been developed for all these datasets. An important layer of aggregation are the ecological divisions of Russia (142 ecological regions are separated) that allows (1) structuring empirical data and models for
naturally homogeneous territories, (2) accounting for anthropogenic impacts on landscapes and ecosystems, and (3) aggregation of information received within natural and administrative spatial units. Climatic data (monthly data on temperature, precipitation, degree days for growth seasons with temperature >0°C, >5°C and >10°C, hydrothermal coefficient by Seljaninov for these periods, some others) are presented by in 0.5 x 0.5° grid for the Russian territory for 1961-2005.

The enormous size of Russia, vast remote territories with sparse population, availability of areas with rapid land use – land cover changes, wide distribution of natural and human-induced disturbances, and lack of infrastructure define the crucial role of remote sensing in the development of land cover, its actualization and parameterization. The usual trade-off between area of the coverage, spatial and temporal resolution of remote sensing imagery is achieved by (1) combining RS products and diverse sources of other relevant information, and (2) accounting for regionality and major processes studied. A special dataset was developed for validation of RS imagery (over 80 test areas have been developed at the total area of 3.5 million ha; the test areas are represented by GIS components at a scale of 1:50,000 and detailed description of primary land cover units).

The combination of RS products, ground data, auxiliary models and expert systems resulted in a hybrid land cover for 2005. The GLC2000 land cover and the Vegetation Continuous Field (VCF) products were used as the initial layers for designing the most common classes of the land cover. Harmonizing the data and delineation of land classes were provided based on decision rules which are based on availability and quality of ground data. Data of the State Forest Account-2003 (appr. 2000 forest enterprises) were linked by forest enterprise and land class; forest areas were adjusted (expanded or decreased) using the VCF thresholds and taking into account reliability (method, time of provision) of forest inventories. Agricultural land was adjusted to the land account statistics of administrative regions based on the spectrum of soils used in agriculture and statistics on cultivated land. Wetlands were delineated based on recent maps, the spectrum of soils, and other sources. Procedures of such a type allowed for high general agreement between the two major sources of information (remote sensing and ground data) across the country. The final classification for forests includes a complete biometric description (aggregated species composition, age, site index, growing stock volume etc.). Non-forest ecosystems are described in the 4 level classification (land class type, subtype, bioclimatic zone, botanical class of vegetation). Finally, this land cover is presented via a multi-layer hierarchical classification of 1 km pixels. The latter are parameterized with respect to indicators used in the FGGA (numerous ecological indicators describing functioning of ecosystems, e.g., live biomass by components, Net Primary Production, Heterotrophic Respiration; Net Ecosystem Production; quantification of disturbances; many others).

Other environmental data include data bases and data sets of measurements in situ: (1) live biomass of forest stands (3750 sample plots from about 500 different studies) and NPP (~ 1400 records); (2) coarse woody debris in forests (~450 records); (3) live biomass and NPP of non-forest vegetation classes (~1000 records); (4) soil respiration (~600 records); (5) data on decomposition of vegetation organic matter in ecosystems (~500 records); (6) data on content of organic and inorganic carbon and nitrogen in rivers and lakes; others. These data are used for preparation of empirical models of different types. The latter, as well as different empirical and “semi-empirical” models derived from different sources (models of growth and biological production of forests; models of yields and structure of produced vegetation matter; etc.) are stored as a special module of the ILIS. The important part of environmental data includes results of different inventories and surveys as well as diverse statistical data (e.g., data of State
Forest Account and State Land Account for 1961-2003 at different levels of detail; data on vegetation fire, harvest, and insect outbreaks in forests; data on consumption of plant production; etc.).

A substantial part of the information described above is publicly available from two CD ROMs titled – “Land resources of Russia” and “Russian forests and forestry” (http://www.iiasa.ac.at/Research/FOR) and special publications (e.g., Shvidenko et al. 2007).

References

Figure 1. Principle scheme of the Integrated Land Information System.
Figure 2. Simplified structure of the ILIS 2005.
Environmental remote sensing data used at VTT

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VTT Technical Research Centre of Finland is a not-for-profit organization for applied research. The total number of staff is 2740. Research on remote sensing using space borne data has been conducted already since early 1970’s. The most important area of application has been and is today forestry and forest ecosystem monitoring. Other important application fields include winter navigation on the sea and natural disaster mitigation. VTT focuses on the method development. The methods are often implemented as software tools that are further delivered for customers and partners. Because of the nature of the work, VTT does not have large data archives in its possession. The remote sensing data includes all types of imagery from weather satellite images to high resolution polarimetric SAR (Synthetic Aperture Radar) data and ground-based digital cameras. The importance of data fusion applications is increasing. Satellite data are still a key data source but they are combined with the in-situ data, data from models, and archived data. Below some applications are briefly described with a foresight to the future.

A probability method was originally developed for mapping of forest extent in the pan-European region (i.e., Europe up to the Ural Mountains) using the AVHRR instrument data of the NOAA series satellites (Häme et al. 2000 and 2001). The method combines unsupervised classification of images and reference data from sampling, and finally estimates all the variables as continuous values. In the case of categorical variables, the probability of the target class is estimated at a certain pixel.

The images are radiometrically corrected by applying an atmospheric correction and an additional BRDF (Bi-directional Reflectance Distribution Function) correction before the probability method is applied. The calibration makes it possible to combine images that have been acquired during the same period of the growing season, into large image mosaics. For instance, in the project for the pan-European forest mapping an image reflectance mosaic was compiled from the whole target area. It was used as a single image in the analysis process. Image calibration also makes it possible to compute spectral models that are directly applicable in other images, acquired from a different region, if the land cover types are similar.

The probability method using mainly Landsat data is being operatively used by the Finnish forest industry in global locations fro several years. Also, forest classification in the Finnish CORINE land cover mapping as part of the European Community program was based on the application of the probability method.

The probability method has been also applied for the very high resolution optical data from Ikonos and QuickBird satellites for forest parameter estimation. As an additional phase, image segmentation is used (Astola et al. 2004).

Another method, called biomass function method, was developed for the estimation of the forest growing stock volume for cases when only very limited ground data are available. A model, resembling the gamma distribution density function is computed to predict the growing stock volume using some field plots and higher resolution imagery
(e.g. Landsat). The model is then applied to a calibrated image mosaic with a lower resolution. In the study a model was developed using ground reference data from an area of 1 km$^2$ and a Landsat TM image. It was applied to a Modis image mosaic from Finland and Sweden. The bias for the average growing stock volume for whole Finland, computed by comparing the Modis estimates with the Finnish national forest inventory statistical data, was only -2.3 m$^3$/ha (Sirro et al. 2002).

In the SAR domain, Methods, developed by VTT were used to compile a JERS radar mosaic from northern Eurasia using 100 m pixel size. The project was cooperation between the Joint Research Centre of the European Community, Japanese Space Agency JAXA, and VTT (DeGrandi et al. 2004). Recently, methods have been developed for the forest and land cover classification and change monitoring using SAR data and for the analysis of polarimetric SAR data (Häme et al. 2007, Rauste, et al. 2007a).

A forest fire alert system, based on NOAA AVHRR and recently also Modis data, has been operative since 1996. The system automatically analysis the images and transmits alert messages via email and facsimile. The time for the submission of the alert message is on the average 20 minutes after the satellite overpass (Kelhä et al. 2003).

An example of the data fusion is the system that is being developed for the monitoring of the seasonal dynamics of the nature. The system combines frequent ground observations and Modis image data. The manual ground observations can be augmented or even replaced with digital cameras that automatically collect images from the same location, submit them via the internet to the analysis center where the seasonal status is automatically analyzed. The analysis results are combined with Modis based estimates about the seasonal status (Rauste et al. 2007b).

VTT has proposed launching a near-polar orbiting satellite that regularly and globally acquires very high-resolution (0.5 m) optical images using a statistical sampling principle (Häme et al. 2006). This image resolution enables observation of individual trees.

The core concept of the satellite mission, i.e., the statistical sampling of high resolution images, is considered to be the most effective feasible approach to monitoring land cover and ecosystems reliably over large areas (> 25 000 km$^2$). No other existing or planned very high resolution satellite mission is currently envisaged for the monitoring of the global land ecosystems. The mission should include several successor satellites to enable a continuous land ecosystem monitoring system.

The main driving forces behind the mission are inaccuracies in current global and regional statistics on forest cover and land use change dynamics and the monitoring needs for future policies as concerns incentive mechanisms on avoided deforestation and forest degradation (REDD). The very high resolution sampling satellite would realize the philosophy of ecosystem analysis using data fusion. The image sample would be a key data source in the chain from ground measurements to wall-to-wall mapping.
References

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Figure 1. Autumn progress in Finland in September-October 2007 (Rauste et al. 2007b).

"Wall-to-wall" optical or radar satellite data - medium to low resolution

Kioto+ — sample of very high resolution images

Ground measurements

Maps with variable or unknown accuracy

Maps with known and harmonized accuracy

Reliable statistical data on forest and land cover - feasible, with reasonable costs

Statistical data with reduced field sampling rate, many variables, including biomass

Reliable statistical data, many variables - expensive, can be unfeasible to collect

Figure 2. The proposed Kioto+ mission in the chain of data sources in ecosystem monitoring.
Agenda of the Regional Science Team Meeting devoted to the High Latitudes of the NEESPI domain
June 2-6, 2008, University of Helsinki, Helsinki, Finland

Day 1. Monday, 2 June 2008

9.00 – 9.30 Welcome from the Host Organizations, Introduction and Aims of the Meeting
Anni Reissell, Pavel Groisman, Richard Lawford

9.30 – 12.00 Programmatic talks of the Representatives from International and National Programs, Projects, and Agencies
Chair: Pavel Groisman

9.30 – 10.00 WCRP
Ghassem Asrar

10.00 – 10.30 RAS
Alexander Georgiadi

10.30 – 10.50 NASA
Garik Gutman

10.50 – 11.10 Coffee Break

11.10 – 11.25 ESA
Einar Herland

11.25 – 11.40 GEWEX, GEO
Richard Lawford

11.40 – 12.00 AIMES
Kathy Hibbard

12.00 – 15.00 Research talks on the current status of climate research in the NEESPI region.
Chair: Anni Reissell

12.00 – 12.30 Recent research topics and plans related to NEESPI at JAMSTEC and other Japanese projects
Tetsuo Ohata (JAMSTEC)

12.30 – 13.00 Climatic change in high latitudes of Eurasia
Pavel Groisman (UCAR at NOAA NCDC)

13.00 – 14.00 Lunch

14.00 – 14.20 iLEAPS research in Northern Eurasia
Pavel Kabat (iLEAPS Steering Committee, co-chair)

14.20 – 14.40 Projected changes in frost and snow in northern Europe based on regional climate model simulations
Kirsti Jylhä (Finnish Meteorological Institute)

14.40 – 15.00 Regional LCLUC and Human Dimension
Bruce Forbes (Arctic Centre, University of Lapland)

15.00 – 17.00 Coffee & Poster Session (presentations of the ongoing NEESPI Projects)
17.00 – 19.00 Welcome reception at University of Helsinki, hosted by Vice Rector Thomas Wilhelmsson

Day 2. Tuesday, 3 June 2008.

9.00 – 10.30 Topical Lectures
Chair: Garik Gutman

9.00 – 9.30 Remote Sensing of the high latitudes
Annett Bartsch (Vienna University of Technology)
9.30 – 10.00  Quantifying the carbon budget in Northern European Russia: CARBO-North studies
   Tarmo Virtanen (University of Helsinki)
10.00 – 10.30  Boreal forest in high latitudes
   Anatoly Shvidenko (IIASA)
10.30 – 11.00  Coffee Break
11.00 – 11.30  Large-scale vegetation cover disturbances
   Hank Shugart (University of Virginia)

11.30 – 13.00  Topical Lectures (cont.)  Chair: Scott Goetz
11.30 – 11.55  Arctic ecosystems and their feedbacks
   Scott Goetz (Woods Hole Research Center)
11.55 – 12.20  Land Surface Modeling for the NEESPI domain
   Eric Wood (Princeton University)
12.20 – 12.45  Modeling of CO2 and CH4 fluxes in the Arctic
   Qianlai Zhuang (Purdue University)
12.45 – 13.10  Hydrological changes across the Eurasian Arctic
   Alex Shiklomanov (University of New Hampshire)
13.10 – 14.00  Lunch

14.00 – 15.30  Topical Lectures (cont.)  Chair: Lauri Laakso
14.00 – 14.30  Atmospheric Aerosols in the high latitudes
   Irina Sokolik (Georgia Institute of Technology)
14.30 – 15.00  Air pollution in the Northern Eurasia
   Eugeny Genikhovich (Main Geophysical Observatory)
15.30 – 16.00  Aerosol studies in Pallas, Northern Finland
   Veli-Matti Kerminen (Finnish Meteorological Institute)
17.00  Ferry to Suomenlinna Island from Kauppatori, sightseeing, informal discussions
   OR
18.20  Ferry to Suomenlinna Island from Kauppatori

19.00  Meeting Dinner at Restaurant “Suomenlinna Upseerikerho”,
   Address: Suomenlinna C 53.

Day 3. Wednesday, 4 June 2008

9.00 – 13.00  The IPY-138 and IPY-140 Activity Workshops

9.00 – 10.30  IPY-140 “Hydrological Impact of Arctic Aerosols”.  Session Chair: Irina Sokolik
9.00 – 9.30  Aerosol-cloud-precipitation-climate: The interlinked formation processes.
   Markku Kulmala (University of Helsinki)
9.30 – 9.50  Investigations of atmospheric aerosol based on the polarization measurements of the twilight sky,
   Oleg Ugolnikov (RAS Inst. Space Studies)
9.50 – 10.30  Open discussion:
   Active discussion team: Kulmala, Laakso, Genikhovich, Kukkonen, Vesala, Sofiev, Herland, Petropavlovskikh, Paatero, Kerminen, Ugolnikov, et al.
10.30 – 11.00  Coffee break

11.00 – 12.45  IPY-138 “Cold Land Processes in the Northern Hemisphere continents and their Coastal Zone: Regional and Global Climate and Societal-Ecosystem Linkages and Interactions”.
   Session Chair: Richard Lawford
11.00 – 11.30  RAS IPY Program: First results.  Tatiana Khromova (Russian Academy
Active layer thickness over the Russian Arctic: Observations and Modeling Nikolay Shiklomanov (University of Delaware)

Open discussion

Active discussion team: Yoshikawa, Häme, N. Shiklomanov, Virtanen, Gutman, Ohata, Ozdogan, Groisman, Georgiadi, Khromova, Forbes, Shmakin, Shugart, A. Shiklomanov, Tchebakova

Future NEESPIans briefing how to join NEESPI

Groisman (UCAR at NCDC), Ozdogan. (University of Wisconsin)

Lunch

Informal break-out groups’ work (preparation of the workshop documents).


Group 2: “Cold Land Processes in the Northern Hemisphere continents and their Coastal Zone: Regional and Global Climate and Societal-Ecosystem Linkages and Interactions”. Group lead: Rick Lawford.


Day 4. Thursday, 5 June 2008

Field trip to the Hyytiälä Research Station (whole day)

Guided by Prof. Timo Vesala

Hyytiälä Forestry Field Station (http://www.mmm.helsinki.fi/hyytiala/english/eng_index.htm) is part of the Faculty of Agriculture and Forestry at the Helsinki University, located some 210 km N-NW from Helsinki. A comprehensive measurement site, SMEAR II (Station for Measuring Ecosystem – Atmospheric Relationships) is situated at Hyytiälä Field Station. SMEAR II is situated in a 45-year-old Scots pine stand. It has several operation units to reach into and above the stand canopy: a 73 m high tower for atmospheric and flux measurements, 18 m tower for irradiation and flux measurements and 24 m tower for tree physiology measurements. Concurrent soil and soil-water measurements are performed on two catchment areas. In the vicinity of the SMEAR II station, solar irradiance and boundary layer wind profiles are measured. Some 50 to 100 people are involved in the research carried out at the stations, and they produce about 50 peer-reviewed papers annually. By 2005, the stations have been involved in more than 10 EU projects.

Tentative programme of the trip:

8.00 Departure from Helsinki, Hotel Academica (front of the main entrance) to the Hyytiälä Field Station, there will be a bus transfer with short stop at a cafeteria on the way.
11:30 – 12.30 Lunch in Hyytiälä
12:30 – 15:00 Guided tour on Field Station (about 2.5 hours)
15:00 – 15:30 Coffee break
15:30 – Departure from Hyytiälä
18:00 Estimated arrival time to Helsinki

Before the departure, please look at the weather forecasts at http://www.fmi.fi/weather/local.html?kunta=Tampere just to be sure you are have appropriate clothes and shoes.
Day 5. Friday, 6 June 2008.

9.00 – 9.30 Laboratory perspectives on the processes of complex organic aerosols
Yinon Rudich, Editor of Journal of Geophysical Research-Atmospheres

09.30 – 13.00 Data availability and needs Training sessions aimed specifically at
postgraduate students and early career scientists. Chair: Gregory Leptoukh

Lead by the representatives of GCOS IIASA, and the NEESPI Science and Data Support Centers.

09.30 – 10.00 Data availability at the U.S. National Climatic Data Center.
GCOS data sets. Karsten Shein (NCDC)

10.00 – 10.15 Observations in the Russian Arctic. Data availability at the Russian
Research Institute for Hydrometeorological Information.
Pavel Groisman (UCAR at NCDC)

10.15 – 10.30 The Irkutsk Regional Information System for Environmental Protection.
Karsten Frotscher (Friedrich-Schiller-University-Jena)

10.30 – 11.00 Coffee break

11.00 – 11.30 Data availability at the NEESPI Focus Research Center for Water System
Studies. A. Shiklomanov, University of New Hampshire

11.30 – 12.00 Giovanni System Services for the NEESPI domain.
Gregory Leptoukh (NASA GSFC)

12.30 – 12.45 IIASA environmental data holdings for Northern Eurasia.
Anatoly Shvidenko (IIASA)

12.45 – 13.05 Data Holdings of the Nordic countries
Heikki Tuomenvirta

13.05 – 13.20 Environmental remote sensing data used in VTT
Tuomas Häme

13.20 – 14.15 Lunch

General Discussion Chairs: Pavel Groisman, Garik Gutman

14.15 – 15.00 Topic 1: What data we have and what we have not in Northern Eurasia.

15.00 – 16.00 Topic 2: Unresolved issues of contemporary research in high-latitude land areas.

16.00 Adjourn
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