PEEX Science Plan

Version 0.7

PEEX "Pan-Eurasian Experiment" study is a multidisciplinary climate change, air quality, environment and research infrastructure program focused on the Northern Eurasia, and particularly on arctic and boreal regions. PEEX research agenda is reinforced by the services, adaptation and mitigation plans for the Northern societies to cope with the global change. It is a bottom up initiative by several European, Russian and Chinese research organizations and institutes. PEEX is open for other institutes to join in. More information on the project can be obtained from: www.atm.helsinki.fi/peex.

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PREFACE

PEEX Science Plan is built on four focus area: research- research infrastructures – society dimension and knowledge transfer. PEEX research agenda introduces the large-scale key topics of the land-atmosphere-aquatic-anthropogenic systems in order to have advanced scientific and social-economic understanding of the future role of the Arctic-boreal regions in the Earth system. The key topics of different subsystems are interlinked with complex feedbacks, thus the scientific approach of each topic should be based on a multidisciplinary – multi scale research chain. A side of the research agenda as important elements of the PEEX initiative are (i) the development of the research - education infrastructures in Russian and China domains and (ii) the knowledge transfer of the scientific outcome for the fast tract policy making and (iii) the education of next generation of scientists and technical experts and for the benefits of the Northern societies. The Science Plan also introduces the key aspects of these elements.

Pan-Eurasian Experiment (PEEX) is a bottom-up initiative by several European, Russian and Chinese research organizations. The promoter institutes here have been University of Helsinki, Finnish Meteorological Institute in Finland and Inst. of Geography, Moscow State University, AEROCOSMOS and Inst. of Atmospheric Optics SB RAS in Russia. The first PEEX meeting was held in Helsinki in October 2012 followed by meetings in Moscow and in Hyytiälä, Finland in 2013. The content of the Science Plan is based on the scientific presentations introduced in the PEEX meetings and for specific comments received during the Science Plan writing process.

PEEX can be, in the best case, truly fast track action in the global climate policy making providing new knowledge on the mitigation and adaptation strategies for the Arctic-boreal regions. Solving the research challenge of the climate and cryosphere changes requires a large scale co-operation of the international research communities, but solving the climate policy challenge of the Northern societies to cope with the environmental changes needs a strong involvement and collaboration with Russian and Chinese partners. From European perspective PEEX can be considered as a crucial part of the strategic aims of several European and national roadmaps for climate change research and the development of next generation research infrastructures.

VISION

PEEX is a multidisciplinary research initiative aiming at resolving the major uncertainties in the Earth system science and global sustainability questions in the Arctic and boreal Pan-Eurasian region. The vision of PEEX is to solve interlinked global challenges influencing the human well-being and societies in the northern Eurasia, such as climate change, air quality, biodiversity loss, chemicalisation, food supply, energy production and fresh water, in an integrative way, recognizing the significant role of boreal regions and Arctic in the context of global change.

The PEEX vision includes the establishment and maintenance of long-term, coherent and coordinated research and education activities and research infrastructures in the PEEX domain. PEEX aims to contribute to the Earth system science agenda and climate policy in topics important to the Pan-Eurasian environment and to provide adaptation and mitigation strategies for the northern Pan-Eurasian societies to cope with climate change.

MISSION

To be a next generation natural sciences and socio-economic research initiative having a major impact on the future environmental, socio-economic and demography development of the Arctic and boreal regions. To be a science community building novel infrastructures in the Northern Pan Eurasian region.

ABSTRACT

Pan Eurasian Experiment (PEEX) is a multidisciplinary research project aimed at resolving the major uncertainties in the Earth system science and global sustainability in the Arctic and boreal Pan-Eurasian regions. The vision of the PEEX is to solve interlinked global challenges influencing human well-being and societies in northern Eurasia. Such challenges include climate change, air quality, biodiversity loss, chemicalisation, food supply, use of natural resources by the mining and industry, energy production and transport. Our approach is integrative and interdisciplinary, recognizing the important role of the Arctic and boreal ecosystems in the Earth system. The PEEX vision includes establishing and maintaining long-term, coherent and coordinated research activities and research and educational infrastructures across the PEEX domain.

PEEX will use an integrated observational and modeling framework to identify different climate forcing and feedback mechanisms in the northern parts of the Earth system, and therefore enable more reliable predictions of future regional and global climate. Because of the already observable effects of climate change on society and the specific role of Arctic and boreal regions in this context, PEEX emphasizes the need to establish next-generation research and research infrastructures in this area. PEEX will provide fast-track assessments of global environmental change issues for climate policy-making and mitigation and adaptation strategies for the northern Pan-Eurasian region.

PEEX is built on the collaboration between European, Russian and Chinese partners, and is open to a broader collaboration in the future. The PEEX community will include scientists from various disciplines, funders, policy-makers and stakeholders from industry, transport, renewable natural resources management, agriculture production and trade, and it will aim at co-designing research in the region in the spirit of the Future Earth initiative.

PEEX aims to be operational starting from 2014. It will start building the long-term, continuous and comprehensive research infrastructures (RI) in the Northern Pan-Eurasia. These RIs will include ground-based, aircraft and satellite observations as well as multi-scale modeling platform. The PEEX domain covers the Eurasian boreal zone and Arctic regions of the hemisphere, including the marine areas such as the Baltic, North Sea and the Arctic Ocean. The PEEX research agenda focuses on the multidisciplinary process understanding of the Earth system on all relevant spatial and temporal scales ranging from the nano scale to the global scale. The strategic focus is to ensure the long-term continuation of advanced measurements in the land-atmosphere-ocean continuum in northern Eurasian area and to educate next generation of multidisciplinary scientists and technical experts capable to solve the large scale research questions of the area and

The scientific results of PEEX will be used to develop new climate scenarios at global and regional scales. PEEX aims to contribute to the Earth system science agenda and climate policy for topics important to Pan-Eurasian environment and society to help the Pan-Eurasian region build a sustainable future.

EXTENDED ABSTRACT

PEEX "Pan Eurasian Experiment" is a multidisciplinary climate change, air quality, environment, ecosystems and research infrastructure program focused on the Northern Eurasian particularly Arctic and boreal regions. *The overall goal of PEEX is to solve interlinked global challenges like climate change, air quality, biodiversity loss, chemicalisation, food supply, energy production and fresh water in integrative way recognizing the increasing role of the arctic and northern biomes in the context of global change*. PEEX is targeted to provide fast tract assessments for the climate policy making in a global scale and mitigation strategies for the Northern Pan Eurasian region. PEEX initiative was initiated in 2012 and is planed be active in a continuous manner. PEEX domain covers major part of relevant areas of boreal forest zone and permafrost regions of the Northern hemisphere including the maritime environments. PEEX research is based on the collaboration of Russian, Chinese and European parties and is aimed to prove revolutionary impact on global climate policy making.

PEEX vision includes to establish and to maintain a long-term coherent and coordinated research and education activities and research infrastructures in PEEX domain. PEEX aims to contribute to the Earth system science agenda and climate policy for topics inherent to Pan-Eurasian environment and provide mitigation and adaptation assessment of Northern Pan-Eurasian societies. To cope with the consequences of climate change in a global scale, the transformation of the civilization and natural ecosystems, are one of the ultimate challenges of the 21st century.

The PEEX agenda is divided into four focus areas: 1. Research agenda, 2. Infrastructures, 3. Societal Dimension and 4. Knowledge Transfer. The agenda is motivated by the fact, that the northern regions, land and ocean areas lying 45°N latitude or higher, will undergo consequential change during the next 40 years. Even the most moderate climate scenarios predict that the northern high latitudes will warm 1.5 °C -2.5 °C by the mid of century and 3.5 °C by the end of the century, which is more than double compared to the global average warming (ref. IPCC). Climate warming is shaking the dynamics of the whole global climate system and is also triggering interlinked loops between the global forces; the demographic trends, use and demand of natural resources and globalization. Warming will affect the demography trends in a way that the urbanization and the migration to northern regions will be increased. One of major consequences of warming of northern latitudes is related to changes in cryosphere including the thaw of permafrost and the Arctic Ocean being ice free part of the year. This will accelerate global trade activities in the Arctic region if the Northern Sea Route is opened for shipping between the Atlantic and Asia's Far East. Northern ecosystems and arctic regions are a source of major natural resources such as oil, natural gas and minerals. The exploitation of natural resources depends, how badly the permafrost thaw is damaging the infrastructures. In addition, the ecosystems will undergo oppressive changes including new species expansion or extinction of existing ones, having unpredictable consequences on food webs or primary production of different plant ecosystems.

Focus-1: PEEX Research Agenda

The main goal of PEEX Research agenda is to contribute the scientific questions that are specifically important for the Pan-Eurasian region in the coming years, in particular the global climate change and its consequences to nature and human society. The PEEX Research agenda covers different spatial and temporal systems and geographical regions including natural and urban environments. The large scale systems studied by PEEX are: land, atmosphere, ocean and anthropogenic system. Each of them can also be divided into smaller sub-systems such as land system into boreal forests, burnt of clear-cut areas, grasslands tundra and peat lands. PEEX large scale research questions are focused on (i) the key processes of the main systems and on (ii) the identification and quantification of the main feedbacks in the Pan-Eurasian Arctic-Boreal region

The scientific outcome is filling the current gaps of knowledge of the process understanding, feedback and link within and between the systems and biogeochemical cycles in the Arctic-boreal context. Bbiogeochemical cycles studied are: water, carbon, nitrogen, phosphorus, and sulphur cycles. The PEEX domain covers wide range of human-natural system interactions and feedback processes, with humans acting as both the source of climate and environmental change and the recipient of the impacts. Reliable climate information and scenarios for the coming decades are crucial to support adaptation to cryosphere and climate change impacts on the Northern societies. Human decision-making regarding Earth system components such as land use and fossil fuel burning are represented by Agent-Based Models (ABM), Integrated Assessment Models (IAM), and climate scenarios that will be utilized and further developed for the Northern Pan-Eurasia region. In urban and industrialised regions the process understanding of biogeochemical cycles includes anthropogenic sources such as industry and fertilisers as indispensable parts of the biogeochemical cycles. PEEX climate scenarios, especially estimates on the type and frequency of natural hazards will be used to improve climate prediction capacities for Europe, Russia and China. Furthermore, socio – economic research covers (i) the *superposition* of natural and socio-economic factors, (ii) the *dependence of consequences of natural change on socio-economic condition* and its dynamics, (iii) identification of opportunities and ways of *mitigation and adaptation* to natural and socio-economic change, (iv) the *spatial differentiation* of the response of societies on national, regional, and local levels (regional and local, urban and rural cases) to natural and socio-economic challenges.

PEEX research outcome is used for producing different types of scenarios on the impacts of climate change and air quality on human population, society, energy resources and capital flow. PEEX will provide information for the mitigation and adaptation strategies for the changing Arctic environments and societies and risk-analysis on the human related activities and natural hazards (floods, forest fires, droughts, air pollution). These plans include aspects of sustainable land use, public health and energy production. The improved knowledge and scenarios on climate phenomena and impacts, especially estimates on the type and frequency of extreme events and possible nonlinear responses for past, present and future conditions are needed to provide enhanced climate information and climate prediction, and further to support adaptation.

Large-scale research questions

LAND SYSTEM

- **Q-1 How could the land regions and processes, shifting of vegetation zones, especially sensitive to climate change be identified and what are the best methods to analyse their responses?**
- ***Key Topic: Shifting of vegetation zone***
- **Q-2How fast will the permafrost thaw proceed and how will it affect ecosystem processes and ecosystem-atmosphere feedbacks, including the hydrology and greenhouse gas fluxes? ‘**
- ***Key Topic: Risk areas of permafrost thawing***
- **Q-3 What are tipping points in the future evolution of the Pan-Eurasian ecosystem changes?**
- ***Key Topic: Ecosystem structural changes***

ATMOSPHERIC SYSTEM

- **Q-3 What are the critical atmospheric physics and chemistry processes with large scale climate implications?**
- ***Key Topic: Atmospheric Composition and Chemistry***
- **Q-4 Quantification of the feedbacks between air quality and climate at Northern high latitudes**
- ***Key Topic: Urban air quality, megacities and changing ABL***

  Q-5 How will the atmospheric dynamics (weather; synoptic, BL) change in the Arctic – boreal regions?
- ***Key Topic: Weather and atmospheric circulation***

AQUATIC SYSTEMS – THE ARCTIC OCEAN

- **Q-6 How will the Arctic sea ice extend, snow cover and permafrost, change with changing climate and what are the connection to the climate system?**
- ***Key Topic: the Arctic Ocean in the climate system***
- **Q-7 What is the joint effect of the arctic warming, the pollution load and acidification on the arctic marine ecosystem, mainly on the primary production (algal blooms and the following sedimentation, i.e. carbon sink)?**
- ***Key Topic: The Arctic maritime environments***
- **Q-8 What is the future role of the arctic-boreal lakes and large river systems in biogeochemical cycles (incl. thermokarst lakes and running waters of all size) and how will these changes affect societies (livelihoods, agriculture, forestry, industry)?**
- ***Key Topic: Lakes and Large scale river systems in Siberian region***

ANTHROPOGENIC SYSTEM

- **Q-9 How will human actions (land-use changes, energy production; efficiency, use of renewable energy sources) influence further environmental change in the region?**
- ***Key Topic: Anthropogenic impact***
- **Q-10 How do the fast the changes in physical, chemical and biological state of the different ecosystems, inland water, coastal areas affect the economies and societies in the region and vice versa?**
- ***Key Topic: Environmental impact***
- **Q-11 In what ways are socio-economic areas vulnerable to climate change and how can their vulnerability be reduced and their adaptive capacities improved? What responses can be identified to mitigate and adapt to the climatic changes?**
- ***Key Topic: Natural hazards***

FEEDBACKS – INTERACTIONS

- **How will the changing permafrost conditions affect the Arctic climate system?**
- **Improving the understanding of biogenic aerosol formation and feedback processes?**
- **How intensive urbanization processes are changing local and regional climate and environment?**
- ***Key topics: Biogeochemical cycles; water, C, N, P, S***

Focus-2: PEEX Infrastructure

PEEX research infrastructure (F-2) aims to establish a long-term research a comprehensive field station network in the region covering Scandinavia and Baltic countries, Siberia and northern China. The integrated measurements of the hierarchical station network are designed to increase the quantitative process understanding of the land-atmosphere-ocean-anthropogenic systems. In the first phase the network will be based on the existing infrastructure consisting of i) basic weather stations, (ii) flux (Fluxnet) stations and (iii) flag ship stations and (iv) satellite receiving stations. The strategic focus is to ensure the long-term continuation of advanced measurements on aerosols, clouds, GHGs and trace gases in Northern Eurasian area.

A flag ship stations measure meteorological and atmospheric factors simultaneously together with ecosystem relevant processes (incl. carbon, nutrient and water cycles, vegetation dynamics, biotic and abiotic stresses). Ideally, the ground station network will contain one flag ship station in all major ecosystems, in practice a station in every 2000- 3000 km. The future PEEX research infrastructure is supporting and complementing aircraft and satellite observations which provide complementary (to the local in situ observations) information on the spatial distribution of atmospheric composition (aerosols, trace gases, greenhouse gases, clouds), land and ocean surface properties including vegetation and snow/ice. Vice versa, the PEEX infrastructure has an important role in validation, integration, full exploitation of satellite data for Earth Observations. The role of remote sensing observations is emphasized in remote areas such as the Arctic Ocean, maritime environments and most of the Arctic land areas with virtual no in situ observations.

The PEEX infrastructure will deliver critical long-term datasets for the climate and air quality research including evaluation of weather forecast, air quality and climate models. The procedures for improved data quality including standardization of instruments, methods, observations, data processing will be developed in co-operation with the European research infrastructure development (ESFRI). Linking PEEX to European RI development ensures the optimal use of the infrastructures, the data and infrastructure sharing of Earth Observations and their scientific contribution towards Earth System modelling. For this purpose a hierarchy/framework of modern multi-scale models for different elements of the Earth System integrated with the observation system will be elaborated as a PEEX Modelling Platform.

Focus-3: PEEX Society dimension

PEEX initiative is taking into account the ongoing social (political, economic) characteristic of the PEEX domain macro regions. The main part of the Arctic and boreal Pan-Eurasian region situated within the boundaries of the Russian Federation (Russia's North and East), has undergone rapid socio-economic transformation during last twenty years. Climate and other natural change are taking place parallel with ongoing socio-economic changes interacting in complex ways. The complexity and uncertainty of the consequences of natural (including climate) change in this macro region are much higher than in the others. Russia is greatly differentiated in socio-economic sense from West to East (European and Asian parts of the country), but both by its federal subjects and within most of them. Therefore the consequences of one and the same natural change are spatially not alike. Since China is a country in the northern hemisphere, the cold air activities in the Arctic region and changes in atmospheric circulation in high altitudes have a direct impact on weather and climate in China, and have significant influence on China's ecological environment, agricultural production and other social and economic activities. The sea level rise in the world caused by speedy melting of Arctic ice affects economic and social development in China's east coast. Because the Arctic affairs are related to many natural, economic and social aspects in China as well as China's sustainable development, China attaches great importance to Arctic affairs. The PEEX mitigation and adaptation strategy take into account this high uncertainty and variation of the consequences of natural (including climate) change influencing the human wellbeing and societies in the Arctic and boreal Pan-Eurasian region. Thematic areas of concern for the consequences of climate change are (i) living standards and quality of life (ii) industrial construction and house building, (iii) land use, (iv) agriculture and forestry, (v) mining industry, (vi) transport and (vii) tourism and recreation.

PEEX initiative is linked to climate policy making and integrates the scientific results into policy making. PEEX initiative collaborates with the international scientific organizations and networks such as Intergovernmental Panel on Climate Change (IPCC), IGAC and iLEAPS of the International Geosphere-Biosphere Programme (IGBP). The IGBP co-projects like iLEAPS are bringing PEEX at an international policy level and opens the channel to respond to the Future Earth initiative and Digital Earth programme. These initiative and programmes are coordinated by International Council for Science, ICSU's, global environmental change (GEC) programmes and bring PEEX impact closer to social science and economics. They will be indispensable partners for natural sciences on the road to solve the equation of one Earth (Future Earth programme) and a growing human population. Future Earth will mobilize international science community to work with policy-makers and other stakeholders to provide sustainability options and solutions in the wake of Rio+20.

PEEX Focus-4: Knowledge Transfer

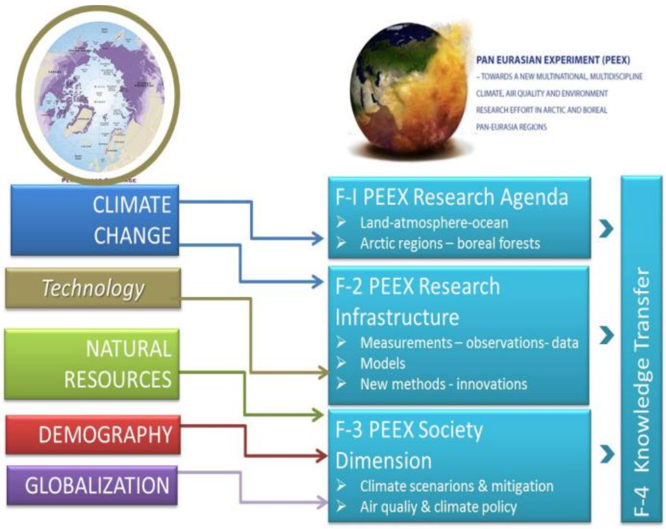
PEEX initiative provides education programmes for the next generation scientists, instrument specialists and data engineers. It will distribute information for general public to build the awareness of climate change and human impact on different scales of the climate problematic and increase visibility of the PEEX activities in Europe, Russian and China.

The major challenge is to explore the means to make PEEX research useful with clear messages to decision makers and to integrate the PEEX infrastructure across national and scientific boundaries to build up a genuine international infrastructure. As a part of knowledge transfer PEEX will engage the larger international scientific communities also by collaborating with European observation infrastructures such as the ICOS (greenhouse gases), ACTRIS (aerosols and trace gases) and ANAEE (ecosystem measurements) to build its own in the Pan-Eurasian region.

PEEX will have a major input in Earth system research in Pan-Eurasia on many levels and, as a bottom-up initiative; it has engaged a large international scientific community already in the planning phase. PEEX will build a new, integrated Earth system research community in the Pan-Eurasian region by opening its research and modelling infrastructure and inviting international partners and organisations to share in its development and use. PEEX will be a major factor integrating the social and natural science communities to work together towards solving the major challenges influencing the wellbeing of humans, societies, and ecosystems in the PEEX region.

CONTENTS

1.PEEX OBJECTIVES AND GRAND CHALLENGES



SYNOPSIS. Solving of any of the Grand Challenges requires a multiscale – multidisplinary research programme linked with the fast track policy making.

Pan-Eurasian Experiment (PEEX) is contributing to the global scale grand challenges in the Northern Pan-Eurasian context. The PEEX approach emphasis the converging understanding of the physical and socio-economic processes in land-atmosphere-ocean-anthropogenic continuum in a changing pristine and urban environments of the Northern (45 N *lat or higher*) and the Arctic regions. PEEX initiative aims to be a next generation natural sciences and socio-economic research initiative having a major impact on the future environmental, socio-economic and demography development of the Arctic and boreal regions and to be a science community building novel infrastructures in the Northern Pan Eurasian region.

Earth system is facing several global scale environmental challenges, called as "Grand Challenges". Grand Challenges are the main factors controlling the human well-being, security and stability of the future societies. All the Grand Challenges are interlinked via complex feedbacks in the Earth System. The dynamics of Grand Challenges are driven by "G*lobal forces" identified as* (i) demographics, (ii) increasing demand for natural resources, (iii) globalization and (iv) climate (Smith 2010). The global forces are strongly geographically orientated phenomena's shifting from one region to another, migration trends of human populations, variations in the availability of natural resources, the capital flows of the economics, and diverse impacts of the global mean temperature increase.

Pan-Eurasian Experiment (PEEX) is contributing to the grand challenges in the Northern Pan-Eurasian context. PEEX initiative consists of four main focus areas, each of the focus area having a specific objective:

Focus-1 PEEX Research agenda

- **to understand the Earth system and the influence of environmental and societal changes in pristine and industrialized Pan-Eurasian environments. Especially, PEEX aims to determine the processes relevant to the climate change in the Pan Eurasian region.**

Focus-2 PEEX Infrastructures

- **to establish and sustain long-term, continuous and comprehensive ground-based airborne and seaborne research infrastructures, and to utilize satellite data and multi-scale model frameworks. The data sets and archives will be developed and utilized in a joint manner. Validated and harmonized data products will be implemented to the models of appropriate spatial and temporal scales and topical focus.**

Focus-3 PEEX Society dimension

- **to contribute to regional climate scenarios in the northern Pan-Eurasia and determine the relevant factors and interactions influencing human and societal wellbeing. Furthermore, it will assess the natural hazards (foods, forest fires, air pollution, extreme water events, risks for structures built on permafrost) related to cryospheric changes in the PEEX domain and provide**

information for the adaptation and mitigation strategies for sustainable land-use, energy production and human well-being.

Focus-4 PEEX Knowledge Transfer

- **to promote the dissemination of PEEX scientific results and strategies in scientific and stake-holder communities and policy making, to educate the next generation of multidisciplinary global change experts and scientists, and to increase the public awareness of climate change impacts in the Pan-Eurasian region.**

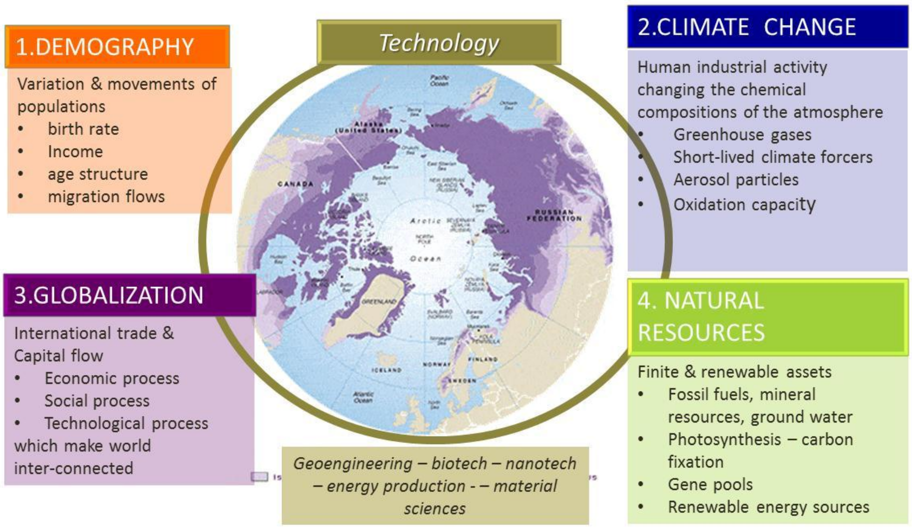


Fig.2 Global forces modifying the Northern regions future (Lappalainen based on Smith 2010)

2 MOTIVATION

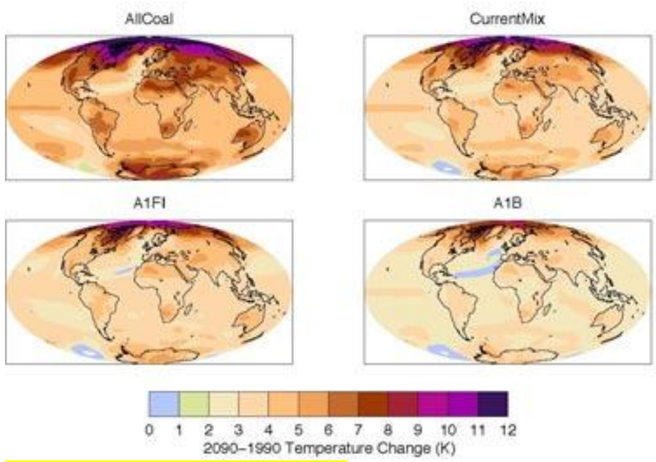


Fig 3. 1. IPCC –2013 UPDATE !!!

SYNOPSIS: PEEX initiative is motivated by the fact that the Northern regions, land and ocean areas located at 45°N latitude or higher, will undergo substantial changes during the next 40 years. Even the most moderate climate scenarios predict that the northern high latitudes will warm 1.5 C -2.5 °C by the mid of century and 3.5 C by the end of the century, which is more than double compared to the global average warming (ref. IPCC 2013

To cope with the climate change in a global scale and with the transformations of civilizations and ecosystems, is one of the ultimate challenges of the 21st century. Solving any of the grand challenges, such as climate change, requires framework, where the multidisciplinary scientific approach (i) *has the critical mass* and (ii) *is vitally connected to the fast track policy making*. It is also important to ensure

the sustainable development of the sensitive environments and societies of the Northern regions. This can be done by establishing coherent research infrastructures and educating programs and increasing public awareness of environmental related matters.

The Northern regions, land and ocean areas located at 45°N latitude or higher, will undergo substantial changes during the next 40 years. Even the most moderate climate scenarios predict that the northern high latitudes will warm 1.5 C -2.5 °C by the mid of century and 3.5 °C by the end of the century, which is more than double compared to the global average warming (ref. IPCC <UPDATE>) (Fig.3). One of the most stimulating visions related to Arctic warming has been the opening of the Northern sea route for shipping between the Atlantic and Asia's Far East (Fig.4). The Arctic Ocean is ice-covered preventing ship traffic from October to June. For most of the year, the sea is covered with ice, but the amount of sea ice has been declining rapidly. The predicted shortening of the ice cover period draws attention to the capitalized natural resources. The future role of the natural resources of the Arctic Sea for the global energy market will be significant because it may hold 25% or more of the world's undiscovered oil and gas resources (Yenikeyeff & Krysiek 2007)

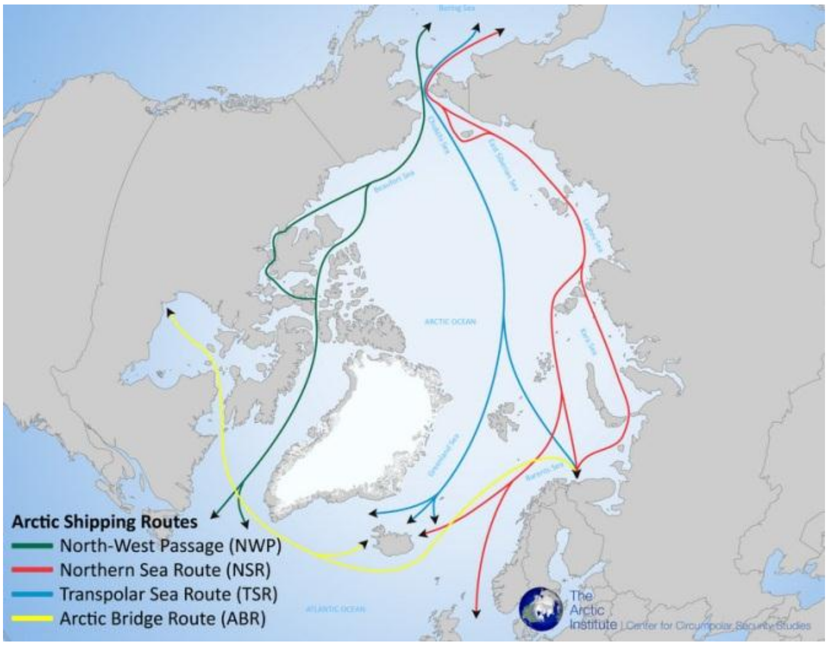
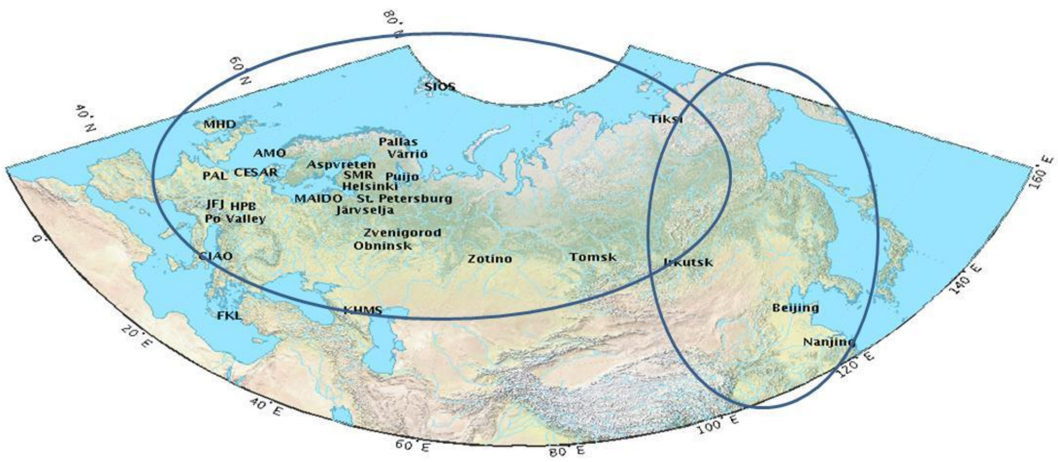


Fig.4 Expected shipping routes in the Arctic (The Arctic Institute)

Along with these trends of the human activities in the North, ecosystems will undergo significant changes, including appearance of invasive species or extinction of existing ones, changes in ecosystem productivity and structure, and modifications in their roles as sinks or sources of climatically relevant gases of vast areas boreal forests and peat lands (Smith 2010). These ecosystem changes may have unpredictable consequences on e.g. food webs or interactions between different ecosystems and human activities. In addition to the large scale aspects related to global change, the regional societal dimension includes e.g. the durability of the infrastructure (power networks, buildings, ice roads) built on the thawing permafrost areas and issues related to ensuring the living conditions and culture of aboriginal people living in the North.

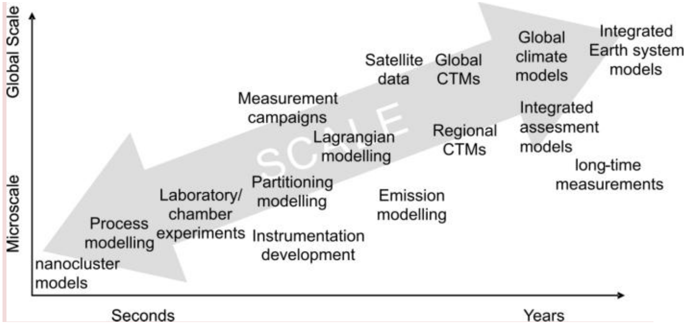
Motivation to study the Northern Pan Eurasian Arctic-boreal system lies on the fact that major part of the areas critical for the climate change process is situated in the territories of Russian and China. Vast areas of the permafrost regions and boreal forest (taiga) zone are situated in Siberian. Thawing of permafrost and shifting of the taiga zone towards North will have significant consequences on the climate system. The most important driving force will be the predicted changes in (i) the sources and sinks dynamics of GHG (greenhouse gases) and (ii) the BVOC (Biogenic volatile organic compounds) emissions. The taiga forests and peat land in Siberian cover significant part of the global GHG emissions at the moment. BVOC are contributing the atmospheric aerosols and cloud formation processes and the emission volume is linked the boreal forest areas and the structural changes of forest ecosystems. The other geographical area dominating the acceleration of climate change is the Arctic Ocean and its maritime environments. Changes in taking place in the Arctic sea ice will have both short term and long-term large scale effects. The oceanographic changes in the Arctic Sea; sea ice coverage, arctic water flows and masses are tele-connected to global climate and weather dynamics.



Station network, remote sensing, multiscale modelling
Supradisciplinary

Fig. PEEX geographical domain (figure to-be-updated).

3 PEEX RESEARCH AGENDA (F1)

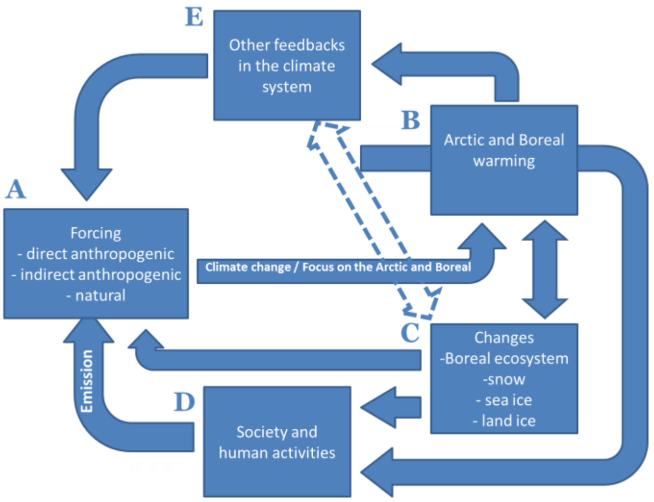


PEEX research agenda is designed as a research chain that aims to advance our understanding the interactions of the land- atmosphere-ocean-anthropogenic systems through a series of connected activities beginning at the molecular scale and extending to the regional and global scale

Fig. multidisciplinary – multi scale research chain- method (Kulmala et al. 2010

PEEX Research agenda underlines *(i) the holistic understanding of the impacts and feedbacks* to Climate and Earth system and impacts on biogeochem cycles in Northern Pan Eurasian region, but also *(ii) highlights the key topics related to land – atmosphere- aquatic – anthropogenic systems*. PEEX research outcome is utilized for producing new climate scenarios, natural hazards - warning services and mitigation and adaptation strategies. PEEX research agenda introduces the large-scale key topics of the land-atmosphere-aquatic-anthropogenic systems. The key topics of different systems are interlinked and complex feedbacks which are studied by a multidisciplinary – multi scale research chain- method (Kulmala et al. 2010). Processes are studied from pristine and industrialized in the Arctic and the Northern Pan-Eurasian environments.

3.1 LARGE SCALE RESEARCH SCHEMATICS OF THE ARCTIC-BOREAL REGION



SYNOPSIS. PEEX research agenda is focused on understanding the complex interlinked land - atmosphere-ocean-society system in the Arctic and Northern Pan-Eurasian context. PEEX will study the changes and processes *driven by interlinked forces:* A) Radiative forcing, B) Arctic warming, C) Changes in the cryosphere, D) Society and human activities, E) Feedbacks in the climate system, F) Feedbacks in biosphere system.

Fig.6 PEEX large scale schematics addresses strong role Both the Arctic and the boreal regions.

The future Arctic climate change, including the role of the boreal forest is a specific issue for the Northern science communities and societies (Fig.6). There is no clear understanding why climate changes so fast in the Arctic, and whether the amplified Arctic warming will continue at the same rate in the future (Lu and Cai, 2010).

PEEX research agenda is built on holistic understanding the complex feedback system sustaining the warming of the Northern regions and to quantify the most curial driving forces. The main components of the system are the Arctic Ocean, different ecosystems of the Northern Pan-Eurasian regions and the Northern societies. Climate change is upsetting the dynamics of the whole global climate system (E) inducing the warming of the Arctic and vast regions of boreal forests (B). One of the major consequences of warming in the Northern latitudes is the changes in the cryosphere and the Arctic Ocean, especially the quantitative and qualitative changes in snow and ice coverage (C). The warming of the Northern regions will affect the societies and human action (D). The economic growth related to like demography trends; urbanization, trade and use of natural resources would further hasten the anthropogenic emissions and strengthen the forcing factors of the Arctic-Nordic system (A).

3.1.1 ARCTIC-BOREAL DOMAIN IN THE EARTH SYSTEM

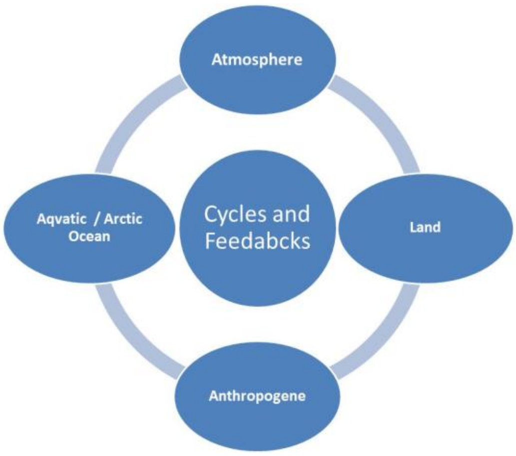


Fig.7

SYNOPSIS. One of the acute topics in the international debate on land-atmosphere interactions in relation to Global Change is the Earth System Modeling. The question is whether our model components actually represent how the Earth is functioning. The EMSs are the best tools for analyzing the effect of different environmental changes on future climate or for studying the role of whole processes in the Earth System. These types of analysis and prediction of the future change are especially important in the high latitudes of Arctic, where climate change is proceeding fastest and where near-surface warming has been about twice the global average during the recent decades.

Earth System Models consist of equations describing the processes within and among the atmosphere, ocean, cryosphere, and the terrestrial and marine biosphere (Fig.7). These models are the best tools for analyzing the effect of different environmental changes on future climate or for studying the role of whole processes, and interactions and feedbacks in the Earth System. These types of analysis and prediction of future change are especially important in the high latitudes of Arctic, where climate change is proceeding fastest and where near-surface warming has been about twice the global average during the recent decades.

The processes, and hence parameterization, in Earth System Models (ESMs) are still based on insufficient knowledge of physical, chemical and biological mechanisms involved in the climate system and the resolution of known processes is insufficient. Global scale modeling of land-

atmosphere-ocean interactions using ESMs provides a way to explore the influence of spatial and temporal variation in the activities of land system and on climate. We lack, however, ways to advance the necessary process understanding effectively to the ESMs and to link all this to the decision making process. The Arctic-boreal domain plays a significant role in terms of GHG and anthropogenic emissions and as an aerosol source area in the Earth System.

3.1.2 PEEX LARGE SCALE RESEARCH QUESTIONS AND KEY TOPICS

The large scale research questions (PEEX-Q) of the main systems and the interactions-feedbacks are listed here. Each of the large scale research questions is introduced as a Key Topic of PEEX Research agenda.

LAND SYSTEM

- **Q-1 How could the land regions and processes, shifting of vegetation zones, especially sensitive to climate change be identified and what are the best methods to analyse their responses?**
- ***Key Topic: Shifting of vegetation zone , see Chapter 3.2.1***
- **Q-2How fast will the permafrost thaw proceed and how will it affect ecosystem processes and ecosystem-atmosphere feedbacks, including the hydrology and greenhouse gas fluxes? '**
- ***Key Topic: Risk areas of permafrost thawing, see Chapter 3.2.2***
- **Q-3 What are tipping points in the future evolution of the Pan-Eurasian ecosystem changes?**
- ***Key Topic: Ecosystem structural changes, see Chapter 3.2.3***

ATMOSPHERIC SYSTEM

- **Q-3 What are the critical atmospheric physics and chemistry processes with large scale climate implications?**
- ***Key Topic: Atmospheric Composition and Chemistry, see Chapter 3.3.1***
- **Q-4 Quantification of the feedbacks between air quality and climate at Northern high latitudes**
- ***Key Topic: Urban air quality, megacities and changing ABL, see Chapter 3.3.2***

  Q-5 How will the atmospheric dynamics (weather; synoptic, BL) change in the Arctic – boreal regions?
- ***Key Topic: Weather and atmospheric circulation, see Chapter 3.3.3***

AQUATIC SYSTEMS – THE ARCTIC OCEAN

- **Q-6 How will the Arctic sea ice extend, snow cover and permafrost, change with changing climate and what are the connection to the climate system?**
- ***Key Topic: the Arctic Ocean in the climate system, see Chapter 3.4.1***
- **Q-7 What is the joint effect of the arctic warming, the pollution load and acidification on the arctic marine ecosystem, mainly on the primary production (algal blooms and the following sedimentation, i.e. carbon sink)?**
- ***Key Topic: The Arctic maritime environments , see Chapter 3.4.2***
- **Q-8 What is the future role of the arctic-boreal lakes and large river systems in biogeochemical cycles (incl. thermokarst lakes and running waters of all size) and how will these changes affect societies (livelihoods, agriculture, forestry, industry)?**
- ***Key Topic: Lakes and Large scale river systems in Siberian region , see Chapter 3.4.3***

ANTHROPOGENIC SYSTEM

- **Q-9 How will human actions (land-use changes, energy production; efficiency, use of renewable energy sources) influence further environmental change in the region?**
- ***Key Topic: Anthropogenic impact, see Chapter 3.5.1***
- **Q-10 How do the fast the changes in physical, chemical and biological state of the different ecosystems, inland water, coastal areas affect the economies and societies in the region and vice versa?**
- ***Key Topic: Environmental impact, see Chapter 3.5.2***
- **Q-11 In what ways are socio-economic areas vulnerable to climate change and how can their vulnerability be reduced and their adaptive capacities improved? What responses can be identified to mitigate and adapt to the climatic changes?**
- ***Key Topic: Natural hazards, see Chapter 3.5.2***

FEEDBACKS – INTERACTIONS

- **How will the changing permafrost conditions affect the Arctic climate system?**
- **Improving the understanding of biogenic aerosol formation and feedback processes?**
- **How intensive urbanization processes are changing local and regional climate and environment?**
- ***Key topics: Biogeochemical cycles; water, C, N, P, S, See Chapters 3.6.1-3.6.5***

3.2 ARCTIC-BOREAL LAND SYSTEM – KEY TOPICS

3.2.1. SHIFTING OF VEGETATION ZONE

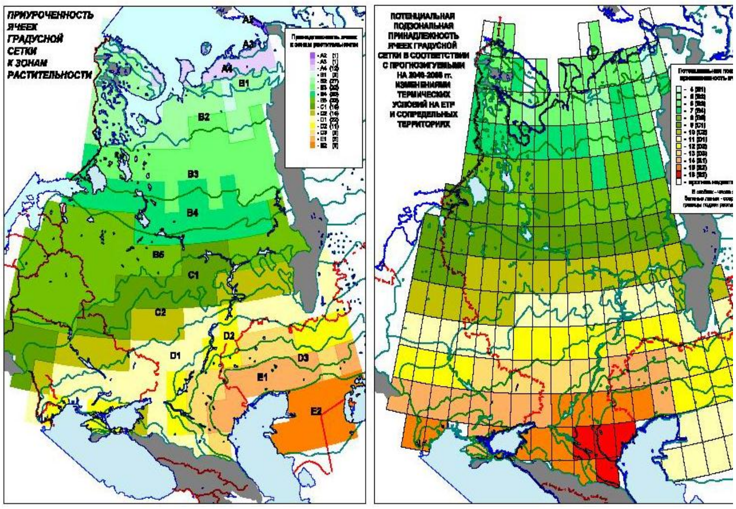


Fig 8. Zones of vegetation: observed (left) and potentially projected at 2046-2065 years (right) (Chubarova).

SYNOPSIS. The PEEX geographical domain is characterized by tundra, boreal forest and wetlands. Expected climate change and increasing anthropogenic pressure will provide substantial redistribution of bioclimatic zones with following changes in structure, productivity and vitality of terrestrial ecosystems and their impact on the Earth system. The predictions on shifting of vegetation zones are important for estimating the impacts of the region on future global GHG, BVOCs and aerosols budgets.

Q-1 How could the land regions and processes, shifting of vegetation zones, especially sensitive to climate change be identified and what are the best methods to analyse their responses?

Larger scale vegetation shifts are anticipated with climate change in Arctic-boreal region. Predictions of this process are diverse (Tchebakova et al. 2009; Hickler et al. 2012; Shvidenko et al. 2013. It is estimated that the shift of bioclimatic zones in Siberia northward will be as far as 600 km by end of this century (Tchebakova et al. 2009). Taking into account that the rate of natural migration of boreal tree species does not exceed 200-500 m per year, such a forecast promises a high risk of death of forests on huge areas of the southern part of the region. Some other models predict substantial but less dramatic changes (Yan & Shugart 2005; Gustafson et al. 2010). Nevertheless, all the models forecast pronounced changes in the vegetation cover affecting forest distribution, vitality and productivity, carbon and water cycles of ecosystems (Fig.8), and consequently intensity and composition of greenhouse gas fluxes and BVOC emissions and concentrations (Noe et al. 2011 and 2012, Walter et al. 2006; Zimov et al. 2006; Schuur et al. 2008). Circumpolar sub-arctic and boreal zones are internationally recognised due to their exceptional importance in terms of expected ecological and social change, climate feedbacks, transformation of vegetation, and the impacts on life of indigenous people (26 nations of the total population of 91 thousand persons in 2008). Large scale changes in the structure and location of this zone will affect the total northern environment with its people, landscapes and sustainability of resource use.

***Boreal* forests form one of the largest terrestrial biome and account for around one third of the Earth's forested area (Global Forest Watch, 2002). Nearly 70% of boreal forests of the world are situated in Siberian region. With a large fraction of forest surface area (800x106 ha) and its huge stocks of carbon (~320 GtC), Siberia is a significant player of the global carbon budget. Potential for managed carbon storage in ecosystems exist (Kurganova et al., 2010). Permafrost, a dominant feature of Siberian landscapes, stores ~1672 GtC (Tarnocai et al., 2009). But its ecosystems are vulnerable to global climate change through modification of the balance between Net Primary Production and respiration in a warmer climate, release of carbon by permafrost melting and an increase in wildfires. Siberian forests are currently assumed to be a sink, although with a large uncertainty (range 0-1 PgC yr^{-1}; Gurney et al., 2002) due to data scarcity for atmospheric inversions. Atmospheric inversions infer surface fluxes from measured atmospheric CO_2 concentration gradients using atmospheric tracer transport models. But the scarcity of observations and unknown biases in tracer transport models affect CO_2 inversions ('rectifier effect', Denning et al., 1999). Siberia, with its large forested area and highly seasonal CO_2 flux and transport, is a 'hot-spot' of CO_2 transport model uncertainties (Gurney et al. 2002).**

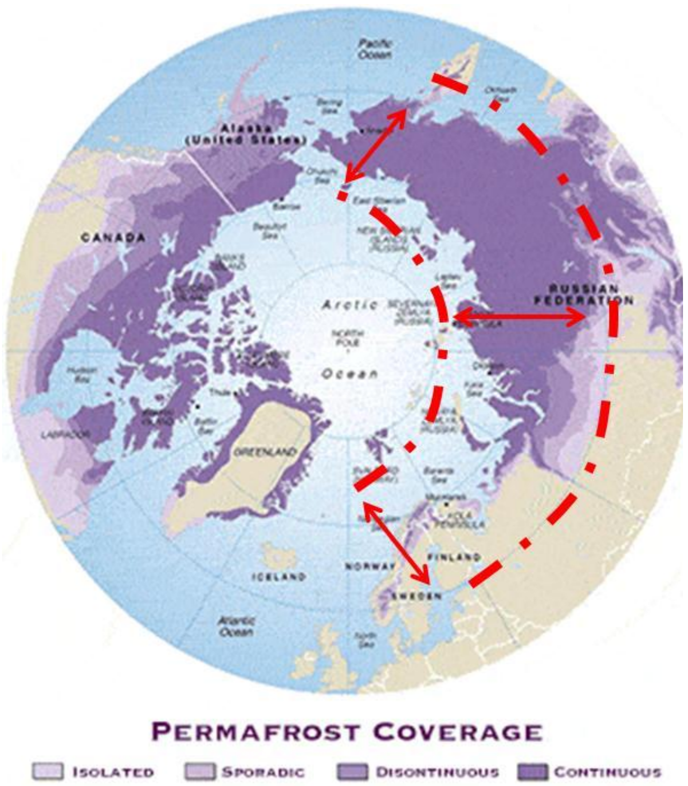
Taking into account conditions of evolutionary development of this forest formation and the expected level of warming in the Northern Eurasia boreal zone, it is difficult to properly estimate resilience thresholds of boreal forests under the future warming. Due to current understanding they should be considered as one of tipping elements of the biosphere (Lenton et al. 2008). Boreal forests form the main vegetation zone in the catchment areas of large river systems, and thus are also an important part of global water-energy-carbon interactions. The boreal forests in high latitudes of Siberia are a vast, rather homogenous ecosystem dominated by larch (of the total area of ~260

million ha, or almost one-third of Russian forests). Larch forests survive in the semi-arid climate because of a unique symbiotic relationship they have with permafrost. The permafrost provides enough water to support larch domination and the larch in turn blocks radiation, protecting the permafrost from intensive thawing during the summer season. The anticipated thawing of permafrost could decouple this relationship and may cause a strong positive feedback, intensifying the warming substantially (REF).

Peat lands occupy a relatively small fraction, about 3%, of the Earth's land area, but they are a globally important *carbon* storage and especially important in the boreal regions and high latitudes (Frolking et al. 2011). The storage of carbon in peat of the 1 m top layer of soil cover in Russia is estimated about 115 Pg C (Schepaschenko et al., 2013). The processes underlying CH_4 emissions are complex and depend on several climate-, landscape- and vegetation-related variables, such as inundation, depth of water table, vegetation composition and soil temperature. Peat lands fell under extensive management already in distant past (O'Sullivan 2007), with the activities ranging today from drainage and peat harvesting to establishing crop plantations and forests. Complete understanding of climatic effects of peat land management remains a challenging question, although there are reasons to expect an overall negative effect (Maljanen et al. 2010).

As summary forest biomass and peat lands in the boreal forest zone together make up one of the world's largest carbon reservoir (Bolin et al., 2000; Kasischke, 2000; Schepaschenko et al. 2013). The storage was built over centuries due to rather favourable conditions for carbon assimilation by vegetation and the simultaneous low temperatures, restricting microbial decomposition. The forest biomass forms a positive climatic feedback via the anticipated changes in nutrient availability and temperatures, impacting carbon sequestered both into the aboveground biomass and the soil compartment. However, expected acceleration of fire regimes in Northern Eurasia might substantially impact this process (Shvidenko & Schepaschenko 2013).

3.2.2 RISK AREAS OF PERMAFROST THAWING



SYNOPSIS. The major part of Northern Pan-Eurasian geographical region is covered by continuous permafrost (Fig.9). Eeven small proportional permafrost changes in the turnover of the soil carbon stocks will reverse the terrestrial carbon sink to a source with a consequent increase in the atmospheric CO_2 concentration if the photosynthetic production of the forest is not increased simultaneously. The fate of permafrost soils in tundra is important for global climate in regards to all greenhouse gases. These scenarios underline urgent need of systematic permafrost monitoring together with GHG measurement in various ecosystems. ***The treatment of permafrost conditions in climate models is still not fully developed. Therefore, the estimated rapid changes in climate projections in regions with permafrost are likely overestimated.***

Fig.9 The Arctic permafrost: darker shades of purple indicate larger percentages of permanently frozen ground. Lighter purples, and the terms isolated and sporadic, refer to lower percentages of frozen ground. Map by Philippe Rekacewicz, UNEP/GRID-Arendal; data from International Permafrost Association, 1998. Circumpolar Active-Layer Permafrost System (CAPS), version 1.0.

Q-2 How fast will the permafrost thaw proceed and how will it affect ecosystem processes and ecosystem-atmosphere feedbacks, including the hydrology and greenhouse gas fluxes?

Permafrost (ground temperature at or below 0^oC > 2 years) is very typical characteristic of the Arctic occupying; 25% of land area in the Northern Hemisphere and 50% of land area in Russia and Canada. With climate warming also permafrost is getting warmer and thawing. The terrestrial biosphere is a key regulator of atmospheric chemistry and climate via its carbon uptake capacity (Arneth et al 2010, Heimann & Reichstein 2008). The Eurasian area holds a large pool of organic carbon both in the soil and frozen ground, stored during Holocene and the last ice age and within the living biota (both above and belowground) but also a vast storage of fossil carbon. The soil carbon storage of the circumpolar northern high latitude terrestrial ecosystems is estimated to be between 1400 and 1850 Pg (McGuire et al. (2009), Tarnocai et al. (2009)) in the upper three meters of soil. About 400 Pg of carbon is located in currently frozen soils that was accumulated in no glaciated regions during the Pleistocene, in what was then steppe–tundra vegetation (Zimov et al. (2006)), and ca.250 PgC may be stored in deep alluvial sediments below 3m in river deltas of the seven major Arctic rivers (Schuur

et al., 2008). Due to these large storages, even small changes in processes influencing carbon release and emissions can have significant impact on the behavior of global climate.

In high-latitude ecosystems with large, immobile carbon pools in peat and soil, the future net CO_2 and CH_4 exchange will depend on the extent of near-surface permafrost thawing, the local thermal and hydrological regimes and interactions with the nitrogen cycle (Tharnocai et al 2009). The extra heat produced during microbial decomposition could accelerate the rate of change in active-layer depth, potentially triggering a sudden and rapid loss of carbon stored in carbon-rich Siberian Pleistocene loess (yedoma) soils (Khvorostyanov et al 2008).

Hot spot CH_4 emitting mud ponds may form when permafrost mires thaw. On the contrary, lakes have disappeared as a result of intensification of soil water percolation resulting (Smith et al., 2005). The fast summer ice loss, together with increasing temperature and melting Ice Complex deposits, results in coastal erosion, activation of old carbon and elevated CO_2 and CH_4 emissions from sea bottom sediments (Vonk et al., 2012). High methane emission has been observed from the East Siberian Arctic Self (Shakhova et al., 2010).

The connection between the thermal and climatic conditions of the subsurface layers (soil and bedrock) in an extremely important aspect in the forthcoming decades. The warming in the atmosphere will inevitably result in warming of the permafrost layer and is easily observed in deep borehole temperature data (Fig. 10). However, the changes depend on the soil and rock type as well as the pore-filling fluids. As long as the pore-fill is still ice the climatic changes are reflected mainly in the thickness of the active layer and slow diffusive temperature changes of the permafrost layer itself. In areas where the ground is dominated by low ground temperatures and thick layers of porous soil types (e.g., sand, silt, peat), the latent heat of the pore filling ice will efficiently 'buffer' and retard the final thawing efficiently. This is one of the reasons why relatively old permafrost exists at shallow depths in high-porosity soils. On the other hand, quite different conditions results prevail in low-porosity areas, e.g. in crystalline rock areas.

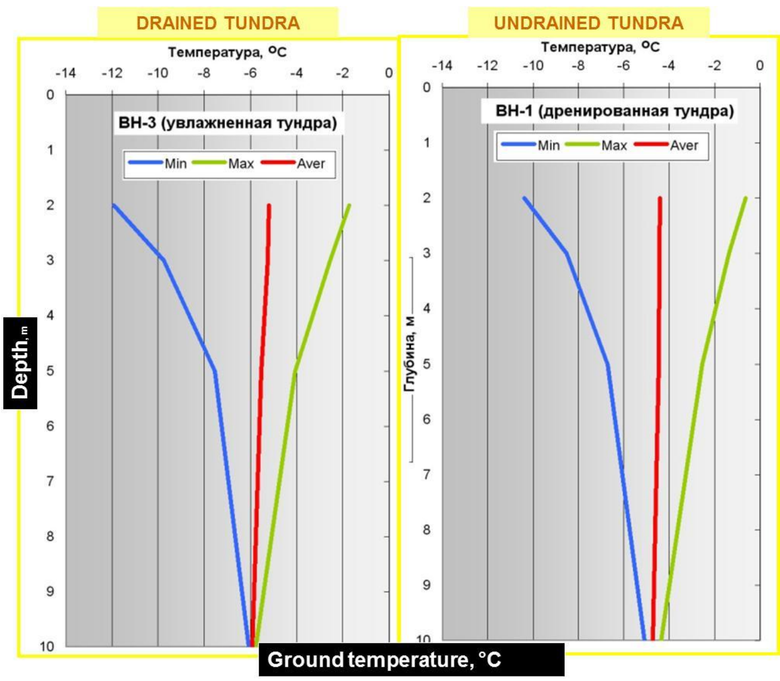
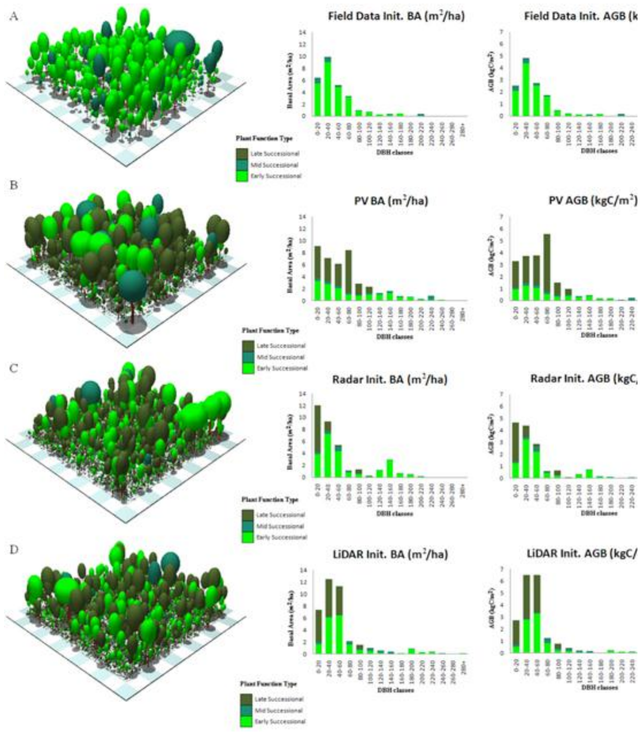


Fig.10 Annual ground temperature in bore holes at Yamal, Russia (Melnkov).

3.2.3 ECOSYSTEM STRUCTURAL CHANGES



SYNOPSIS. The large variations and significant temporal trends of climatic indicators influence the composition and functions of all boreal ecosystems. Global forests will be at the risk of undesirable transformation under increasing in global average temperature above 2ºC (IPCC 2007). Very likely, this threshold will be exceeded by end of this century. Many of the species found in boreal ecosystems are living at the edge of their distribution, and are susceptible to even moderate changes in their environment. In these regions the natural and anthropogenic stresses such as land use changes and disturbances are shaping the ecosystems and have many important feedbacks to climate. The ecosystem structural changes are tightly connected to the adaptation needs and development of effective mitigation and adaptation strategies.

Fig.11 Template figure – ecosystem structural changes (Harvard University).

Q-3 What are tipping points in the future evolution of the Pan-Eurasian ecosystem changes?

The exchange of energy and material impacts ecosystems and their environment and the environment impacts the ecosystems. Excessive variability and trend changes of the environment impact the species distribution and diversity, succession regularities, structure, growth, productivity, fertility of ecosystems, as well as biotic and abiotic stressors on multiple timescales (e.g., Lapenis et al. 2005; Gustafson et al. 2010; Shvidenko et al. 2013). At the same time, boreal vegetation is exposed to increased anthropogenic influence by pollutant deposition and land use changes (Dentener et al., 2006; Bobbink et al., 2010, Savva & Berninger 2010). To predict dynamics of ecosystems and be unable to get proper estimates of GHG, BVOC and reactive trace gas fluxes, both current and future, it is necessary to investigate ecosystems' structural changes over long periods of time. The spatial scale of the changes could be different – from the biome level to individual plants.

One example of an ecosystem structural change and the climatic feedbacks is the reaction of the plant cover to rising CO_2concentrations. While higher ambient CO_2 concentrations increase plant growth and productivity (e.g. Ciais et al. 2005), several other feedbacks can also be important as regards to climatic effects. A recent study (Sun et al, 2013) shows, that on a whole plant canopy

scale, the stimulated growth under doubled atmospheric CO_2 concentration can compensate for eventual reductions in the BVOC formation rates. Also, thawing of permafrost in tundra might change tundra ecosystems from stable state into dynamically changing and alternating land-water mosaic, and the impacts on GHGs cycling may strongly depend on such changes.

The other example is, how the degradation and progradation of soil and vegetation cover, as well as subsequent permafrost transformation, is caused by changes in domestic and wild reindeer populations in tundra and forest-tundra of the North. On the other hand, agrogenic and post-agrogenic changes of permafrost-affected soils and landscapes in the regions with cold ultra-continental climates and the consequences of these changes on the carbon dynamics are an important question to tackle (AMAP, 2009). Due to the temperature increase, there are multiple effects in the soil-vegetation-snow environment. For example, due to warmer climate, mosses and other vegetation grow faster, which provides better thermo insulation of the permafrost in summer and better feeding conditions for reindeers. However, snow can easily accumulate on thicker vegetation, thus protecting deeper soil from cooling during the winter (Tishkov 2012).

The third example is, how the increase in average temperature by 4-6^{0}C during the growth period at the end of 21st century will change the state of ecosystem carbon balance in tundra. The adaptation process of tundra ecosystems to the new temperature conditions possibly will proceed during decades and will be accompanied by acceleration not only in GHG emissions but also in increasing of gross primary production. Expected changes will require developments of a new generation of different vegetation models. The range of such models is large - from landscape models of successions and disturbances coupled with ecophysiological models which would include zones of critical changes of climatic and environmental indicators (Gustafson 2013) to models describing how the microbes in permafrost will respond to thaw, through the processes such as respiration, fermentation, methanogenesis, methane oxidation and nitrification-denitrification.

Northern ecosystems evolutionary developed under stable cold climate and their thresholds and buffering capacity are unknown. This is particularly important for boreal forests due to the long period of life of major forest forming species that limits their adaptation capacity. Very likely, that boreal forests of Northern Eurasia will be specially affected due to (i) dramatic changes of heat and hydrological regimes over huge territories caused by permafrost melting; (ii) sensitivity of boreal forest ecosystems to warming and the high rates of expected worming in the region (up to 7-10 ºC in the regions of continental Asia); and (iii) dramatic acceleration of disturbance regimes, particularly fire, outbreaks of insects and diseases, coupled with the tough anthropogenic impacts (Shvidenko et al., 2013). The warming and insignificant change of precipitation during growth periods will substantially increase water stress and following massive mortality of trees. This process is already clearly intensified over the entire circumpolar boreal belt (Allen et al. 2010)

ECOSYSTEM STRUTURAL CHANGES – Research Questions

There is no fundamental understanding how trees and forest ecosystems would function in dynamic conditions under multiple restrictions on vital resources

- **How much stable is the direct stimulation of photosynthesis and NPP by such changes of environment?**
- **How much limitations of nutrients limit CO2 fertilization effect and how long the impact of such limitations remains substantial?**

- **To what extent nitrogen deposition could mitigate the lack of available nitrogen in ecosystems of high latitudes?**
- **How these changes interact with the hydrological cycle? These and other questions should be considered within PEEX research program.**

Wildfires. Wildfires strongly influence boreal forest structure and function, as they can result in losses of 15% – 35% of above-ground biomass and 37% – 70% of on-ground organic layers (Yarie and Billings 2002, Shorohova et al. 2009). Release of carbon from fires and insect disturbances in Siberia is currently about 6 % of the net primary productivity, NPP (Shvidenko et al. 2013). Fires create large amounts of woody debris that release carbon (Kolari et al. 2004) and may change stands from carbon sinks into sources for decades after the fire. Current estimates show that the carbon flux due to decomposition of the coarse woody debris in Russian forests is about 175 Tg C year^{-1} (Shvidenko & Schepaschenko 2014). At present about 0.8% of the boreal forest burn each year and both stand replacing and intermediate severity fires are widely distributed in Eurasia (Conard et al. 2002, Kasischke et al. 2005, Bond-Lamberty et al. 2006). Warming of the last decades in Asian Russia substantially increased the occurrence of catastrophic fires which envelope tens and hundreds thousands hectares within large geographical regions (Shvidenko and Schepaschenko 2013). Dependently on type and severity, fire consumes the understory and moss layers along with a portion of the humus pool and with a portion of the total C stored in the O horizon (DeLuca and Boisvenue 2012) and may cause post fire mortality up to 70-90% of growing stock volume. In case of fire the amount of C in mineral soil remains unchanged (Seedre et al. 2011) but impacts heterotrophic respiration substantially (Mikhortova et al. 2014) . Fire alters the microbial biomass and species composition structure e.g. by reducing significantly the abundance of decomposing bacteria (Hart et al. 2005) and fungi (Allison and Treseder 2008), which regulate the transfer of C from terrestrial ecosystems to the atmosphere via the decomposition of soil organic matter in soil (Dooley and Treseder 2012, Holden et al. 2012) and thus are likely to play a major role in mediating indirect fire feedbacks to the C dynamics. Fungi in boreal forests are particularly important as they can degrade and mineralize organic material in soils with low soil pH (Högberg et al. 2007). Ash deposition following fires increases soil pH (Peay et al. 2009), which may also result in decline in fungal biomass and changes in their diversity. In the long-term run, fire substantially impacts succession regularities and species composition of forests (Vaschuk & Shvidenko 2006).

3.3 ARCTIC-BOREAL ATMOSPHERIC SYSTEM –KEY TOPICS




3.3.1 ATMOSPHERIC COMPOSITION AND CHEMISTRY

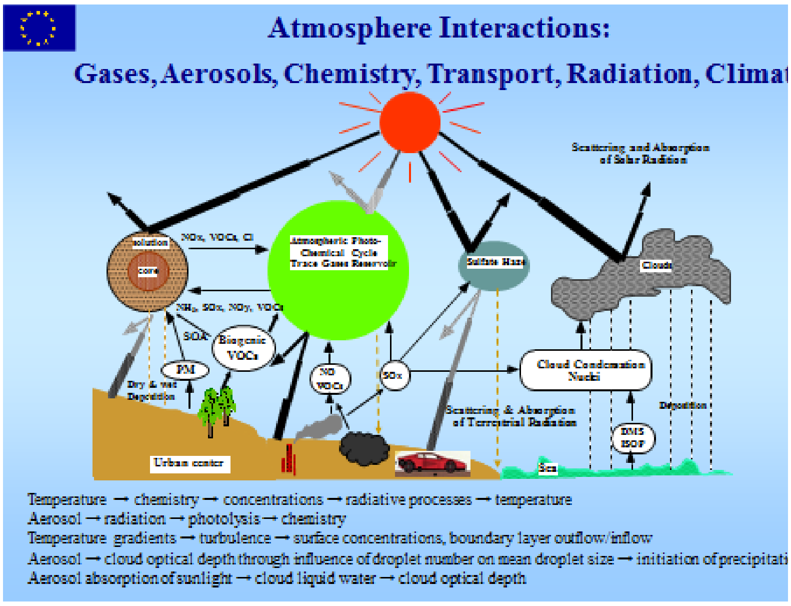


Fig. 12 Atmospheric system – interactions (Baklanov)

SYNOPSIS. The largest anthropogenic climate forcing agents are greenhouse gases (GHGs) and aerosol particles. Especially in the Arctic, there are also several possible amplifying feedbacks related to aerosols and GHGs which are expected to follow the changing climate. Furthermore, Arctic environment is also highly sensitive to changes in aerosol concentrations and composition, largely due to the high surface reactance for the most part of the year. Concentrations of aerosols in winter and spring Arctic are affected by 'Arctic Haze' (Shaw, 1995); a phenomenon suggested to arise from the transport of pollutants from lower latitudes e.g. (Stohl, 2006) and further strengthened by the strong stratification of the Arctic wintertime atmosphere (Asmi 2012).

Q-3 What are the critical atmospheric physics and chemistry processes with large scale climate implications?

3.3.1.1 ATMOSPHERIC GHG

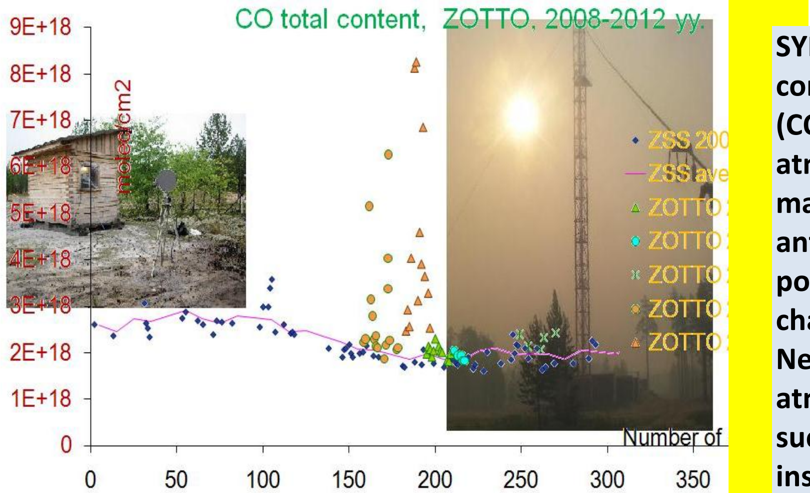


Fig 11. CO and CH_4 total content at ZOTTO-station, (Elansky).

SYNOPSIS. There is an urgent need to (i) better constrain the sources and sinks budget of GHG (CO2, CH4) in Siberia and (ii) quantify the atmospheric impact of CH4 emissions over the major natural (wetlands, permafrost) and anthropogenic sources and (iii) observe short lived pollutants (CO, O3, BC, fine particles) to characterize long range transport across Eurasia. New data of GHGs are need to validate atmospheric models, land flux models. The succesfull approach requires space-borne instruments over Siberia, a vast under-documented region and characterize local sources, esp. forest fires, and their impact on regional air quality and in the Arctic.

Very few measurement programmes exist over Siberia to document the tropospheric composition (Crutzen et al., 1998; Ramonet et al., 2002; Paris et al., 2008; Sasakawa et al., 2010; Kozlova et al., 2008). Therefore, large uncertainties currently surround our knowledge about biogeochemistry and the distributions/emissions of compounds important for tropospheric chemistry and climate change. Relevant species that require further measurements include CO_2 and CH_4 for biogeochemical cycles, and CO, O_3, and aerosols including black carbon for tropospheric composition. Other tracers need

further investigation, including stable isotopic composition of CO_2 and CH_4 for the attribution of sources and sinks of these species in the considered area.

High latitude biomes influence the global methane budget (Bousquet et al., 2006) in several ways, including wetlands emissions, reactivation of bacterial activity through permafrost melting (Zimov et al., 2006), thermokarst lakes bubbling (Walter et al., 2006) and potential destabilization of methane hydrates in coastal permafrost. In a warming climate, these altered processes are expected to feed back into the global radiative forcing and hence further enhance climate change. Our current understanding of the extent and amplitude of these sources, as well as the large scale driving factors, remain highly uncertain (Bloom et al., 2010). Anthropogenic emissions of CH_4 from leakages of natural gas pipelines are also not well quantified. In addition, as northern regions of Russia warm there is likely to be additional exploitation of natural gas reserves. As a result and due to the lack of regional observations, it can only be conjectured from zonal gradients that the recently resumed increase in global atmospheric CH_4 concentrations was initiated by unusually high temperature at high northern latitudes in 2007 (Dlugokencky et al., 2009).

Atmospheric pollutants released by human activities in mid-latitude industrialized regions of the Northern Hemisphere are quickly moved over long distances by atmospheric transport. Intercontinental pollution transport has become of increasing concern because of its effect on local and regional air quality levels. The main pollution transport pathways differ qualitatively between North Asia (including Siberia), Western Europe and North America. Model simulations show that European pollutants are predominantly dispersed eastwards over Siberia in summer, or North-eastwards towards Siberia and the Artic in winter (Stohl and Eckhardt, 2004, Wild et al., 2004; Duncan and Bey, 2004). Emissions from Europe remain mostly below 3000 m during transport eastwards and model studies undertaken as part of the Task Force on Hemispheric Transport of Atmospheric Pollutants (TF-HTAP), under the auspices of the Convention on Long-Range Transport of Air pollutants (CLRTAP) have shown that European pollution is a major contributor to background pollutant levels over Asia (e.g. Fiore et al., 2009). Whilst pollutant export from North America and Asia have been characterised by intensive field campaigns (Fehsenfeld et al., 2006; Singh et al., 2006), the export and long-range transport of European pollution across Siberia has received very little attention. Satellite provide information about spatial distributions but often retrievals have low sensitivity in the lower troposphere (Pommier et al., 2010) making validation against in-situ observations imperative. In addition, emissions from forest fires (van der Werf et al., 2006) and by prescribed agricultural fires in Southern Siberia, Kazakhstan and Ukraine (Korontzi et al. 2006) in spring and summer are large sources of trace gases such as CO (Nédélec et al., 2005) and aerosols which can have a significant impact on the chemical composition over Siberia, and more generally the CO budget of the NH (Wotawa et al., 2001). They also vary greatly from year to year. These pollutants can also be transported to the Arctic (Warneke et al., 2009) where they can influence the radiative budget. Deposition of absorbing black carbon aerosols on snow may also impact snowmelt and sea-ice melt in the Arctic.

Despite Siberia's vast dimensions and importance in the climate system, little is known about whether and how the regional O_3 budget differs from the rest of the Northern Hemisphere (Berchet et al., 2013). For example, O_3 production in boreal wildfire plumes seems to be weaker or to turn into net destruction, compared to fire plumes at lower latitudes (Jaffe and Wigder, 2012). This may be due to lower NO_x emissions and/or more sequestration of NO_x as PAN (peroxyacyl nitrates;

although PAN can produce O_3 downwind). Also, given their importance for atmospheric environmental issues and the global greenhouse gas budget, more atmospheric measurements of O_3, its precursors and other pollutants over Siberia are needed (see Elansky, 2012). These data are particularly useful for the validation of atmospheric chemistry models and satellite products. Emissions of NO_x, VOC (volatile organic compounds) from anthropogenic and biogenic sources is responsible for O_3 production and/or destruction downwind of source regions (review in HTAP, 2010). Observations in the Arctic and sub-Arctic areas have revealed production of O_3 in pollution and biomass burning plumes during transport (e.g. Oltmans et al., 2010; Jaffe and Widger, 2012; Thomas et al., 2013). Ozone destruction was also reported in some plumes from biomass burning or anthropogenic pollution (e.g. Verma et al., 2009; Alvarado et al., 2010). Ozone is lost by photochemical destruction following photolysis and reaction with water vapour. Halogen oxidation in the Arctic lower troposphere (Gilman et al., 2010; Sommar et al., 2010) can also lead to significant O_3 destruction, but this is generally confined to the Arctic boundary layer in springtime. Another major sink for O_3 is dry deposition on leaves via stomatal exchanges, harming the vegetation.

RESEARCH QUESTIONS - GHGs

- **What are the main anthropogenic sources of CO_2, aerosol particles and their precursors in Pan-Eurasia, how they are distributed over the territory, and how they are changing in time?**
- **What are the climatic parameters controlling the seasonal and inter-annual variability of regional CO_2 concentration in the atmosphere?**

3.3.1.2 ATMOSPHERIC AEROSOLS AND VOCS

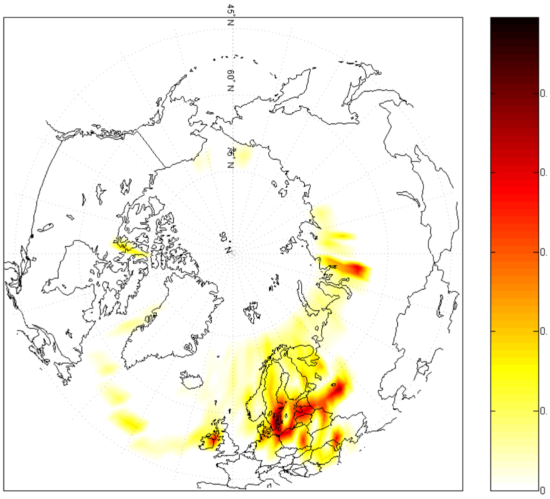


Fig.12 BC source regions determined by a PSCF model and BC measurements at Zeppelin station during summer months(May to October), 2001-2007. Eleftheriadis, et al., 2009

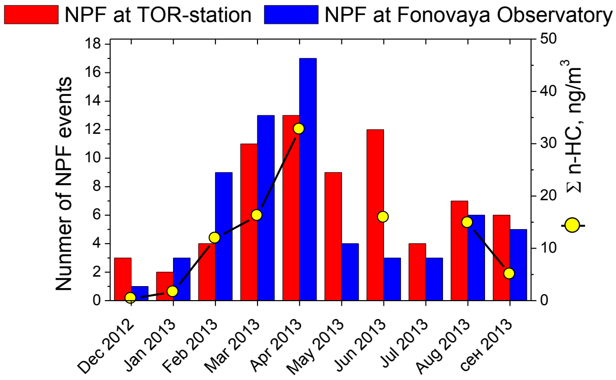
SYNOPSIS. Refer to SLCF: Black carbon and other aerosols in the Arctic/Eurasia context, there is an urgent question to address as northern latitude regions are expected to experience temperature changes higher than the global mean while being large enough to feedback to regional and global climate systems. Our understanding of the relevant physical processes has been hampered by a lack of concurrent measurements of aerosols, clouds, radiation, snow, and sea ice processes. Analysis of Short-living climate forcers (SLCF) in the Arctic and Siberia: Integrated modelling of BC/OC and sulphur reduction effects and elaboration of the mitigation strategy are needed.

Aerosols and the Boreal region

The main constituents of atmospheric aerosol particles are the primary (POA) and secondary (SOA) organic carbon emitted by both natural and anthropogenic sources, black carbon (BC) originating from incomplete combustion of fossil fuels and biomass, secondary inorganic ions (sulphate, nitrate and ammonia) that are formed in the atmosphere from mainly anthropogenic sulphur and nitrogen species and ammonia, sea salt particles coming from oceans, and dust particles including both desert and road dust.

Organic aerosols, originating from boreal forest and possibly other ecosystems, are the main natural aerosol type over most of Eurasia. Studies conducted in the Scandinavian part of the boreal zone suggest that new-particle formation associated with boreal forest emissions is a frequent phenomenon, being the dominant source of the particles in terms of their number concentration during the summer part of the year (Mäkelä et al. 1997, Kulmala et al. 2001, Tunved et al. 2006, Dal Maso et al. 2007). If the same applies to the whole boreal forest zone, natural emissions from boreal forests might induce regionally significant indirect radiative effects (Spracklen et al. 2008, Tunved et al. 2008, and Lihavainen et al. 2009). Recent observations and model simulations indicate enhanced organic aerosol formation at higher temperatures (Day and Pandis, 2011; Leaitch et al., 2011; Makkonen et al., 2012; Paasonen et al., 2013), which suggest that aerosols associated with boreal forest emissions might be part of a significant negative climate feedback loop in a warmer future climate (Kulmala et al., 2004).

Continuous aerosol measurements carried out in recent years at two West Siberian stations enabled a frequency and seasonal dependency of the new particle formation (NPF) events to be revealed (Arshinov et al., 2012). NPF events in Siberia are more often observed during spring (from March to May) and early autumn (secondary frequency peak in September). On average, NPF evens took place on 23-28 % of all days, and it is a little bit higher than it was reported by Dal Maso et al. (2008). The observed seasonal pattern of event frequencies is similar to one observed at Nordic stations (Dal Maso et al. 2007). At the Aerosol Conference held in Tomsk in November 2013, A. Kozlov presented first results of the analysis for organic compounds contained in the atmospheric particulate matter sampled during the flights over a coniferous forest not so far from these stations, which showed a good agreement between concentration of *n*-hydrocarbons and seasonal dependency of NPF events (Fig. ii). Molecular distribution of *n*- alkane mass concentration in spring was more wider than in



winter.

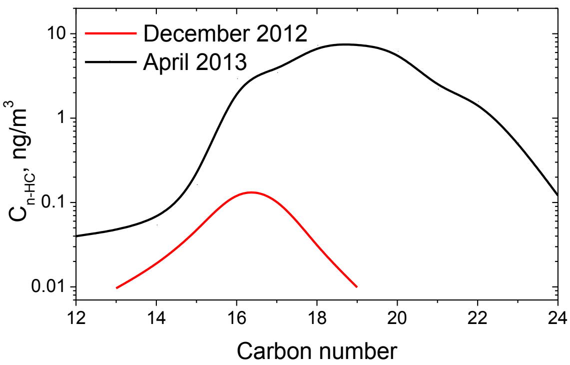


Fig.ii. Number of NPF events observed at two West Siberian stations (TOR-station – 56°28′41"N, 85°03'15"E and Fonovaya Observatory – 56°25'07"N, 84°04'27"E) and the total concentration of *n*-hydrocarbons contained in aerosol samples (left panel); molecular distribution of *n*- alkane mass concentration in particles observed in December 2012 and April 2013 (right panel).

Sulphate and nitrate aerosol concentrations are usually highest in and downwind major urban areas or industrial centres, enhancing the level of air pollution and aerosol climate forcing in those regions. Sea salt particles make an important contribution the atmospheric aerosol over the Arctic Ocean and its coastal areas, having influences on cloud properties over these regions. The climatic effects of sea salt particles are expected to be changed in the future as a result of changes in the sea ice cover and ocean temperatures (Struthers et al., 2011). Mineral dust particles affect regional climate and air quality over large regions in the PEEX domain, especially during the periods of high winds and little precipitation. Road dust is an important contributor to air pollution in many populated areas.

Aerosols and climate

A key point related to the climatic effects of both natural and anthropogenic organic aerosols (OA) are their hygroscopic properties and cloud condensation nuclei (CCN) activity. While a large fraction of OA is known to be water soluble, the influence of organic species on the aerosol water uptake and cloud formation are poorly known. Earlier studies indicate that microstructure of particles (Pöhlker et al., 2012), their phase state (Mikhailov et al., 2004, 2009, Virtanen et al. 2010) and surfactant properties of OC (Prisle at al., 2010, Raatikainen and Laaksonen, 2011) significantly impact on aerosol-water interaction under sub- and supersaturated conditions.

Aerosols – Research Questions

- **How and what aerosols transmission from the middle latitude regions to the Pan-Eurasian and Arctic regions?**
- **Improving the understanding of aerosol, snow surface albedo and radiative forcing in the north Pan-Eurasian and Arctic regions?**

3.3.1.3 UPPER ATMOSPHERE

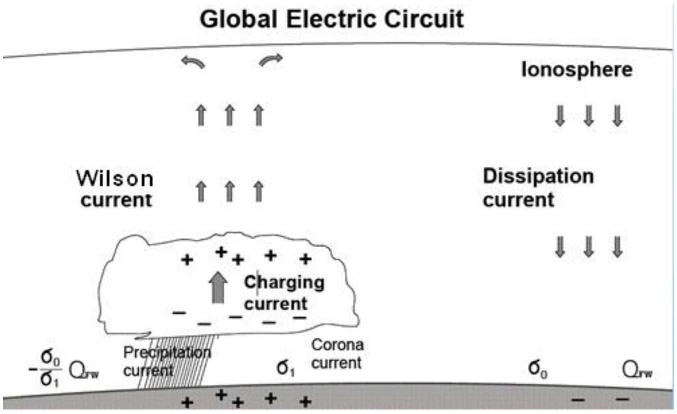


Fig 13. Anisimov and Mareev, 2009; 2011

SYNOPSIS: Development of the methods of diagnostics and modelling of aero electric structures is important for a study of both convective and electric processes in the lower troposphere (Shatalina et al., 2005, 2007).

Cconvection in PBL leads to the formation of aero electric structures manifested in ground-based measurements in short-period electric-field pulsations with periods from several to several hundred seconds (Anisimov et al., 1999; 2002). The sizes of such structures are determined by characteristic variation scales of aerodynamic and electrodynamics parameters of the atmosphere, including the PBL and surface-layer height as well as in homogeneities of the ground (water) surface. Formed as a result of convective processes and capture of positive and negative charged particles (both ions and aerosols) by convective elements (cells), aeroelectric structures move in an air flow along the Earth's surface. The further evolution of convective cells results, in particular, in cloud formation

The Global Electric Circuit (GEC) is an important factor connecting solar activity and upper atmospheric processed with the Earth's environment including the biosphere and climate. Thunderstorm activity maintains this circuit whose appearance is dependent on atmospheric conductance variations in a wide altitude range. The anthropogenic impact to GEC through aviation, forest fires and electromagnetic pollution has been noticed with great concern and the importance of lightning activity in climate processes has been recognized. The GEC forms due to continuous operation of ionization sources providing the exponential growth of conductivity in the lower

atmosphere, from one hand, and to continuous operation of thunderstorm generators providing a high rate of electrical energy generation and dissipation in the troposphere. Therefore, the GEC is upon the influence of both geophysical and meteorological factors, and can serve as *a convenient framework for the analysis of possible inter-connections between the atmospheric electric phenomena and climatic processes*. Further exploring of the GEC as a diagnostic tool for climate studies requires an accurate modelling of the GC stationary state and its dynamics. A special attention should be paid to the study of generators (thunderstorms, electrified shower clouds, mesoscale convective systems) in the global circuit, their observations and modeling.

3.3.2 URBAN AIR QUALITY, MEGACITIES AND BOUNDARY LAYER CHARACTERISTICS

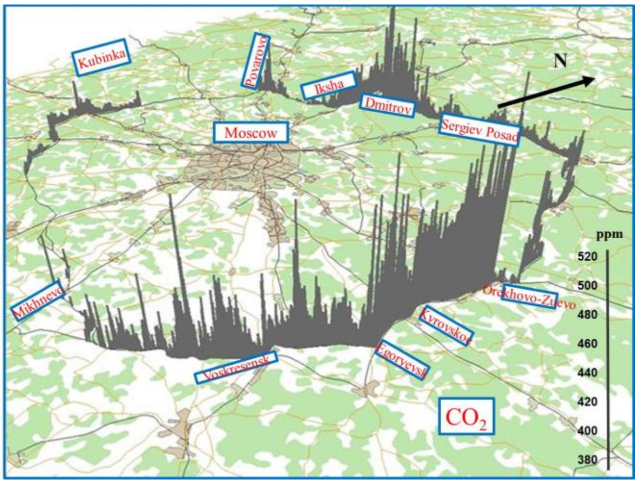


Fig.14 Example of CO2 concentrations around Moscow megacity surroundings. (ELANSKY)

SYNOPSIS. PEEX urban environments are mainly characterized by cities in Russian and China with the heavy anthropogenic emissions of local industry and by the megacity regions of Moscow and Beijing with alarming air quality levels (Fig.14). Bad air quality has serious health effects and damaging ecosystems. Furthermore, via the direct and indirect effect on global albedo and radiative transfer atmospheric pollutants and their oxidants (SO_2, O_3, Knox, BC, sulphate, secondary organic aerosols) have strong role in the climate change dynamics.

Q-4 Quantification of the feedbacks between air quality and climate at Northern high latitudes

Deposition of black carbon onto snow enhances greatly its albedo, enhancing the spring and early-summer melting of the snow with concomitant warming over this region (Flanner et al., 2009; Goldenson et al., 2012). Close to its source areas, BC containing aerosols cause the heating of the atmospheric layers where they reside, being thereby capable of perturbing cloud formation and atmospheric circulation patterns (Koch and Del Genio, 2010; Persad et al., 2012). In urban areas, high BC concentrations are usually indicative of poor air quality. Over the whole PEEX domain, BC is a good tracer for combustion aerosols, including those originating from domestic heating, forest fires or agricultural burning.

Climate-relevant major national emission sources in Pan Eurasian regions are of important concerns for assessment, with special emphases on Arctic pollution sources such as diesel stationary stations, gas flares, and shipping. The major deliverables will be source-specific aerosol characterization,

including molecular markers for source-apportionment studies. The chemical fingerprints will be evaluated to separate source contributions at receptors, especially for deposited BC in Arctic snow with impact the icecap melting and radiation balance of atmosphere.

Siberian region

Urban air quality in several Siberian cities (e.g. Norilsk, Barnaul, Novokuznetsk) is especially alarming among the Russian and European cities. To sketch a scope of environmental problems of Siberian cities, it is necessary to underline an essential dependence of atmospheric quality from climatic conditions typical for Siberia. A stable atmospheric stratification and temperature inversions are predominant weather patterns for more than half a year. This contributes to accumulation of pollutants of different nature in the low layers of the atmosphere, namely where ecosystems function and people live. In addition to the severe climatic conditions, man-made impacts on the environment in industrial areas and large cities strengthen more and more. The impacts manifest themselves in pollution of environment, change of the Earth surface, of hydrological and hydrodynamic regimes of the atmosphere, etc.

The main atmospheric pollution sources in Siberia can be distinguished on anthropogenic (industrial, transport, combustion, etc.) and natural emission (biogenic emissions, wild fires, dust storms, sea aerosols, volcano eruptions, pollen emission, etc.) sources, and characterized by different types, characteristics and time dynamics, including local, regional, and outside sources, accidental releases, etc. The main pollutants to be considered can be classified as health harmful, climate effecting and ecosystem damaging gases and aerosols. The main acidifying compounds in atmospheric deposition are SO_2, sulphate (SO_4), NOx, and NH_3. Sulphur dioxide emissions are mainly associated with point sources such as power plants, the pulp and paper industry, non-ferrous metal smelters, and oil and gas processing. Oil and gas production involves the emission of exhaust gases containing CO_2, NOx, SOx and volatile organic compounds (VOC).

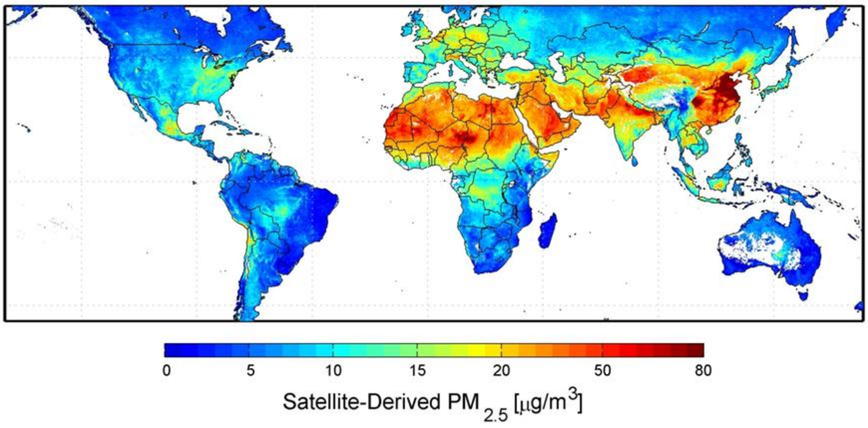


Fig 15. Global distribution of PM2.5 (van Donkelaar et al. 2010,EHP)

China region

Asia is currently one of the main regions still suffering from heavy air pollution (Fig.15). The main characteristics of air pollution in monsoon Asia can be summarized as the following two aspects:

Firstly, there are very high emission rate of fossil fuel (FF) combustion sources and hence a high concentration of primary and secondary pollutants in Asia, especially in coastal regions of China and India. Because of their direct or indirect impacts on radiative transfer, many pollutants and/or their oxidants, e.g. sulphur dioxide (SO_2), ozone (O_3), nitrogen oxides (NOx), black carbon (BC), sulphate, secondary organic aerosols, are important species for the perspectives of climate change. In addition, observations show that the Asia is the only region having a positive trend of some pollutants (e.g. NOx and O_3). Secondly, besides anthropogenic FF combustion pollutants, the monsoon Asia was also influenced by intensive pollution from biomass burning and dust storm in some seasons. For example, intensive forest burning activities often appeared in South Asia in spring and in Siberia in summer, and intensive man-made burning activities of agricultural straw occurred in the North and East China Plains in June. Dust storm frequently occurred from Taklimakan and Gobi deserts in Northwest China and transported over the eastern China, southern China and also the Pacific Ocean even the globe. These biomass burning or mineral dust aerosols have been found to cause complex interactions in the climate system, after them are mixed with the anthropogenic pollutants.

China's air pollution in 2013 is at its worst for some 52 years, with 13 provinces hitting record-high levels of air pollution, according to the ministry of environmental protection. Nearly half of China has been hit by smog, with the south eastern regions experiencing severe conditions. Increasingly, more cities are now monitoring air quality in real time using meteorological towers and remote sensing from satellites to track pollutants. In Beijing concentrations of micro particles in the atmosphere have been found to be more than 10 times the safe level recommended by the WHO. This has prompted authorities to take measures such as limiting industrial emissions and reducing traffic across the nation. Also in these cities the haze is so thick that often in winter it blocks out the sun, reducing natural light and warmth significantly. As a result temperature drops, households use more energy for heating; pollution gets worse, causing respiratory diseases and eventually more people are hospitalised. The country's five-year action plan has provisions to improve environment technology, planning and regulation. The plan aims at reducing heavy pollution by a large margin and improves air quality in Beijing-Tianjin-Hebei province, the Yangtze River Delta and the Pearl River Delta.

Urban air quality – Research questions

- **< LIST HERE>**

Boundary layer dynamics

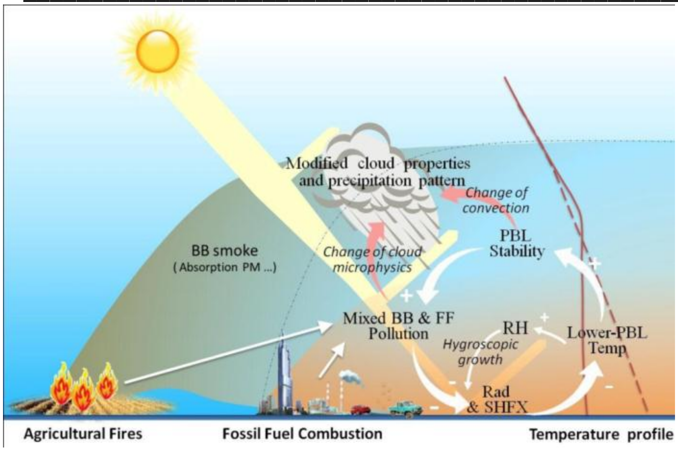


Fig 16. A schematic figure for interactions of air pollution-PBL dynamics and aerosol-radiation cloud under a condition of mixed agriculture burning plumes and fossil fuel combustion pollutants(Ding et al., 2013b)

SYNOPSIS: Most of the land-atmosphere-ocean processes take place the lowest part of the troposphere, in the Planetary Boundary Layer. The quantified behavior of the PBL over the Pan-Eurasian region is needed in the analysis of the spatial and temporal distribution of surface fluxes, predicting the microclimate and extreme weather events, and for modeling of clouds and air quality. The shallow, *stably stratified PBLs* are typical in the Northern Scandinavia and Siberia especially in winter time and are extremely sensitive to even weak impacts.

Atmospheric planetary boundary layers (PBLs) are strongly turbulent layers immediately affected by dynamic, thermal and other interactions with Earth's surface. PBLs are subject to diurnal variations, absorb surface emissions, control microclimate, air pollution, extreme colds and heat waves and are sensitive to human impacts. Very stable stratification in the atmosphere above the PBL prevents entities provided by surface fluxes or emissions to efficiently penetrate from the PBL into free atmosphere. Therefore, the PBL height and turbulent fluxes through *the PBL upper boundary control local features of climate and extreme weather events* (e.g., heat waves associated with convection; or strongly stable stratification events triggering air pollution). This concept (equally relevant to hydrosphere) brings forth the problem of modelling and monitoring the pbl height.

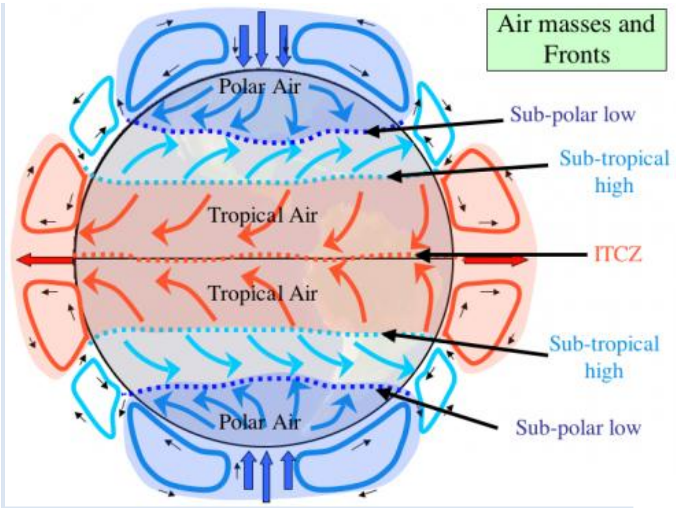
Dozens to thousands metres in height the boundary layer also controls the dispersion and transport of the atmospheric admixtures, extreme cold and heat periods (Zilitinkevich 1991, Zilitinkevich et al. 2007, Zilitinkevich and Esau 2009).Comprehensive inventory of planetary boundary layer (PBL) height over Eurasia will be addressed in a PEEX, as it is the layer where the basic observations will be performed and is the weather human population is exposed to.

A big variety of geophysical and climatic conditions over the Eurasia make a study of surface substance-energy flows (including aerosol and GHG flows) especially complicated. On the other hand, just this variety will allow us to investigate in detail and verify different physical mechanisms of these processes. It can be easily illustrated with the mechanisms responsible for new particle formation (NPF) in the planetary boundary layer. There are many proposed nucleation mechanisms and their contributions are not well known. As was revealed due to recent studies, the relative contribution of these mechanisms into NPF varies substantially from one place to another (Manninen et al., 2010), from one day to another and even during nucleation (Laakso et al., 2007; Gagn´e et al., 2010, 2012). The gradient from arctic deserts to boreal forests, mires, steppes, deserts, and broadleaf forests gives a possibility of simultaneous NPF observations in different ecosystems and reveal dominant physical mechanisms.

Shallow, stably stratified PBLs, typical of winter time in the Northern Scandinavia and Siberia, are especially sensitive to even weak impacts and, therefore, deserve particular attention, especially in the conditions of environmental and climate change (Zilitinkevich and Esau, 2009). Unstably stratified PBLs essentially interact with the free atmosphere through turbulent ventilation at the PBL upper boundary (Zilitinkevich, 2012). This mechanism, still insufficiently understood and poorly modelled, controls development of convective clouds, dispersion and deposition of aerosols and gases, essential features of hot waves and other extreme weather events.

The traditional view on the atmosphere-Earth interaction as fully characterised by the surface fluxes no longer copes with the modern concept of the multi-scale climate system, wherein PBLs couple the geospheres and regulate local features of climate. In this context important role acquire the PBL height and the turbulent fluxes at the PBL upper boundary. Good knowledge of the global atmosphere-Earth interaction requires investigation, observation and monitoring of all these parameters.

3.3.3 WEATHER AND ATMOSPHERIC CIRCULATION



SYNOPSIS: The changes in the atmospheric dynamics taking place in the Arctic-Boreal region have severe impacts (1) on short-term prediction of physical conditions in the domain, and more widely due to non-linear multi-scale interactions in the atmosphere and closely coupled sub-systems, and (2) on long predictions and projections about the bio-geochemical systems in the domain, and world-wide

Fig.17 Global atmospheric circulation patterns.
http://montessorimuddle.org/2011/04/21/global-atmospheric-circulation-and-biomes/

Q-5 How will the atmospheric dynamics (weather; synoptic, BL) change in the Arctic – boreal regions?

CHINA Investigate the Asian monsoon change on annual to decadal scales and its teleconnection with high-latitude climate changes, as well as the underlying mechanisms, evaluate the effect of natural and anthropogenic drivers, and project its potential change in the 21st century.

3.3.3.1 PLANETARY AND SYNOPTIC SCALE WEATHER

The driving motivation to better predict and understand high impact weather is to mitigate economic and human loss in weather related natural hazards. The key issues here are the reliability of weather forecast and the extension of the time-range of useful forecasts. Currently this range in Europe is on average about 8 - 9 days and allows reliable early warning to be issued in weather related hazards, such as wind storms and extreme precipitation events with flash floods. The range of useful forecasts has typically increased by a day per decade over the past three decades (Uppala et al. 2005). The aim of PEEX in this topic is to enhance scientific and technical basis for maintaining and developing these capabilities across the study domain. The challenges are related to the ongoing environmental change and its impact on occurrence and predictability of weather.

Skill in predicting weather related natural hazards can be attributed to all components of numerical forecasting systems: formulation of the prediction model, exploitation of observations, and probabilistic aspects of forecasting. Improving forecast skill calls for a balanced research program to cover all these aspects. Improvements in prediction model formulation include issues such as more accurate numerical methods to solve the underlying set of thermo-dynamic equations and improved parameterizations of sub-grid scale processes. PEEX provides a unique opportunity to better understand and quantify near-surface physical and bio-geochemical processes and thus improve the scientific basis for model development.

Weather prediction is predominantly an initial value problem, and the initial state for the prediction model is generated by data assimilation of observational information into the model initial state. Volumes of observational data used daily in operational numerical weather prediction centres are staggering: some 50 – 100 million individual measurements from all possible in situ and remote sensing instruments world-wide are transmitted and used in near-real time. Observation modeling ("virtual instrumentation") is a cornerstone in utilizing all these measurements in data assimilation. For PEEX this poses a special challenge. It is crucial that observational data generated in the region are transmitted without delay to the global telecommunication system to be used in operations, and this should be supported by activities directed towards better understanding of the measurements by observation modeling.

Probabilistic aspects of forecasting address the fact that proper risk assessment of hazardous events cannot be based on a single forecast. It has to be accompanied by some probability of the event so that users can decide the risk they are prepared to take depending on how likely they are going to be affected by the event and act accordingly (Palmer and Slingo 2011). Probabilistic forecasting systems include methods to assess unavoidable uncertainties in the model initial state and the prediction model formulation. Initial state uncertainties are typically addressed via ensemble based data assimilation methods, such as ensemble Kalman filtering, and they allow generation of ensemble forecasts from alternative but equally likely initial states. The prediction model transports in time the initial uncertainty to the forecast uncertainty. It is clear that the accuracy of the prediction model contributes towards the accuracy of the forecast uncertainty. The forecast model itself contains uncertainties, too. These include structural (inaccurate modeling of included processes), parametric (inaccurate closure parameters), and uncertainties related to completely missing processes. These are typically addressed by some stochastic methods, such as additive or multiplicative stochastic noise included into the tendencies generated by sub-grid scale processes,

closure parameter variations, and energy backscatter schemes at the truncation scales of spectral discretization. These generate additional spread to the ensemble of forecasts corresponding to modeling uncertainties. In summary, accuracy of a probabilistic forecasting system is a result of a skilful high-resolution data assimilation and forecasting system, while its reliability can be attributed to the design of uncertainty representations. Reliability means here the capability of a probabilistic system to represent the range of observed events. It is a challenge of PEEX to apply the new data sources and process studies to characterize uncertainties in key processes and feedbacks in benefit of better prediction of natural hazards.

In summary, development of more accurate prediction tools supports more accurate data assimilation and probabilistic forecasting. This in turn enables better characterization of uncertainties in benefit of users of the forecast products and also, in return, accelerating model development as uncertainties are better known.

The ongoing environmental change and its amplification in the PEEX domain pose special challenges to the prediction of weather related hazards, and also longer term impacts. This line of thinking can be illustrated by considering the recent changes in the Arctic sea-ice. First, they have been much more rapid than models and scientists anticipated, say ten years ago. Second, the sea-ice changes have no doubt impacted the weather conditions in the Northern European region. For instance, increased winter-time snowfall in Scandinavia during 2010 - 2013 can be partly attributed to the thermal forcing of the increasingly open sea surface in the Arctic sea and its impact on the atmospheric circulation upstream in the Atlantic sector. This mechanism alters movements of weather patterns and undermines preparedness to natural hazards based on past experience. It is thus vital to enhance routine observations, data assimilation techniques, and prediction models in order to properly monitor the physical state of the environment. Longer term impacts of the reduced ice cover are largely unknown because science community has had only little time to create new knowledge on essential climate variables across the domain. Thus, for improved preparedness, new observational evidence is needed to reduce uncertainties in the system dynamics both on short and longer time-scales.

Research question

What are the characteristics and inherent uncertainties of the key atmospheric processes and how they should be accounted for in prediction of weather related natural hazards?

3.3.3.2 NEAR-SURFACE WEATHER

The main impacts of weather related natural hazards are felt due to near-surface weather which is particularly sensitive to lower boundary condition, such as soil temperature and moisture. The ongoing global change affects surface conditions in the Arctic-Boreal region and this is naturally linked to changes in atmospheric circulation. For better prediction of hazardous near-surface

weather, one has to be well aware of these important linkages and how they are constructed into prediction models.

For prediction model development the surface-atmosphere coupling is built mainly into the physical parameterizations which need to be continuously improved and optimized for high-resolutions models. At grid resolutions between 5 and 10 km in non-hydrostatic models, convective processes are partly resolved and partly parameterized posing a general need to continuously revise convection schemes. Cloud parameterizations and interactions with radiation call for corresponding refinements, especially regarding developments in representation of cloud microphysics and aerosol effects. Mass-conserving time-integration schemes therefore become more important in treating advection of water vapor, cloud water, and aerosols. Boundary layer processes are particularly important, especially in stable conditions, and the representation of boundary layer clouds, and their further coupling to convection remains an important research topic. Refined models also need improved data assimilation systems. Linking model improvements into data assimilation of cloud and precipitation is largely an open question, which calls for further research. With higher resolution modeling, the surface conditions (land use type, fraction of water, vegetation state, snow cover, etc.) become very important. Investigations how to consistently couple surface and upper level data assimilation and modeling remain high priority research issues. In summary, PEEX can offer unique new knowledge on near-surface conditions in the study domain and it is the task of the research community to respond by a development effort to improve predictive skill and power of near-surface weather parameters from daily and weekly over to seasonal-to-annual time-scales, and beyond.

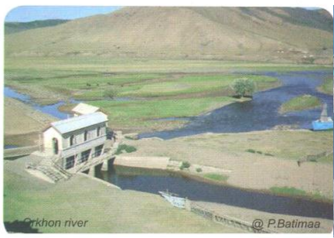
Research question

How to convert the improved knowledge of near-surface characteristics and processes into improved predictive skill of high impact near-surface weather?

Palmer, T and J Slingo (2011) Uncertainty in weather and climate prediction. *Phil. Trans. R. Soc. A*, 369, 4751-4767. doi:10.1098/rsta.2011.0161.

Uppala et al. (2005) The ERA-40 re-analysis. *Q. J. R. Meteorol. Soc*., 131, 2961–3012. doi:10.1256/qj.04.176

3.4 ARCTIC-BOREAL AQUATIC SYSTEM – KEY TOPICS


3.4.1 THE ARCTIC OCEAN IN THE CLIMATE SYSTEM

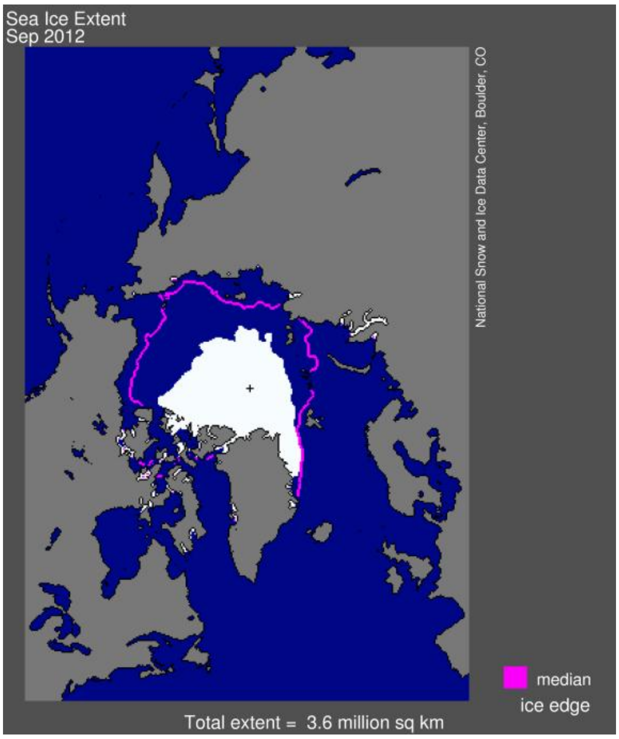


Fig. 18 Record minimum sea ice extent in the Arctic in Sep2012 (white). The purple line: the median Sep ice extent in 1979-2012. National Snow and Ice Data Center, Boulder.

SYNOPSIS: SYNOPSIS:The Arctic Ocean plays an important major role in the climate system. The essential processes related to the interaction between the ocean and the other components of the Earth system include the air-sea exchange of momentum, heat, and matter (e.g. moisture, CO2, and CH4) and the dynamics and thermodynamics of sea ice. The major issues to be studied are (a) the role of the ocean in the Arctic amplification of climate change, (b) reasons for the Arctic sea ice decline, and (c) influence on greenhouse gas exchange between ocean and atmosphere, (d) effects of the sea ice decline on the ocean and surrounding continents.

Q-6 How will the Arctic sea ice extend, snow cover and permafrost, change with changing climate and what are the connection to the climate system?

The Arctic Ocean occupies a roughly circular basin and covers an area of about 14,056,000 km^2. The oceanographic changes in the Arctic Seas; sea ice coverage, arctic water currents and masses are teleconnected to global climate and weather dynamics. The Arctic Ocean can influence the mid-latitude weather and climate. The cold air from Arctic moves toward the equator, meeting with warmer air at latitude 60°N and causing rain and snow. The warmer and moister atmosphere of ice-demised Arctic during autumn has been associated with enhanced autumn snow cover in Asia (Park et al. 2013). In general this flow is the lower portion of the polar cell, the highest (by latitude) of the three principal circulation cells of the Earth's atmosphere each spanning thirty degrees of latitude.

Many of the processes considered responsible for the Arctic amplification of climate warming are related to the ocean. Among them, the snow/ice albedo feedback has received the most attention (e.g. Flanner et al., 2011). The feedback is largest when sea ice is replaced by open water, but the feedback starts to play a significant role already in spring when the snow melt on top of sea ice starts. This is because of the large albedo difference between dry snow (albedo about 0.85) and wet,

melting, bare ice (albedo about 0.40). More work is needed to quantitatively understand the reduction of snow/ice albedo during the melting season, including the effects of melt ponds and pollutants in snow. Other amplification mechanisms related to the ocean include the increased fall-winter energy loss from the ocean (Screen and Simmonds, 2010). Further, the melt of sea ice strongly affects (a) evaporation and, hence, the water-vapor and cloud radiative feedbacks (Sedlar et al., 2011) and (b) the ABL thickness, which controls the sensitivity of air temperature to heat input into the ABL (Esau and Zilitinkevich, 2010). The relative importance of the mechanisms affecting the Arctic amplification of climate warming are not well known, but will be studied in PEEX.

The rapid decline of Arctic sea ice cover has tremendous effects on navigation and exploration of natural resources- To be able to predict the future evolution of the sea ice cover, the first priority is to better understand the reasons beyond the past and ongoing evolution. Several processes have contributed to the decline of Arctic sea ice cover, but the role of these processes needs better quantification. PEEX will conduct further studies on the impacts of changes in cloud cover and radiative forcing (Kay et al., 2008), atmospheric heat transport(Ogi et al., 2010), and oceanic heat transport (Woodgate et al., 2010). In addition, as the ice thickness has decreased, sea ice cover become increasingly sensitive to the ice-albedo feedback (Perovich et al., 2008). Other issues calling for more attention include the reasons for earlier spring onset of melt (Maksimovich and Vihma, 2012), the changes in the phase of precipitation (Screen and Simmonds, 2011), and the large-scale interaction of sea ice extent, sea surface temperature distribution and atmospheric dynamic (cyclognesis, cyclolysis, and cyclone tracks).

In addition to thermodynamic processes, another factor affecting the sea ice cover in the Arctic is the drift of sea ice (Kulakov & Makshtas, 2013). The momentum flux from the atmosphere to the ice is the main driver of sea-ice drift, which is poorly represented in climate models (Rampal et al., 2011). This currently hinders a realistic representation of sea-ice drift patterns in large-scale climate models. Further, the progressively thinning ice pack is becoming increasingly sensitive to wind forcing (Vihma et al., 2012). PEEX will address the main processes that determine the momentum transfer from the atmosphere to sea ice, including the effects of atmospheric stratification and sea ice roughness.

To better understand the links between the Arctic Ocean and terrestrial Eurasia, there is particular need in PEEX to study the effects of Arctic Sea ice decline on Eurasian weather and climate. Several recent studies suggest that the strong sea ice decline in the Arctic has been favoring cold, snow-rich winters in Eurasia (Honda et al., 2009; Petoukhov and Semenov, 2010). Some studies have also suggested a link between the sea ice declines and increased autumn snow fall in Siberia, which also tends to favor hard winters (Cohen et al., 2012).

One of the poor understudied problems, related with the Arctic Ocean is the role of sea ice in gas exchange between ocean and atmosphere. Preliminary results of field studies at the drifting stations "North Pole" (Makshtas et al, 2011) showed that shrinking of sea ice cover could be the reason of increasing CO_2 uptake from atmosphere in annual cycle and growth of seasonal amplitude CO2 concentration in the Arctic.

The increase of air temperatures and precipitation over the Arctic Ocean, projected by climate models, may also have important effects on the structure of sea ice. Increased snow load on a

thinner ice tends to cause ocean flooding, which further results in formation of snow ice. Increased snow melt and rain, on the other hand, results in increased percolation of water to snow-ice interface, where it refreezes forming super-imposed ice (Cheng et al,. 2006). Snow ice and super-imposed ice have granular structure and differ thermodynamically and mechanically from the sea ice that nowadays prevails in the Arctic.

The changes in the Arctic Ocean have also opened some, although limited, possibilities for seasonal prediction. These are mostly related to the large heat capacity of the ocean: if there is little sea ice in the late summer and early autumn, it tends to cause large heat and moisture fluxes to the atmosphere, favoring warm, cloudy weather in late autumn and early winter (Stroeve et al., 2012). On the other hand, the reduction of sea ice thickness may decrease the possibilities for a seasonal forecasting of the ice conditions in the most favorable navigation season in late summer – early autumn. This is because thin ice is very sensitive to unpredictable anomalies in atmospheric forcing. For example, in August 2012 a single storm caused a reduction of sea ice extend by approximately 1 million km2.

3.4.2 ARCTIC MARINE ECOSYSTEM

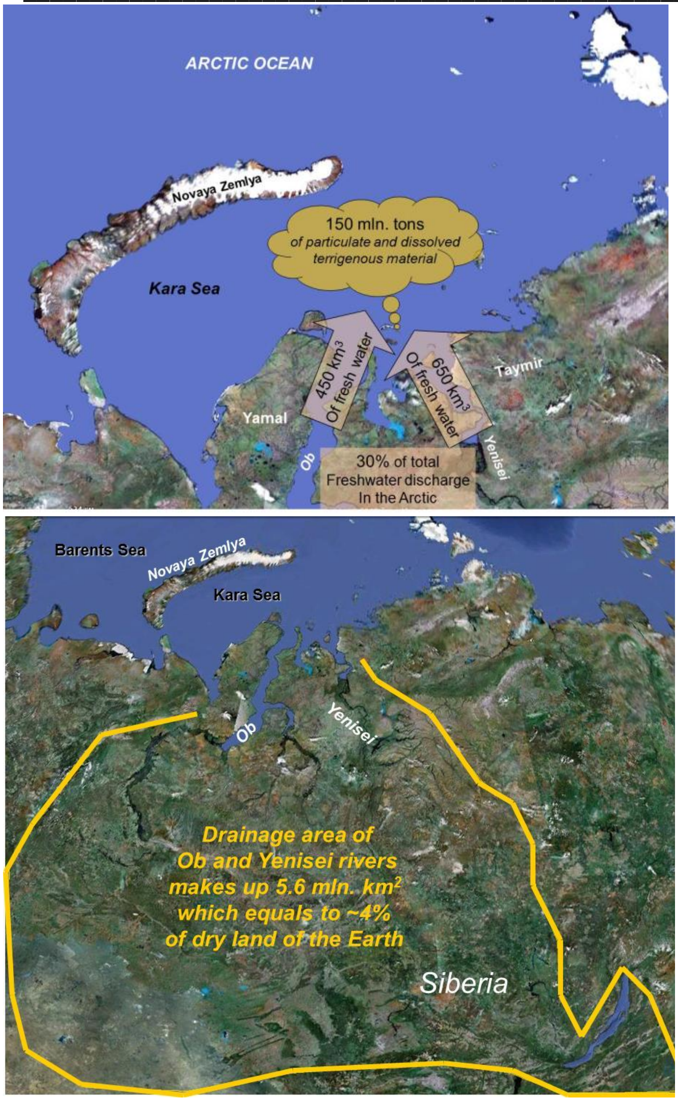


Fig.19 <template>

SYNOPSIS: The ice cover of the Arctic Ocean is undergoing fast changes including decline of summer ice extent and ice thickness. This result in significant increase of ice-free sea surface in vegetation season and increase in duration of the season itself. This could result in the pronounced growth of annual gross primary production (PP) and phytoplankton biomass. In its tern higher PP may cause 1) increase in CO_2 fluxes from atmosphere to the ocean and 2) increase in overall biological production incl. production of higher trophic level organisms, fish populations. Increase in surface water temperature may "open the Arctic doors" for new species and change the Arctic pelagic food webs, energy flows, biodiversity. Climatic and anthropogenic forces at river's drainage areas may lead to increase in amount of fresh water, amount of allochtonous materials, annually delivered to the Artic shelves, further to the Arctic Basin, and to changes in flood timing. All the listed processes may impact the Arctic marine ecosystems, their productivity and key biogeochemical cycles in the region. One of the most important potential changes on the marine Arctic ecosystems is related to progressive increase of anthropogenic impact of oil and natural gas drilling and transportation over the shelf areas via the long-term backwash effect.

Q-7 What is the joint effect of the arctic warming, the pollution load and acidification on the arctic marine ecosystem, mainly on the primary production (algal blooms and the following sedimentation, i.e. carbon sink)?

The ice cover of the Arctic Ocean is undergoing fast changes including decline of summer ice extent and ice thickness. Since late 1970-th – early 1980-th the Arctic summer ice sheet have lost ~3.0-3.5 mln km^2 (National Snow and Ice Data Center, USA). In September 2012 40% of Central Arctic Basin

was open water. In August of 2007 and 2012 (the warmest years of the past decade in the Arctic) in one of the key Arctic areas – the Kara Sea south border of the permanent ice covered area was found ~700-750 km to the north from its mean position during 1970-2000 period. This is equal to a distance from Moscow to St. Petersburg. Theoretically appearance of new ice-free areas should result in the pronounced growth of annual gross primary production (PP) and phytoplankton biomass. For now we do not have enough data to quantitatively estimate the increase in PP and phytoplankton biomass in these areas. Another concern is a loss of ice rich algae communities, associated with the low ice sheet surface (Bluhm, et al. 2011) which input in PP and primary producers biomass, CO_2 consumption/flux and biomass sedimentation may be comparable (or exceed) those of plankton algae which we expect to bloom in ice free areas.

Next problem is related to increase (1 to 2 months) of ice free season in the areas which were normally free of ice before pronounced climate signal was seen in the Arctic. These areas are mostly the Arctic margin seas. It does not look that these areas will exhibit high volumes of additional PP, because of strong nutrients limitation since end of spring bloom and low activity of bacterioplankton (slow nutrients regeneration) due to low temperatures (Demidov, 2010; Makkaveev et al., 2010; Sazhin, Romanova, 2010). High PP in the second part of the vegetation season may be found only in the areas (quite restricted) under impact of riverine inflow in the Arctic or areas of active vertical water transport (Sergeeva, 3013). Some of them we know (Hill, Cota, 2005; Demidov, 2010; Sergeeva, 3013), most stayed unknown. So it can be easily seen the estimate of CO_2 fluxes and role of the Arctic as possible CO_2 sink in context of climate changes have a lot of uncertainties.

The second important question is how do climatically induced increase in PP and phytoplankton biomass may influence productivity of higher trophic levels of the Arctic ecosystem including populations of target interest to humans. If we consider typical Arctic ecosystems (excluding the Barents Sea determined by Atlantic impact) we found that the most important primary consumers are large-sized herbivorous copepods which life cycles are synchronized with seasonal algae bloom (Kosobokova, 2012). Populations of these copepods leave upper productive layers of water column in the middle of vegetation season or a little bit later and descent to a deep. For now we can't see a mechanism due to which small increase of available food in second part of vegetation season may significantly influence this key component of pelagic ecosystem. Another important component of the consumer's community is small-sized herbivorous copepods which role is especially high in shelf ecosystems. They play important role as fish larvae and planktonic carnivorous food. Theoretically increase in available phytoplankton production in fall together with increase in sea temperature may influence small-sized copepod populations and increase their role in mass and energy fry in the ecosystems. Unfortunately today knowledge on a role of small copepods in the Arctic ecosystems is incipient (Arashkevich et al. 2010).

There is a chance that following an increase in sea temperature in the Arctic some alien populations from neighboring regions may penetrate the Arctic ecosystem, form rich regional populations and change native ecosystem structure and functioning. Recently we observed an example with Alaskan pollack in the western Arctic. Regime shift and 1.5^{0}C water temperature increase occurred in the Bering Sea in mid-1970-th allowed pollack to penetrate the Arctic ecosystem and occupy a place of a key-stone species in several years which supports one of the World biggest regional harvests (Shuntov et al., 2007). The Bering Sea ecosystem is very rich one contrary to the Arctic ecosystems. For now we can't see sufficient food sources which may support massive invader even in case of

climate induced changes in the ecosystem. But even appearance of aggressive alien species with low numbers may dramatically impact sensitive Arctic ecosystem. Anyway the problem is very important and related to international fisheries regulation in the Arctic in a projection of future ecosystem changes.

One of the major consequences of climate warming in the Arctic and adjacent Boreal areas, increase of their impact over the Arctic marine ecosystems are associated with changes in riverine discharge to the Arctic shelves. Degradation of permafrost, soil erosion, changes in snow cover and summer precipitation may lead to increase in amount of fresh water, amount of allochtonous materials including organic matter and nutrients, annually delivered to the Artic shelves, and further to the Arctic Basin, as well as to changes in flood timing. Increase of anthropogenic activities over the drainage areas, unpredicted anthropogenic catastrophes will result in quick delivery of pollutants and other anthropogenic signals to the Arctic via river stream. We have just started understanding of the processes in estuarine zones which regulate freshwater – marine ecosystems interactions (Futterer D.K., Galimov E.M. 2003; Flint 2010) and poorly know mechanisms which determine impact of riverine waters over the Arctic shelves and Central deep-basin and their dependence of specific climatic forces. Estuary of big Siberian River is a key place for location of flag-station or permanent observation point in a frame of future Program.

One of the most important concerns about marine Arctic ecosystems today and their future changes is related to progressive increase of all spectrum of anthropogenic impacts associated with oil and natural gas drilling and transportation over the shelf areas. We should keep in mind that this concern is not only economically but climate-related. The warmer and more free of ice the Arctic shelf will be – the more oil and gas activities occur. Anthropogenic impacts associated with oil and gas industry progress will have long-term backwash because of high sensitivity of the Arctic ecosystems. It looks that the place of at least for one flag-station or flag-observation point should be in an area of the highest oil and gas industry activities in the Arctic.

The listed problems are of top importance for understanding oncoming evolution of the Arctic natural system and related processes will have key impact over Arctic marine ecosystems in a context of changing climate and increasing anthropogenic impacts. The processes may cause irreversible changes in marine Arctic productivity, key biogeochemical cycles, potential for CO2 absorbtion by marine ecosystem, the Arctic impact over adjacent Boreal areas.

ACIDIFICATION

Marine Ecosystems – Research questions
− How will the Arctic sea ice extend, snow cover and permafrost, change with changing climate and what are the connection to the climate system? − How will changing climate influence fresh water and allochtonous materials delivery to marine Arctic with river inflow and corresponding impacts on the Arctic marine ecosystems? − What is the effect of the Arctic warming and seasonal ice shrink on the arctic marine ecosystems, mainly on the primary production (extent of phytoplankton vegetation season and corresponding, i.e. carbon sink), productivity of upper trophic level populations including target species?

- **((What is the joint effect of the arctic warming, the pollution load and acidification on the arctic marine ecosystem, mainly on the primary production (algal blooms and the following sedimentation, i.e. carbon sink)? Replaced by the previous))**
- **What is the future role of the arctic-boreal lakes and large river systems in biogeochemical cycles (incl. thermokarst lakes and running waters of all size) and how will these changes affect societies (livelihoods, agriculture, forestry, industry and processes in the Arctic shelf ecosystems)?**

3.4.3 LAKES AND LARGE SCALE RIVER SYSTEMS IN SIBERIAN REGION

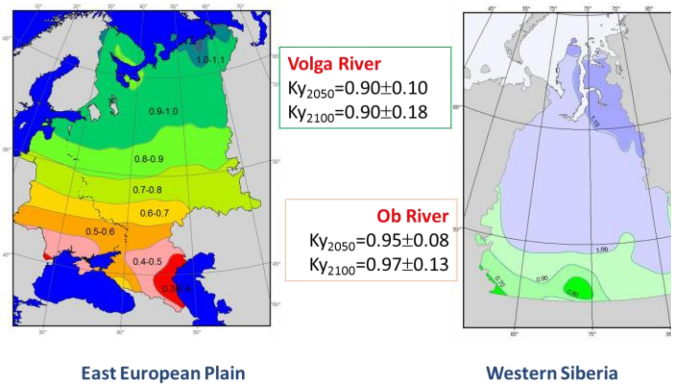



Fig.20 Relative changes of a runoff (Ky_{2050}) based on the CMIP3 ensemble at the middle of XXI century Chubarova

SYNOPSIS. The gradient in water chemistry from tundra to steppe zones in Siberia can provide insight into potential climate change effects on water chemistry. In the last century, long-range Trans boundary air pollution has led to changes in the geochemical cycles of S, N, metals and other compounds. Furthermore, Northern Pan Eurasian methane comes from random bubbling in disperse locations. Permafrost melting may accelerate the lake emission. Furthermore, there is a risk of increasing toxic blooms

Q-8 What is the future role of the arctic-boreal lakes and large river systems in biogeochemical cycles (incl. thermokarst lakes and running waters of all size) and how will these changes affect societies (livelihoods, agriculture, forestry, industry)?

Water systems and GHG

The enhanced decomposition of soil organic matter may significantly affect the transport of terrestrial carbon to the rivers, estuaries and to the coastal ocean, a process with unknown contribution to the global and regional carbon budgets. The role of aquatic systems as a net sink or a source for atmospheric CO_2 is presently under debate. When precipitation or other processes push large volumes of organic matter from land into nearby lakes and streams, this carbon effectively disappears from the carbon budget of the terrestrial ecosystem. Thus, the biological processes taking place in the terrestrial ecosystem (e.g. photosynthesis, respiration and decomposition) and in the aquatic ecosystem are interlinked. The higher temperature response of aquatic ecosystems compared to terrestrial ecosystems indicates that substantial part of the carbon respired or emitted from the aquatic system must be of terrestrial origin (Yvon-Durocher et al. 2012).

The Northern Pan Eurasian region is characterized by the thaw lakes, which comprise 90% of the lakes in the Russian permafrost zone (Romanovskii et al. 2002). The Siberian lakes, which are formed in melting permafrost as temperatures rise, have long been known to emit methane. The latest observations on the lakes in the permafrost zone of northern Siberia indicate that they are belching out much more methane into the atmosphere than previously thought. Rather than being emitted in a constant stream, 95% of the methane comes from random bubbling in disperse locations. In coming decades this could become a more significant factor in global climate change (Walter et al. 2006 Nature).

Water systems and pollution

The Siberian lakes situated in tundra and forest-tundra zone are in general poorly studied. In their natural state they are less productive waters, but their ecosystems are highly sensitive to external

influences. Profuse blooming of cyanobacteria is usually associated with industrial effluents and nutrient run-off. The assessment of impact of climate change on the increasing of water trophicity, accompanied by blooms of cyanobacteria in Northern Pan Eurasian region is needed.

Water chemistry in small lakes along a transect from boreal to arid Eco regions in European Russia, is determined by a combination of physical, chemical, and biological processes occurring both in the lakes themselves as well as in their catchment areas. In the last century, long-range trans boundary air pollution has led to changes in the geochemical cycles of S, N, metals and other compounds in many parts of the world (Schlesinger, 1997; Vitousek et al., 1997a, b; Kvaeven et al., 2001; Skjelkvåle et al., 2001). In the last decade combined effects of air pollution and climate warming have received increasing attention (Skjelkvåle and Wright, 1998; Schindler et al., 2001; Alcamo et al., 2002; Sanderson et al., 2006; Feuchtmayr et al., 2009; Sereda et al., 2011). Water chemistry of small lakes without any direct pollution sources in the catchment can be expected to reflect regional characteristics of water chemistry, as well as of global anthropogenic processes such as climate change and long-range air pollution (Müller et al., 1998; Moiseenko et al., 2001; Battarbee et al., 2005).

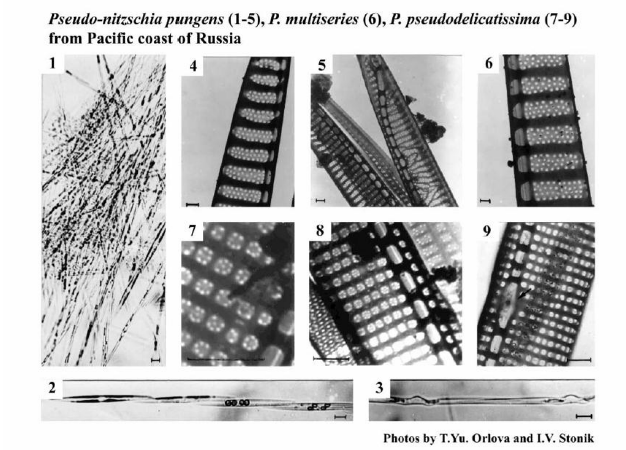
The problem of environmental pollution includes as a central component the waterborne spreading of nutrients and pesticides from agricultural areas, heavy metals that often originate from mining areas, and other elements and chemicals such as persistent organic pollutants from urban and industrial areas. Following river and delta dynamics occurs due to the shifts in downstream loads, with frequently significant aggradation/degradation rates in the fluvial system. The current ground-based stream flow-gaging network does not provide adequate spatial coverage for many scientific and water management applications, including verification of the land-surface runoff contribution to the recipients of intra-continental runoff. ***Special field laboratories of joint observations and modelling capabilities in hydrometeorology, sedimentology and geochemistry, are needed for understanding tracer and pollution spreading as a part of global environmental fluxes in present and future.***

One of the examples is the Selenga River Basin is located in the centre of Eurasia and extends from northern Mongolia into southern Siberia, Russia, and has its outlet at Lake Baikal. The Selenga River Basin and Lake Baikal is located in the upstream part of the Yenisey river system, which discharges into the Arctic Ocean. Lake Baikal has the largest lake volume in the world at about 23000 km3 (comprising 20 % of all unfrozen freshwater globally), hosts a unique ecosystem (Granina 1997), and is an important regional water resource (Garmaev and Khristoforov, 2010; Brunello et al. 2006). There are numerous industries and agricultural activities within the Selenga River Basin that affect the water quality of the lake and its tributaries. Mining is well-developed in the region (e.g. Korytnjy et.al, 2003; Karpoff and Roscoe 2005; AATA 2008; Byambaa and Todo 2011), and heavy metals accumulate in biota and sediments of the Selenga river delta and Lake Baikal (Boyle et al., 1998; Rudneva et al., 2005; Khazheeva et al. 2006).

Direct consequence of climatic changes and toxic water bloom

A direct consequence of climatic changes is an avalanche reproduction of toxigenic cyanobacteria (Nodularia, Microcystis, Anabaena, Aphanizomenon, Planktonthrix) and diatoms (Pseudo-nitzschia)

occurs in ponds, lakes, reservoirs and bays of the seas. Decay of cyanobacteria (Nodularia, Microcystis, Anabaena, Aphanizomenon, Planktonthrix) and diatoms (Pseudo-nitzschia) excrete to water especially dangerous carcinogens and neurotoxins. Toxicity of some cyanotoxins exceeds toxicity of destroyed now warfare agents. Antidotes to these toxins are not found.



LEFT: Algae bloom 29.07.2009, northen part of Gorky reservoir at Volga river. RIGHT In adjacent to Vladivostok Peter the Great Bay, progressing are diatom Pseudo-nitzschia known as producers of neurotoxic domoic acid (analogue of kainic acid), causing amnesia, Alzheimer's disease. It is accumulated by crabs, clams, fish.

One of the most significant element of hydrological, carbon and nitrogen cycles, which enables functioning the climatic system are INLAND WATERS, because in particular they are

- **An important source of aerosol particles, fluxes of heat, gases, momentum etc.**
- **An indicator of climatic changes (e.g., water level rise due to thawing permafrost, changing biodiversity, etc.).**

3.5 ARCTIC-BOREAL ANTHROPOGENIC SYSTEM – KEY TOPICS



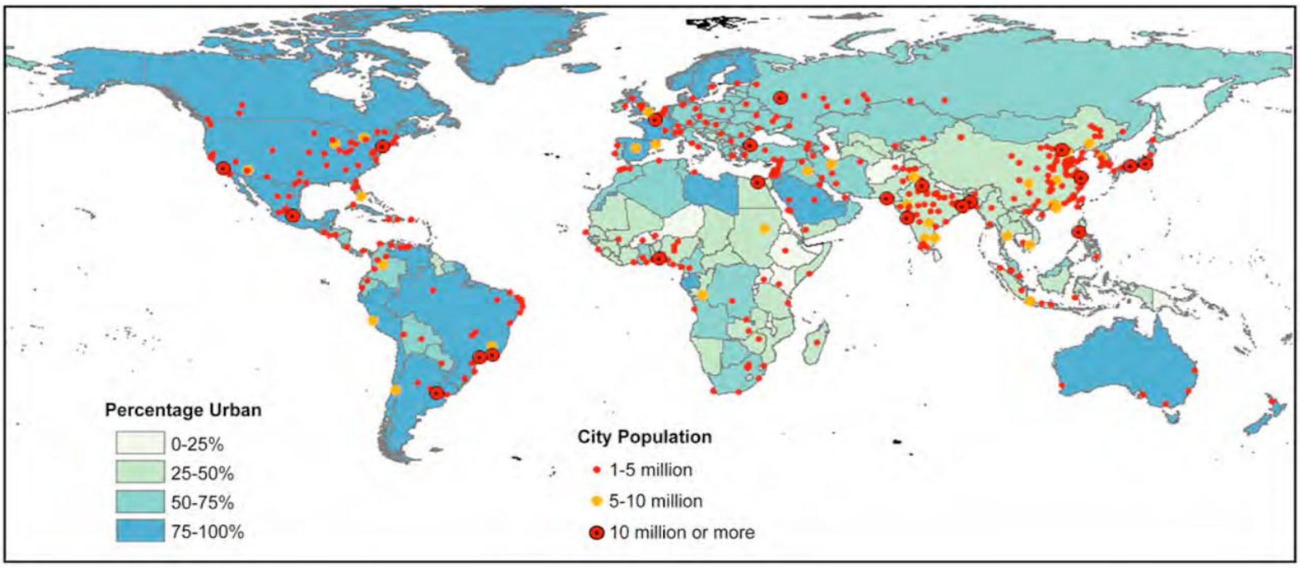


Fig.22 Global distribution of cities with size marked as the population in 2009 (ding)

SYNOPSIS. Environment of Siberia and European North has been subjected to serious man-made transformations during the last 50 years. Current regional level environmental risks are (Baklanov and Gordov, 2006): (i) direct damages to environment caused by accidents in processing of petroleum/gas production and transportation, including their influence on water, soil, vegetation and fauna; (ii) effect of deforestation (cutting and forest fires) on variations in Siberian rivers runoffs and wetland regimes; (iii) direct and indirect influence of forest fires and losses of gas and petroleum during their transportation to regional atmospheric composition; (iv) deposition of hazardous species leading to risks to soil, water and food chain. The position of Northern societies in the changing Arctic-boreal region is twofold: (i) Anthropogenic activities are directly interfering the natural environments and systems and indirectly accelerating the processes relevant to climate change and (ii) The Northern societies are effecting the sensitive environments and ecosystems of the taiga and arctic regions. The relevant aspects associated with the increasing interest and opportunities for utilization of natural resources of the Arctic region are the increasing traffic with increasing risk of accidents, industrial activity with the increasing anthropogenic emissions to land, atmosphere and water systems and land use changes (forest and agriculture surface areas). On the other hand climate change together with increasing threat of extreme weather events is increasing the risk of natural disasters such as forest fires, floods and landslides, infrastructure (buildings, roads, energy distribution systems) damages due to thawing permafrost extreme weather events (droughts, storms, heat). CHINA

3.5.1 ANTHROPOGENIC IMPACT

Land use and land cover changes

Fig.23

SYNOPSIS. Siberia is a “steam room” of natural resources for Russia, containing 85% of its prospected gas reserves, 75% – coal reserves, 65% – oil reserves. Siberia has more than 90% of Russian coal, 75% lignite, 95% - lead; approximately 90% molybdenum, platinum, and platinoides; 80% diamonds; 75% gold; 70% nickel and copper etc. (Korynty 2009). Industrial development of Siberia should be considered as one of most important drivers of future land use-land cover changes in Russian territory.

Q-9 How will human actions (land-use changes, energy production; efficiency, use of renewable energy sources) influence further environmental change in the region?

During the 20th century, a *considerable transformation of landscapes of tundra and taiga zones* in Northern Eurasia has occurred as a result of various industrial, socio-economic and demographic processes, basically dealing with industrial development of previously untouched territories (Bergen et al. 2013). This has led to the *decrease in the rural population* and, mostly after 1990s, to the *weakening of agricultural activity*. There has been a significant reduction in agricultural land use (in some marginal areas of unstable agriculture up to 70%) and its partial replacement by zonal forest ecosystems (Lyuri et al. 2010). As a result, these areas have become active accumulators of atmospheric CO_2 (Kalinina et al. 2009). These new forests (“substituting resources”) could form the basis for sustainable development in these regions if relevant management programs of the abandoned lands management of re-established forests will be implemented.

Inventory of Russian forests

***Dynamics of major classes of land cover, particularly forests*, are documented since 1961, when results of the first complete inventory of Russian forests were published. According to official statistics, the area of forests in Asian Russia increased at ~80 million ha during 1961-2009 (basically before middle of 1990s). Such a large increase is explained by (1) improved quality of forest inventory in remote territories; (2) decrease of unfrosted areas (~50 mln ha during the period) due to natural reforestation (mostly during the Soviet era as a result of forest fire suppression); (3) encroaching forest vegetation in previously no forest land – based on official statistics the area of cultivated agricultural land in the region decreased at ~10 million ha during 1990-2009. After 2000s the forested area in Siberia decreased, mostly due to fire and impacts of industrial transformation in high latitudes (Shvidenko, Schepaschenko 2014). The unsatisfactory situation is also observed in most populated areas with intensive forest harvest (particularly in southern part of Siberia and Far**

East). For example, in Krasnoyarsk kray area of forests decreased at 5%, mature coniferous forests – at 25% etc. Overall, typical processes in such regions are (Shvidenko et al. 2013):

- **dramatic decline of *quality of forests* (decrease of area of conifer forests; substantial reduction of areas of forests of high productivity; no ecological technology and machinery of logging that lead to destruction of logged areas; ineffective use of harvested wood etc.);**
- **unsustainable use of forest resources in northern regions with undeveloped infrastructure;**
- ***Insufficient governance and forest management* in the region – wide distribution of illegal logging, natural and human-induced disturbances etc.**

Future land use - land cover change will crucially depend upon, how successfully will be developed and implemented the strategy of sustainable development of northern territories, primarily use of renewable natural resources. The region requires urgent development and implementation of an effective system of adaptation of boreal forests to global change as an obligatory step of transition to adaptive forest management that is a substantial prerequisite of improving information for the Earth models. "Ecologization" of current practice of industrial development of previously untouched territories would allow for substantially decreasing physical destruction of landscapes and decline of surrounding ecosystems due to air pollution, water and soil contamination.

Expected changes of climate and environment will provide multiple and complicated impacts on ecosystems with following land cover changes. Alteration of fire regimes and thawing the permafrost will intensify the process of "green desertification" on large area. Warming will cause multiple effects in the soil-vegetation-snow interactions. For example, due to warmer climate, mosses and other vegetation grow faster that provides better thermo insulation of the permafrost in summer and better feeding conditions for reindeers; however, snow can easier accumulate on thicker vegetation, thus protecting deeper soil from cooling during winter (Tishkov, 2012).

Both Russia's North and East possess abundant mineral resource potential (Korytnyi 2009). The resource orientation of northern and eastern Russia's economy, which had not changed for centuries, only increased in the post-Soviet period and was influenced primarily by the product market. The natural resource development sector of the economy (extraction and exploration of natural resources over the region and forest industry in areas with sufficient infrastructure) will continue to prevail in the majority of these territories for the next decades. But serious socio-ecological problems remain. In the post-Soviet period, the criteria of profitability have become dominant in the decision making of enterprises and federal/regional governments, but it has not incorporated socially responsible and ecological criteria as well. Consequently, the local population is now faced with grave ecological problems in vast territories of industrial natural resource utilization. There is also social and ecological conflict between industrial exploitation of natural resources and traditional forms of nature management (i.e. reindeer breeding, etc.). Processes aimed at mitigating the negative impacts of resource utilization are weak because the federal tax and overall management policy, wide distribution of corruption etc.. Consequently, local authorities cannot fund adequate social and environmental protection measures. Finally this resulted in a large migration of population.

LAND USE – LAND COVER CHANGES - Reseach questions

- **How climate change will impact future land-use in the high latitudes? How much will it impact the Earth climatic system?**
- **How appropriate classes of integrated models should be improved to capture the specifics of high latitude regions?**
- **What is the connection between land use, land cover and biomass burning in Pan-Eurasia?**
- **What are the regional and global climate and air quality effects of biomass burning in Siberia?**
- **What is the effect of biomass burning on radiative forcing and atmospheric composition?**

Energy production

Fuel balance in Russia and Kazakhstan

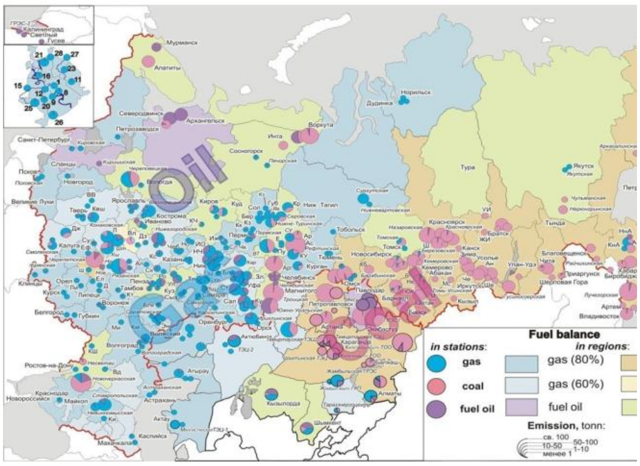


Fig. 25

SYNOPSIS. Specifics of fuel balance in Russia creates the raised levels of pollution. On average, specific emissions in northern and eastern cities of Russia where coal accounts for most of power generation are respectively 3 times higher than in cities where power is generated from gas or fuel oil. Geographical location, undeveloped infrastructure, climate and coal burning are the main reasons for increased levels of anthropogenic pollution in these areas.
CHINA

Crucial factor to emission dynamics and differentiation is *fuel balance*. In small towns, the low-capacity boiler rooms are the main source of emission. Usually the lack of financing leads to using bad quality coal and obsolete boilers. In steppe zone of Asian Russia, Mongolia, Kazakhstan and Buryatia the main source of emission in the traditional land use is burning of harvested residuals.

Dynamics of emission in Russia is largely determined by the *economic condition of production*. The economic crisis of 1990--1998 improved the environmental situation in the country: emissions generally decreased by 40%. However, the environmental problem not only remained unresolved, but significantly deepened and turned into a systemic problem. The most polluting industries were more resistant to declines in production; technological degradation took place; cleaning systems were eliminated; and production shifted to part-time and, consequently, inefficient capacity utilization. Significant amounts of pollution continued to be emitted from the domestic sector. Emissions decreased in most regions of the country and in 83% of cities (but much more slowly than production). As a result, the specific emissions (per product cost at comparable prices) had grown by the end of the 1990s in all categories of cities, except million-plus cities (Bityukova et al. 2010). All this provides negative impacts on ecosystems – there are about 2 million ha of technogenic desert around of Norilsk, probably the biggest smelter in the world – more than 2 million tons of pollutants per year (Groisman & Gutman 2013).

The second factor in the dynamics of human air pollution in Russian cities is the *specialization of industry inherited from the previous stages of development*. The influence of industry on the environment is characterized by such high differences that originally presented the technological features of the leading factor of anthropogenic impact on the area. In recent years, these differences are intensified due to the uneven modernization of different sectors.

Thermal power production is associated with high emissions in nearly all parts of the country. Indicators depend on various factors, including capacity and type of power station, age of equipment and, crucially, the type of fuel used. The climate both fuel balances define also absolute and specific levels of anthropogenic pollution and level branch distinctions.

Thus emission, its size, structure and dynamics are largely determined by factors inherited in the period of rapid industrialization and projects realized above 50 years ago, the combination of them gives rise to a large area emission in a variety of cities. First of all - it is the fuel balance of energy and utilities, creating a common background contamination. Secondly, industrial specialization, age and quality of assets. Institutional environment and the policy of regional authorities determine the level of assets modernization, which runs at different speeds and sometimes in different directions. Industry is the most dynamic and often the most modernized factor of the regional environmental state. But environmental problems are deeper, because elevated levels of emission are typical for the regions where the natural conditions increase pollution, having a high potential for pollution of the atmosphere. (*Kulmala et al MS*).

3.5.2 NATURAL HAZARDS

Weather extremes; floods, landslides, natural fires, thunderstorms

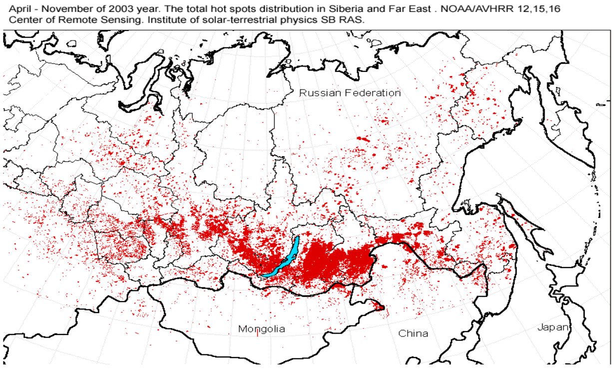


Fig.26Areas of vegetation fire in Asian Russia in 2003 (Baklanov)

Frequency and attitude of weather extremes have been substantially growing during last decades in the PEEX domain, and their acceleration is expected in future. The evolving impacts/risks/ costs of extremes on population, environment, transport and industry have so far not been properly assessed in the northern latitudes of Eurasia. Important research topics include inter alia : analysis and improvements of forecast of extreme weather conditions/ events; examination of the effect of wild fire on radiative forcing and atmospheric composition in the region; impacts of extremes on major biogeochemical cycles; impacts of disturbances in forests on emissions of BVOC and VONs etc.

SYNOPSIS. <to-be-modified>

Q-10 How do the fast the changes in physical, chemical and biological state of the different ecosystems, inland water, coastal areas affect the economies and societies in the region and vice versa?

The frequency of natural hazards will increase under climate change and corresponding transformations in the land cover (IPCC 2007). The North Eurasia territory is prone to natural hazards. Number of large dangerous hydro meteorological events that cause a substantial economic and social losses increased in Russia at about 2 times from 2001 to 2011 (State Report 2011). Hazards are related to the atmospheric processes of various temporal and spatial scales: strong winds, floods and landslides caused by heavy precipitation, fires caused by drought, extreme temperatures, etc. High temperature and long droughts substantially decline productivity and die-back in dark coniferous forests. The damage caused by a heat wave and following wild fires in central European Russia during summer of 2010 is estimated by Russian NGO at above 10 billion US dollars. Hurricanes are rather often in forest zone – so a hurricane of 16.07.2004 destroyed forests at the area of 78 thousand ha in the Irkutsk region (Vaschuk & Shvidenko 2006). However, there are no any reliable statistics on different types of natural hazards.

To build scenarios of their future frequency and behaviour, one should analyse the atmospheric mechanisms behind the circulation structures responsible for most of the atmospheric hazards – the cyclones (mostly responsible for relatively fast hazards such as winds and heavy precipitation) and anticyclones (responsible for slow large-scale hazards such as drought and fires). Studying the cyclones/anticyclones tracks, frequency and intensity can provide statistical basis to understand geographical distribution and properties of the major atmospheric hazards and extremes (e.g. Shmakin & Popova, 2006). For future climate projections, one should interpret atmospheric hazards

and extremes from the viewpoint of cyclone/anticyclone statistics and analyse possible changes in the geography and frequency.

Fires are the most important natural disturbance in the boreal forests that determine strongly the structure, composition and functioning of the forest. About 0.5-1.5 % of the boreal forest burn each year which is a significant land area since boreal forests cover 15% of the Earth's land area (Kasischke 2000, Conard et al. 2002). Already observed climate change substantially impacts current fire regimes in Northern Eurasia. More frequent and severe catastrophic (mega-) fires become a typical feature of the fire regimes. Such fires envelope areas of hundred thousand hectares within large geographical regions; lead to degradation of forest ecosystems; decrease the biodiversity; spread in usually unburned wetlands; cause large economic losses; develop a specific weather conditions over the area that is comparable with pressure systems (~30 mln ha and more); deteriorate life condition and health of local population; and lead to "green desertification" - irreversible transformation of forest cover for long periods (Shvidenko & Schepaschenko 2013). During the period of 1998-2010, the total burnt area in Russian territory is estimated at 8.2±0.8 x 10^6 ha; about two third of this area is in boreal forests. For this period, the fire carbon balance (total amount of carbon in the burnt fuel) is estimated at 121±28 Tg C year^{-1} (Shvidenko et al. 2011). Current model projections by end of the century suppose doubling of number of fires, increase the extent of catastrophic fires escaping from control, increase fire intensity, and 2-4 fold increase of amount and composition of carbon emissions due to deep soil burning (Gromtsev 2002, Malevsky-Malevich et al. 2008, Flanningan et al. 2009, Shvidenko et al. 2011).
During and after fires significant changes take place in the forest ecosystem including soil

- **significant amount of biomass is combusted and large amounts of carbon and nitrogen are released to the atmosphere in the form of carbon dioxide, other gases or particles (Harden et al. 2000);**
- **fire alters the microbial community structure in the soil and the structure of the vegetation (Dooley and Treseder 2012);**
- **fires determine the structure of the vegetation, succession dynamics and fragmentation of forest cover, tree species composition, and productivity of boreal forests (Gewehr et al. 2013)**
- **fire is a crucial driver which defines dynamics of carbon stock in boreal forests (Jonsson, Wardle 2010).**

Disturbances resulting from fire, pests' outbreaks and diseases also have substantial effects on emissions of BVOCs and VONs (Isidorov 2001) and consequently on the atmospheric aerosol formation. Acceleration of fire regimes will also affect the amount of black carbon in the atmosphere and has thus effect on albedo of the cryosphere.

Importance of weather extremes for functioning and surviving of northern ecosystems and their impacts on environment and population of the regions condition a need of a wide number of research questions within the PEEX research agenda including *inter alia* (1) analysis and improvements of forecast of extreme weather conditions/ events; (2) examination of the effect of wild fire on radiative forcing and atmospheric composition in the region; (3) impacts of extremes on major biogeochemical cycles; (4) ways to include extreme effects in Earth system models; (5) impacts of disturbances in forests on emissions of BVOC and VONs etc.

Health issues

Issue of polluting substances is a key source of atmospheric transformations in Northern Eurasia. In Russia about 60% of gross emissions into the atmosphere are due to stationary sources, i.e., industry and heating systems of public services. This figure is the most reliable for emission processes understanding in 1100 Russian cities with total population of over than 95.4 million people. Analyses of the *emission dynamics in Russian cities,* which have the main sources of emissions, are extremely important allowing identifying the factors of pollution (Bityukova, Kasimov, 2012).

Quantification of anthropogenic impact on air quality and long-term climate impacts is one of the research topics in PEEX. Major production centres for copper, nickel and some other non-ferrous metals, where the environmental situation is of great concern are situated in Siberian region; in Krasnoyarsk, Murmansk, Orenburg and Bratsk. They are followed by large centres with coal-fired power generating, such as Troitsk in Chelyabinsk Region, petrochemical and oil refining industries (Omsk, Angarsk, Ufa) and areas where oil mining is just beginning (Tomsk Region).

The factor of climate warming is considered among other known risk factors to population health – environment pollution, food problem, deterioration of drinking water, etc. The analysis of publications proves that influence of such climate change on the personal living is of both direct and indirect nature. In particular, climate leads to changes in borders of vegetation (Malkhazova et al., 2012). General changes of the areas of infectious diseases and those of the epidemiological situation are among the important indirect consequences of climate change (Malkhazova et al., 2013)

Permafrost degradation and infrastrctures

Fig.27

SYNOPSIS: Degradation of permafrost will course serious damages for infrastructure, nature, and water systems in the Arctic and boreal regions, for example

- **pipe-lines and constructions**
- **Technogenic influence upon the frozen ground - the major factor of industrial risks in cryolithozone**
- **Deformations of the roads and railroads in Russia, Mongolia and China**
- **Distribution of ions in soil water decreases from young to ancient landslides.**
- **Cryogenic land sliding leads to spatial and temporal changes of grasses and willow vegetation**
- **saline water is accumulated in local depressions of the permafrost table and forms**

highly saline lenses of ground water called 'salt traps'	**.**

Due to the large extent of permafrost covered areas in the Eurasian north, there are numerous infrastructural issues related to possible changes in the thickness and temperature of the frozen part of subsurface, and thus its mechanical soil properties. In the case of expected significant climatic warming the change in the cryosphere is probably one of the *most dramatic issues affecting the infrastructure* in the Eurasian north, as the infrastructure is literally standing on permafrost. Moreover, an interesting coupling may be related to the *decreasing ice-cover* of the Arctic Ocean resulting to increased humidity and precipitation on the continent and further thickening and longer *duration of annual snow cover*. Snow is a good thermal insulator and influences the average ground surface temperature, thus playing a potentially important role in speeding up the thawing of permafrost.

Future risk of increased damage to local infrastructure, such as buildings and roads, can cause significant social problems and cause pressure on local economy. Thawing permafrost is structurally weak and places variety of infrastructure at risk, for example buildings, roads, pipelines, railways, etc. Infrastructure failure can have dramatic environmental consequences, as seen in the 1994 breakdown of the pipeline to the Vozei oilfield in Northern Russia, which resulted in a spill of 160,000 tons of oil, the world's largest terrestrial oil spill (UNEP 2013). Maintenance and repair costs, caused by permafrost thaw and degradation, on infrastructure in Northern Eurasia has recently increased and will most probably increase faster in the future. This is especially prominent problem in discontinuous permafrost regions where even small changes in permafrost temperature can cause significant damage to infrastructure. Most settlements in permafrost zones are located on the coast, where strong erosion place structures and roads at risk. After the damage to the infrastructure, the local residents and indigenous communities are forced to relocate that can cause changes and disappearances of local societies, cultures and traditions (UNEP 2013).

Sea level rise and risk of accidents in the coastal regions

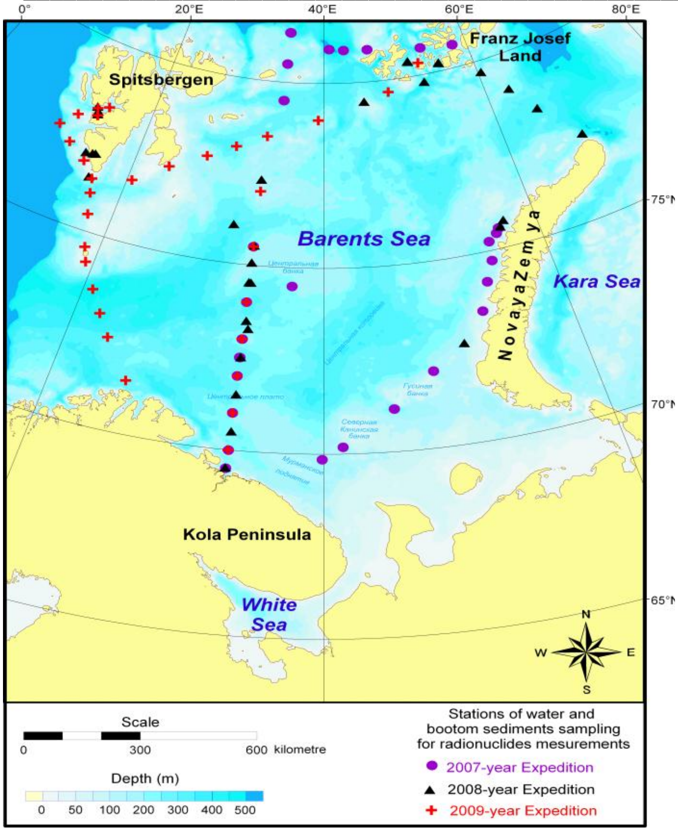


Fig.28. Stations of sampling for radioecolgical investigations (Matishov).

SYNOPSIS. In North Eurasia, from the eastern part of Barents Sea to the Bering Sea, the permafrost is located directly on the sea coast. In many of these coastal permafrost areas, the sea level rise and continuing permafrost degradation leads to significant coast erosion and to the possibility of collapse of coastal constructions such as lighthouses, ports, houses, etc. In this region, the sea level rise is united with the permafrost degradation in a complex way and requires focus in future studies. Understanding and measuring of *Artificial radionuclides in marine ecosystems' components is needed* to improve emergency preparedness capabilities *and* risk assessments of potential nuclear accidents. It is also need for to raise awareness and knowledge in the general public and associated stakeholders across the region as to the nature, challenges and associated risks with nuclear technologies, emergency preparedness and radioactivity in the environment.

The current state of radioactive contamination in terrestrial and marine ecosystems in the EuroArctic region by examining environmental samples collected from the Finnish Lapland, Finnmark and Troms in Norway, the Kola Peninsula and the Barents Sea. The results will provide updated information on the present levels, occurrence and fate of radioactive substances in the Arctic environments and food chains. It will also be possible to estimate where the radioactive substances originate from and the risks they may present in case of a possible accident.

Annual expeditions for sample collection are needed for the development of models to predict distribution of radionuclides in the northern marine environment and for the assessment of the current state of radioactive contamination in marine ecosystems in the Euro-Arctic region. With the view of recent developments and increased interests in the Euro-Arctic region for oil and gas extraction, special attention needs to be given to analyses of NORMs (Naturally Occurring Radioactive Materials) to understand current levels. The Work will focus on atmospheric modelling and the assessment of radionuclide distribution in case of accidents in EuroArctic region with the release of radioactive substances to the environment incl. nuclear accident scenarios for dispersion modelling.

Climate change for Arctic seas and shipping

- **Aim: To estimate consequences of climate change for the Arctic region on seas and shipping and effects of ship emissions on the environment and climate.**

- ***Estimate frequency, spatio-temporal distribution and impact of extreme weather events on shipping traffic. Improve satellite monitoring and modeling of ice formation and movement in areas of the Arctic Seas Route Shipping. Develop approaches to environmental challenges due to possible increase of Arctic shipping.***

Estimating and monitoring anthropogenic emission in the Arctic by using remote sensing

- **Aim: To refine and elaborate methods and design tools including GIS oriented to support decision-making in the fields of living including health, environment, industry, transportation and investment decisions taking into account different scale climate change and extreme weather patterns in the Arctic regions.**
- ***Analyze and harmonize available inventories of BC emission sources into the atmosphere over Russian and Nordic regions.***

3.5.3 SOCIAL TRANSFORMATIONS AND CLIMATE CHANGE

Fig.29

SYNOPSIS. Climate and weather affect controls strongly life conditions of Pan-Eurasian societies. They influence people's health, incidence of diseases, adaptive capacity, and give information to choose a variant of permanent residence or expedition living, acceptable age and gender structure of population. Vulnerability of societies, including their adaptive capacity varies greatly, depending on both the physical environment, as well as on the demographic structure and economic activities.

PEEX focus/consider/investigate scientific backgrounds and robust policies of adaptation and mitigation strategies (AMS) of the region's ecosystems with a special emphasis to the forest sector and agriculture. A high vulnerability of boreal forests to expected climate change including non-zero probabilities of irreversible thresholds and non-linear feedbacks will require development of a new type of dynamic vegetation models describing functioning, productivity and resilience of forest ecosystems under critical environmental condition.

Q- Key questions here relate to the ways in which Pan-Eurasian societies are vulnerable to climate change impacts and what actions are taken to adapt to the changes.

Demography

One of the important factors, yet poorly-quantified players in the Arctic climate change related to air quality; to *the short-lived climate forcers (SLCF)*, such as black carbon and ozone. The climatic impacts

of *SLCFs* are tightly connected with cryospheric changes and *associated human activities*. Black carbon has a special role when designing future emission control strategies, since it is the only major aerosol component whose reduction is likely to be beneficial to both climate and human health. *Health issues* are also important in the multidisciplinary studies of North Eurasia, as the comfort conditions of the humans and livestock are changing dramatically. These changes can be expressed in complex

parameters combining direct effects of, e.g. temperature and wind speed, and indirect effects of atmospheric pressure variability, frequency of unfavourable weather types such as heat waves or strong winds, combined action of several climatic and non-climatic factors, etc. During the last decades, generally the conditions for humans over North Eurasia become more comfortable, but the process varies significantly over the territory and seasons (Zolotokrylin et al., 2012).

Both Russia's North and East have small and diminishing population, mainly due to migration outflow (because of severe/unfavorable life conditions combined to economic crisis) in the 1990s (instead of the previous longstanding inflow). The combination of outflow and natural decrease (with some regional exceptions in several ethnic republics and autonomous regions (okrugs) with oil and gas industry) led to a steady population decline in most regions in Russia's North and East from 1990. Generally, in post-Soviet time the population of Russia's eastern part decreased by 2.7 mln people, population of Russia's Arctic zone decreased nearly by one third (500 thous.), opposite to the majority of world Arctic territories (Glezer, 2007*a, b*). Northeastern Russia was particularly remarkable: Chukotka Autonomous Okrug lost 68% of its population; Magadan oblast – 59%; Kamchatka krai – 33%

Geographical (environmental conditions and type of development of territory – urban or rural) and ethnic (the nomadic Northern people or migrant people, mainly Russians, Ukrainians, Tatars) factors influence the demography and settlement pattern in the region. Two different types of local human communities – of indigenous people and of newly arrived people – are formed by quite different people with specific physiological types and ways of adaptation to natural conditions and of interaction with environment. Therefore the influence of climate and other natural change upon these two types of communities should be studied separately.

Relatively smaller post-Soviet transformations have been exposed in the 1990 – 2000s to the local areas with a large proportion of indigenous people employed in traditional nature management, and the biggest –- with a larger share of Russian people and development of mining industry. The differences in the transformation between settlements with predominantly indigenous and predominantly Russian population are evident: for example, in Chukotka Autonomous Okrug: the former mainly remain and only have a slightly decreased population, the latter were liquidated or depopulated significantly (Litvinenko 2012, 2013).

When assessing climate and other natural change on human societies it should be taken into account that urban environment in many Russian cities in the North and in the East is poor and in its present-day state could scarcely mitigate unfavorable impact. Different climate parameters, such as

temperature (including seasonal, weekly and daily gradients; extreme values), strong winds, snowfalls, snowstorms, precipitation, etc. (including frequency of occurrence and duration) should be investigated. They influence people's health, incidence of diseases, adaptation potential, and give information to choose a variant of permanent residence or expedition living, acceptable age and gender structure of population, etc.

Integrated assessments for mitigation and adaptation together with other research

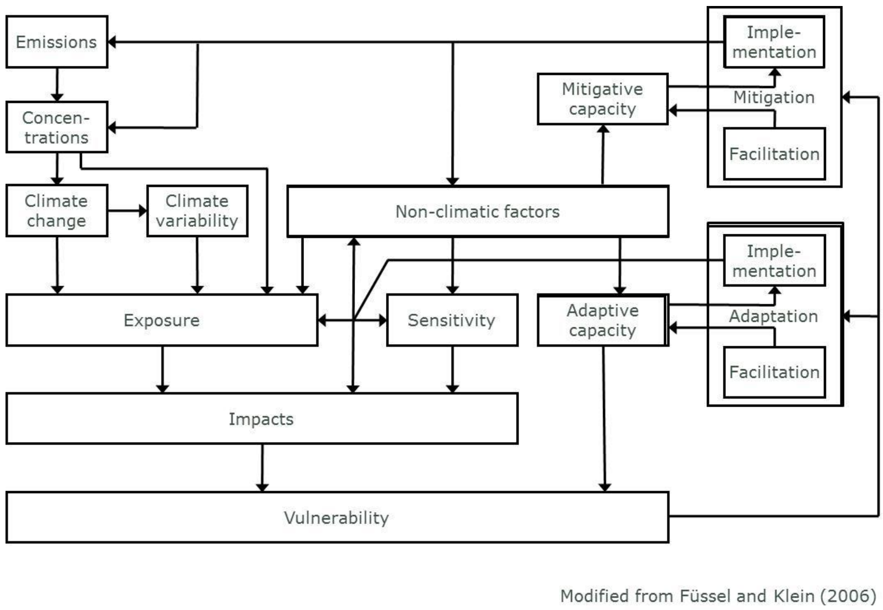


Fig. ref. Juhola

The PEEX domain consists of heterogeneous regions with various combinations of preconditions for the future challenges, such as: geographical disposition, climate conditions, history of socioeconomic development and different degrees of vulnerability to environmental changes. With the development of infrastructure, PEEX brings the resources of all participating communities together in order to answer the needs of each particular region with all the knowledge it is able to produce and expertise substantially improved within the international and interdisciplinary research network.

Development of AMS is a complicated task taken into account needs of decisions for underspecified dynamic systems of a high uncertainty; relevancy to consider dual strategy that integrates mitigating and adaptive measures; necessity to derive minimum mitigation standards from the limits of adaptation; needs for considering transformative adaptation measures; non-linear responses and feedbacks; uncertainty of economic and social developments etc.

Adaptive sustainable agriculture and forest management on the landscape-ecosystem basis will be considered as a cornerstone of ASM and *inter alia* includes (1) integrated land observing systems; (2) new strategy and institutional background of forest fire protection; (3) special measures for adaptation of structure of boreal landscapes to global change; (4) management of major

biogeochemical cycles etc. Taking into account that AMS is an ill-defined and quasi-manageable task, there is a need in development and implementation of new methodologies of applied system analysis by using open, iterative, distributed-modular approaches based on integration of shared pools of models, tools libraries, and observing systems. Very likely, no single AMS appears able to achieve all possible management objectives within the paradigm of sustainable ecosystems management, and AMS should be connected to regional climatic, ecological and social peculiarities.

Despite the importance of urban regions, they have been understudied in the sense of global environmental change (UGEC, 2012). Majority of the research has focused on the effect of urban areas have on the global climate change (Rosenzweig et al., 2010), whereas the impact of the climate change on urban areas has been less examined. The latter is particularly important as the focus of climate research in the field of climate change adaption is increasing and information related to climate-sensitive urban design and planning. Present-day Russian territorial and urban planning almost does not take into account the results of research works and forecasts of possible future natural change and hazards. There is no Master-Plan of spatial development of Russia. At the same time there is profound geographic information of this kind that could be incorporated into interdisciplinary studies. PEEX program should become a source of reliable data on zoning of the territory Arctic and boreal Pan-Eurasian region according to 40-years forecast. Furthermore, in high latitude ecosystems where rapid present and future climate change is expected to take place. Urban areas have particular traits, such as location, structure and density that make their residents and assets vulnerable to climate change (Gasper et al 2011). Several cities have now begun to prepare climate change adaptation strategies (Ribeiro et al. 2009, Hunt, Watkiss 2011). These strategies have taken different kinds of forms with most focusing on identifying local vulnerabilities and designing measures to reduce those vulnerabilities through various adaptation measures (Sanchez-Rodriquez 2009).

The PEEX large scale science questions are focued to support the development of development of anticipatory strategies of adaptation and mitigation of the region to climate change. Taking into account dramatic character of expected climate change and their impacts on environment, standards of life, health of population and ecosystem services, adaptation – reducing the vulnerability of society and ecosystems to climate change - is one of the most important socio-economic dimensions of the Northern Pan-Eurasian region. Adaptation includes adaptive capacity of ecosystems and socio-economic preparedness to realize the planned measures of adaptation. Adaptation and mitigation measures could be effective if they are part of a wide strategy which would involve all relevant sectors of national economy combining in common political and institutional framework. The PEEX research agenda thus also examines the ongoing political and institutional arrangements that are in place to address climate change.

RESEARCH QUESTIONS

- **What are the most probable trajectories of shifting of bioclimatic zones due to change of climate and environment? How will it impact actual redistribution of major land cover classes?**
- **What is the strategy of transition to sustainable land use under expected changes?**
- **What are regional specifics of expected acceleration of disturbance regimes (wildfire, outbreaks of insects and diseases)? How will it impact interactions between ecosystems and environment?**

● What is the buffering capacity and adaptation potential of boreal forests? How expected climate and environment change will impact functioning and vitality of boreal forests? How will it impact biodiversity?
● What is the probability of non-linear changes in functioning and vitality of ecosystems of high latitude (particularly, boreal forests as a tipping element)?
● What are specifics of transition to sustainable agriculture?

- **Biodiversity issues**
- **Old-growth forests**
- **Forest-agriculture transitions**
- **Reforestation**

3.6 FEEDBACKS, INTERACTIONS AND BIOGEOCEMICAL CYCLES

As whole Northern Pan-Eurasian Arctic-Boreal geographical regions covers wide range of human-natural system interactions and feedback processes, with humans acting as both the source of climate and environmental change and the recipient of the impacts. In urban and industrialised regions the process understanding of biogeochemical cycles include anthropogenic sources such as industry and fertilisers as indispensable parts of the biogeochemical cycles. The observed changes in the hydrological cycle and biogeochemical cycles are needed to construct and parameterize the next generation of Earth System models.

The effects of climate change on biogeochemical cycles are still inadequately understood and there are many feedback mechanisms that are difficult to quantify. They are related to, e.g., coupling of carbon and nitrogen cycles, permafrost processes and ozone phytotoxicity (Arneth et al, 2010) and some of them are related to emissions and atmospheric chemistry of biogenic volatile organic compounds (Grote & Niinemets 2008, Mauldin et al., 2012), subsequent aerosol formation (Tunved et al. 2006; Kulmala et al. 2011a) and aerosol-cloud interactions (McComiskey & Feingold 2012; Penner et al., 2012). For a proper understanding of the dynamics of these processes, it is essential to quantify the range of emissions and fluxes from different types of ecosystems and environments and their links to ecosystem productivity, and also to take into considerations that there may be previously unknown sources and processes (Su et al. 2011, Kulmala and Petäjä, 2011, Bäck et al 2010).

3.6.1.1. HYDROLOGICAL CYCLE

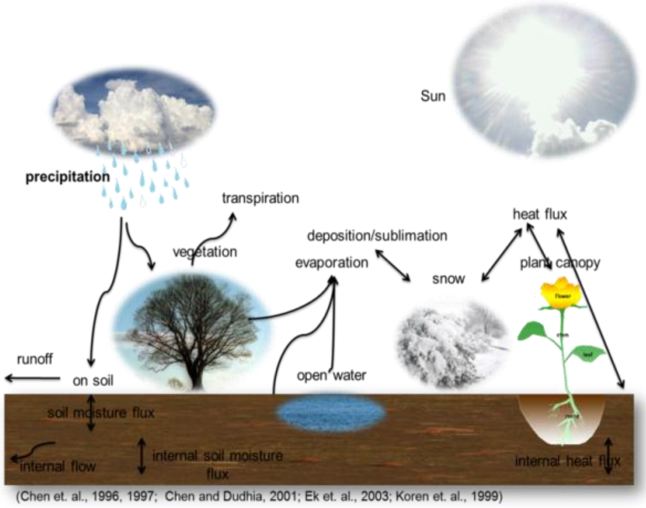


Fig.30

SYNOPSIS. The water cycle or hydrologic cycle is a composition of many different elements, which include evaporation of water from the surface of the ocean and bare soil, evapo-transpiration from vegetation, transport of water vapor in the atmosphere, cloud droplet formation and cloud dynamics, the mechanisms responsible for liquid and solid precipitation, glaciers and snow cover dynamics, surface and river runoff, and subsurface processes such as root dynamics in vegetation and groundwater flow. The Earth's climate changes may profoundly affect most elements of hydrological cycle giving rise to positive or negative feedbacks. Variations in the hydrological cycle often take place at regional or local scale (e.g. variations in ecosystem composition or runoff processes), they also can give rise to large-scale or even global changes in the water cycle.

Hydrological cycle is closely linked to other biogeochemical cycles. Climate change will alter the hydrological cycle affecting all the processes connected to the transport of water (e.g. *evapo-transpiration, atmospheric transport, phase transition and cloud formation, precipitation formation and its spatial distribution, melting and formation of sea ice, ocean currents and atmospheric general circulation, permafrost thawing and dynamics*). Since hydrology is also vital for biogeochemical cycles and lateral fluxes of elements such as carbon, nitrogen and phosphorus between terrestrial and aquatic ecosystems, changes in hydrology due to climate change are of crucial importance. In aquatic ecosystems heat fluxes can be impacted which in turn affects e.g. transfer efficiencies of carbon gases.

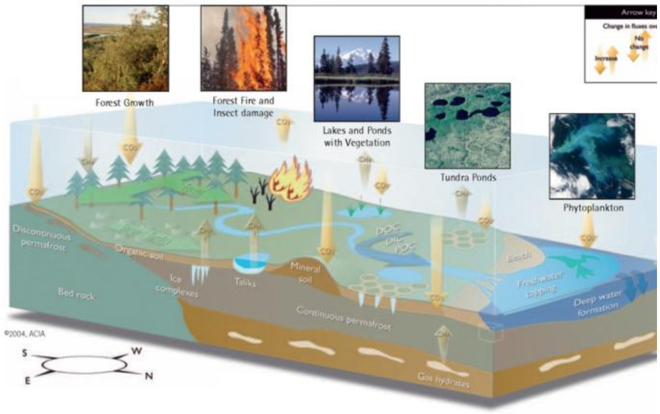
***Precipitation* is a critical component of the hydrological cycle influencing ecosystem properties, a major source of energy for driving atmospheric circulation, and the main sink for aerosol particles and most atmospheric trace gases. Knowledge of precipitation and its underlying processes are required in research and application disciplines directly related to the global energy and water cycle. This includes climate diagnostics and modelling, numerical weather prediction, now casting, hydrological applications, oceanography, flood forecasting, transportation, agro-meteorology and water resource management. It is crucial for understanding weather and climate on all scales and has a growing socioeconomic and political impact as society adapts to climate change. Precipitation has great spatial and temporal variability: knowledge of precipitation processes combined with the lack of global measurements with the necessary detail and accuracy limit the quantification of precipitation. This is especially true in the high-latitude regions where observations and measurements are particularly sparse and the processes poorly known.**

Recent retrievals of multiple satellite products for each component of the terrestrial water cycle provide an opportunity to estimate the water budget globally [Sahoo, A. K et.al., 2011]. Global precipitation is retrieved at very high spatial and temporal resolution by combining microwave and infrared satellite measurements (Huffman et al., 2007; Joyce et al., 2004; Kummerow et al., 2001; Sorooshian et al., 2000). Large-scale estimates of ET have been derived by applying energy balance, process and empirical models to satellite derived surface radiation, meteorology and vegetation characteristics (e.g. Fisher et al., 2008; Mu et al., 2007; Sheffield et al., 2010; Su et al., 2007). The water storage change component can be taken from satellite data and the water level in lakes and large scale river systems can be estimated from satellite altimetry with special algorithms developed for terrestrial waters (Berry et al., 2005, Troitskaya et al., 2012, 2013, Velicogna et al., 2012).

SPESIFIC RESEACH QUESTIONS - HYDROLOGICAL CYCLE

1.What are the future changes in natural and perturbed hydrological cycles from semi-arid to arctic zones in the Pan-Eurasian region?
2.Will climate change accelerate hydrological cycle in the Pan-Eurasian region and how will this affect precipitation patterns
3.How is wetland hydrology affected by the climate change?
4.How does ecosystem productivity change with changes in the hydrological cycle?
5.How are the large river systems changing due to temporal and spatial changes in precipitation patterns?
6.To what extent the increases in winter precipitation (which will come partly as snow) will affect the carbon flux of the PEEX domain?
7. How thawing permafrost in the PEEX domain affect the hydrological cycle (runoff, ?
8. How variations of the Arctic sea-ice extent ocean affect ?

3.6.1.2 CARBON CYCLE



SYNOPSIS. Warming climate could change carbon cycling in the Arctic. Boreal forest may absorb more carbon dioxide and methane from the atmosphere, however there is not much knowledge on the critical supply of recycled nutrients. Also carbon dynamics may change via increased forest fires and insect damage releasing more carbon to the atmosphere. Role of boreal and arctic lakes and chament areas as a carbon storage is unclear.

Fig. 31.

The terrestrial biosphere is a key regulator of atmospheric chemistry and climate via its carbon uptake capacity (Arneth et al 2010, Heimann & Reichstein 2008). The Eurasian area holds a large pool of organic carbon both in the soil and frozen ground, stored during Holocene and the last ice age and within the living biota (both above and belowground) but also a vast storage of fossil carbon. According to Land-Ecosystem Full Carbon Account (Shvidenko et al., 2010a; Schepaschenko et al., 2011a, Dolman et al 2012) the current estimates of C fluxes and storages in Russia estimates

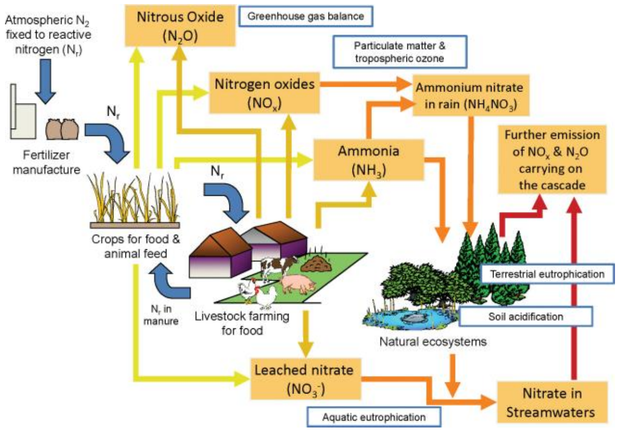
that terrestrial ecosystems of Russia served as a net carbon sink of −0.5-0.7 PgC yr−1 during the last decade. Forests provide for about 90% of this sink. The spatial distribution of this carbon budget shows considerable variation, and substantial areas, particularly on permafrost and in disturbed forests, show both sink and source behaviour. The already clearly observable *greening of the Arctic is going to have large consequences to the carbon sink in coming decades* (Myneni et al., 1997; Zhou et al., 2001). The net biome productivity is usually a sensitive balance between carbon uptake through forest growth and ecosystems heterotrophic respiration, and its release from and after disturbances like fire and insects or weather events such as exceptionally warm autumns (Piao et al., 2008; Vesala et al., 2010). This balance is delicate and for example in the Canadian boreal forest estimated the net carbon balance is about carbon neutral, since fires, insects and harvesting cancel the carbon release from forest NPP (Kurz and Apps, 1995; Kurz et al. 2008).

Although inland waters are especially important in lateral transporters of carbon, their direct carbon exchange with the atmosphere, so called outgassing, has also been recognized to be a significant component in the global carbon budget (Bastviken et al., 2011). In the boreal pristine *forested catchment lakes can vent ca. 10 % of the terrestrial NEE and thus weakening the terrestrial carbon sink* (Huotari et al. 2011). There is a negative relationship between lake size and the gas saturation and especially small lakes are a relatively large source of CO_2 and CH_4 (e.g. Kortelainen et al., 2006) (Vesala 2012). However, on landscape level large lakes can still dominate the GHG fluxes*. Small lakes also store relatively larger amounts of carbon in their sediments than larger lakes. Th*e role of lakes as long term sinks of carbon and simultaneously as clear emitters of carbon gases is strongly affected by the water column physics; especially in lakes with very stable water columns and anoxic hypolimnion sediment carbon storage is efficient but at the same time these kinds of lakes emit CH_4. In general, the closure of landscape level carbon balances is virtually impossible without knowledge on lateral carbon transfer processes and on the role of lacustrine ecosystems as GHG sources/sinks. Besides lakes the studies should include rivers and streams which could be more important than lakes as routes of terrestrial carbon and as emitters of GHGs.

Plant growth and carbon allocation in boreal forest ecosystems depends critically on the supply of recycled nutrients within the forest ecosystem. In the nitrogen limited boreal and Arctic ecosystems the biologically available nitrogen (NH_4 and NO_3) is in short supply although there The flux of assimilated carbon belowground may stimulate the decomposition of soil organic matter (SOM) and nitrogen uptake of trees (Drake et al. 2011, Phillips et al. 2011). The changes in easily decomposable carbon could Enhance the decomposition of old soil organic matter (Kuzyakov 2010) and turnover rates of nitrogen in the rhizosphere with possible growth enhancing feedbacks to vegetation (Phillips et al. 2011).

SPESIFIC RESEARCH QUESTIONS - CARBON CYCLE
1.What are the main sources and sinks of carbon in permafrost and non-permafrost regions? 2.How do the volatile organic carbon (VOC) emissions and condition of ecosystems change with changing climatic conditions? 3.How do different disturbances (fires, insects and harvests) differ in their effects on the greenhouse gas, VOC and pollutant balance in the PEEX domain? 4.How do elevated atmospheric ozone concentrations affect vegetation and carbon cycle in boreal and Arctic areas?

3.6.1.3 NITROGEN CYCLE



SYNOPSIS. In the Arctic, indications of high emissions of N_2O from the melting permafrost (Repo et al., 2009; Elberling et al., 2010) may significantly influence the global N_2O budget. In addition, the emissions of reactive nitrogen (NO, N_2O (Korhonen et al., 2013), HONO (Su et al., 2011)) from the soils tightly link the N cycling processes to aerosol formation in the atmosphere.

Fig.32

Nitrogen is the most abundant element in the atmosphere, however most of the atmospheric N_2 is unavailable for plants and microbes, and can only be brought to the terrestrial ecosystems via biological N_2 fixation. This process is present only in some organisms living in symbiosis with plants, making nitrogen as the main growth limiting nutrient in terrestrial ecosystems. Human perturbations to the natural nitrogen cycle have, however, significantly increased the availability of nitrogen in the environment. These perturbations mainly stem from the use of fertilizers in order to increase crop production to meet the demand of the growing population (European Nitrogen Assessment, 2010). The increased use of nitrogen and the fostered N cycling has also severe environmental problems such as eutrophication of terrestrial and aquatic ecosystems, atmospheric pollution and ground water deterioration (European Nitrogen Assessment, 2010).

In natural terrestrial ecosystems, the nitrogen availability limits the ecosystem productivity, and thus the carbon and nitrogen cycles are closely interlinked, whereas in aquatic ecosystems, the limiting factor for productivity is often phosphorus (P). Higher temperatures due to climate change accelerate nitrogen mineralization in soils leading to increased N availability, transport of N from terrestrial to the aquatic ecosystems, and potentially to large net increases in carbon uptake capacity of ecosystems. The large area of boreal and Arctic ecosystems impose that even small changes in the N cycling and feedbacks to carbon cycling can be significant in the global scale (Erisman et al., 2011). For instance, the increased atmospheric N deposition has led to higher carbon sequestration of boreal forests (Magnani et al., 2007), which, however, can be largely offset by the simultaneously increased soil N_2O emissions (Zaehle et al., 2011). In the Arctic, indications of high emissions of N_2O from the melting permafrost (Repo et al., 2009; Elberling et al., 2010) may significantly influence the global N_2O budget. In addition, the emissions of reactive nitrogen (NO, N_2O (Korhonen et al., 2013), HONO (Su et al., 2011)) from the soils tightly link the N cycling processes to aerosol formation in the atmosphere. Understanding these processes, the interactions of reactive N with the cycles of carbon and phosphorus, atmospheric oxidation, and aerosol formation events,

and their links and feedback mechanisms is therefore essential in order to fully understand how the biosphere affects the atmosphere and the global climate (Kulmala & Petäjä 2011).

SPESIFIC RESEARCH QUESTIONS - NITROGEN CYCLE
1.How sensitive are the boreal and Arctic ecosystems to accelerated nitrogen mineralization?
2.How will the changing climate influence N cycling and the emissions of reactive nitrogen into the atmosphere?
3.How will the N2O emissions from the Arctic respond to changing climate?

3.6.1.4 PHOSPHORUS CYCLE

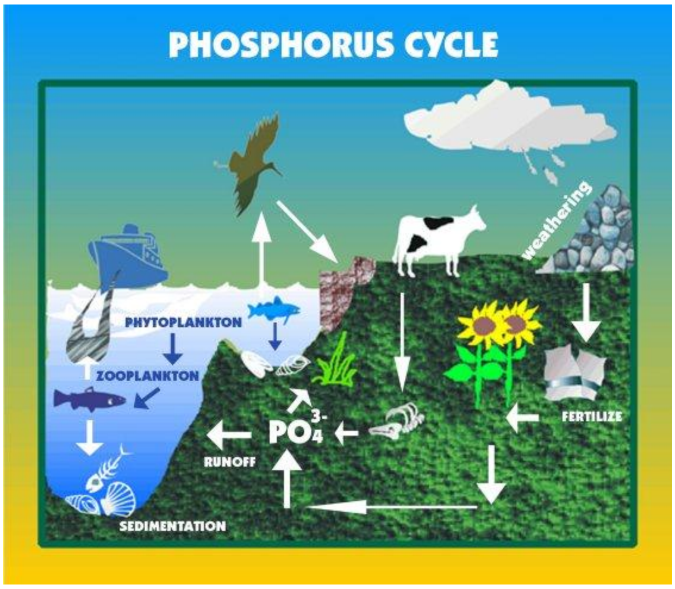


Fig. 34

SYNOPSIS. South western Siberian soils have lately been reported to contain high concentrations of plant-available P (Achat et al., 2013), which may enhance C sequestration of the ecosystems taken that N is not too limited. In freshwater ecosystem, excess P leads to eutrophication processes, which have ecological consequences, such as loss of biodiversity due to changes in physicochemical properties and in species composition (Conley et al., 2009). Due to the scarcity of studies focusing on ecosystem P cycling, the effects of climate change on physicochemical soil properties and P availability, and the interactions of P cycle with the cycles of carbon and nitrogen are largely unknown.

Phosphorus (P) is along with nitrogen (N) one of the limiting nutrients for terrestrial ecosystem productivity and growth, and in marine ecosystems, P is the main limiting nutrient for productivity (Whitehead and Crossmann, 2012). Role of P in nutrient limitation in natural terrestrial ecosystems has not been recognized as widely as in case of N (Vitousek et al., 2010).

In global P biogeochemical cycle, *main reservoirs are in continental soils* where P in mineral form is bound to soil parent material and *in ocean sediments*. Sedimentary P is originated from riverine transported material eroded from continental soils. The atmosphere plays a minor role in P cycle, and P cycle does not have a significant atmospheric reservoir. Atmospheric P is mainly originated from aeolian dust and sea spray. Gaseous forms of P are scarce and their importance for atmospheric processes is poorly known (Glindemann et al., 2005).

In soils, P is in mineral form bound to soil parent material such as in apatite minerals. Amount of P in the parent material is a defining factor for P limitation, and weathering rate determines the amount

of available P in ecosystems in which most of the available P is in organic forms (Achat et al., 2013; Vitousek et al., 2010). In ecosystems growing on P depleted soils, the productivity is more likely to be limited on N in early successional stages and gradually shift towards P limitation along with age of site (Vitousek et al., 2010). *South western Siberian soils have lately been reported to contain high concentrations of plant-available P (Achant et al., 2013), which may enhance C sequestration of the ecosystems taken that N is not too limited*. In freshwater ecosystem, excess P leads to eutrophication processes, which have ecological consequences, such as loss of biodiversity due to changes in physicochemical properties and in species composition (Conley et al., 2009). Due to the scarcity of studies focusing on ecosystem P cycling, the effects of climate change on physicochemical soil properties and P availability, and the interactions of P cycle with the cycles of carbon and nitrogen are largely unknown.

SPESIFIC RESEARCH QUESTIONS - PHOSPORUS CYCLE
1. What are the links between phosphorus in atmosphere, biosphere and hydrosphere?
2.How are the phosphorus fluxes determined under changing climatic conditions?

3.6.1.5 SULFUR CYCLE

SYNOPSIS. Sulphur is released naturally through volcanic activity as well as weathering of the Earth crust. Largest natural atmospheric sulphur source is oceanic phytoplanktons emitting dimethyl sulphide (DMS), which is converted to sulphur dioxide (SO_2), sulphuric acid (H_2SO_4) and methyl sulphonic acid (MSA) via gas phase oxidation. However, human activities have a major effect on the global sulfur cycle via vast emissions of SO_2 due fossil fuel burning and smelting. Main sink of SO_2 is oxidation to sulfuric acid in liquid phase and removal from the atmosphere due precipitation. SO_2 is converted to H_2SO_4 also in gas phase oxidation processes. Gas phase H_2SO_4 triggers new aerosol particle formation in the atmosphere resulting to effects in cloud cover and regional and global climate.

The global anthropogenic SO_2 emissions are predicted to significantly decrease by the year 2100 (IPCC, Special Report on Emissions Scenarios, SRES, 2000). Emissions in Europe and North America started to decrease already in 1970's but that decrease is still globally overwhelmed by increasing emissions in East Asia and other strongly developing regions of the World (Smith et al., 2011). Global present day anthropogenic SO_2 emissions are ca. 120 Tg/yr with Europe, former Soviet Union and China being responsible for approximately 50 percents of the global emission (Smith et al., 2011). Global natural emissions of sulphur, e.g. in form of DMS, are significantly smaller, few tens of Tg sulphur / yr (Smith et al., 2001), and anthropogenic emissions dominate over continents. Main sources of SO_2 are coal and petroleum combustion, metal smelting and shipping with minor contributions from biomass burning and other activities. SO_2 emissions have large spatial variability in Eurasia. Smelters in the Russian arctic areas are emitting vast amounts of SO_2 significantly affecting the regional environment. Smelter complexes in Norilsk, with annual emission of 2 Tg (Blacksmith Institute, 2007), alone responsible for more than 1.5% on global SO_2 emissions. On the other hand, the still remarkably

high emissions from Kola Peninsula smelters have significantly decreased within past decades (Paatero et al., 2008) thus altering the impact of human activities to regional climate and environment. Generally, existing anthropogenic activities are slowly becoming more sulphur effective and less polluting sof new activities and infrastructures counteracting this development.

The future changes in SO_2 emissions in the PEEX research area are partially poorly known. In northern Eurasia, natural resources – fossil fuels, metals, minerals and wood – are vast and their utilization due increasing demand is becoming more and more attractive. This, most likely, increases human activities – e.g. mining, oil drilling, shipping – in that area (see e.g. Smith, 2010 and references therein). Emissions in China are rapidly increasing while the emissions in Europe have significantly decreased within last decades.

Most of natural and anthropogenic SO_2 is removed from the atmosphere by liquid phase oxidation to H_2SO_4 and precipitation. In areas with high sulphur loadings, acid rain leads to acidification of soils and waters. Main sink of sulphur is the oceans. Some SO_2 is oxidized to H_2SO_4 in the gas phase in a reaction chain initiated by the reaction of SO_2 with hydroxyl radical, OH. Especially in forested areas of Eurasia a second important oxidant, stabilized Criegee Intermediate which origins from biogenic VOC emissions, produces significant amounts of H_2SO_4. (Mauldin et al., 2012). Gas phase sulphuric acid plays a key role in Earth's atmosphere triggering secondary aerosol formation thereby connecting anthropogenic SO_2 emissions to global climate via indirect aerosol effects on radiative forcing (Kulmala 2013). Sulphuric acid particles are also connected to air quality problems and human health deterioration. Understanding the spatial and temporal evolution of SO_2 emissions in northern Eurasia and the role of biogenic emissions to gas phase concentrations of H_2SO_4 is crucial for understanding the impact of anthropogenic activities and SO_2 emissions to air quality, acidification as well as to regional and global climate.

SPESIFIC RESEARCH QUESTIONS - SULFUR CYCLE
1.What effect does the sulphur deposition have on ecosystem resilience in the boreal and Arctic conditions? 2.How does atmospheric N and S deposition affect the ecosystem vitality and productivity, and what are their links to hydrological conditions?

4. PEEX RESEARCH INFRASTRUCTURES (F2)

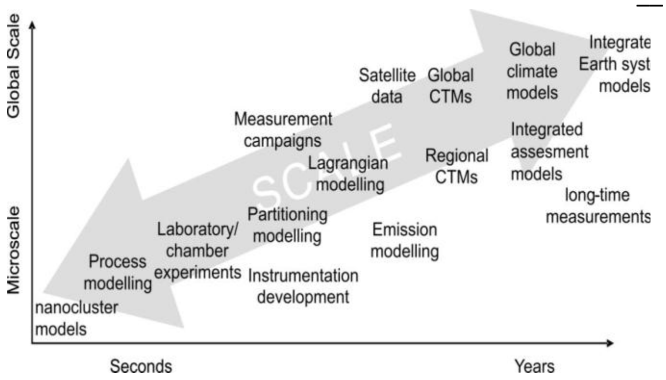


Fig. 35 PEEX infrastructures reaching over spatial and temporal scales pertinent to the PEEX science.

SYNOPSIS: Solutions to the interconnected global environmental problems can be provided only with a harmonized and holistic approach that utilizes all available tools in unison. The PEEX approach uses tools, which cover measurements, observation systems and models representing different spatial and temporal scales; starting from microscale to global scale and from seconds to years. The vision of the PEEX infrastructures is to provide comprehensive and reliable harmonized data products for the PEEX science community as well as to other end users.

The PEEX Foci-2 is to establish a sustainable, long-term Pan Eurasian research infrastructure including measurement hardware, software and validated and harmonized data products to be implemented to the models of appropriate spatial, temporal and topical focus. The PEEX research infrastructures include comprehensive field observations on atmosphere, biosphere, hydrology, cryosphere and oceanic observations and targeted laboratory experiments. The approach includes a hierarchical station network as well as a suite of modelling tools. In practice the PEEX network is based on existing infrastructures, which are updated and harmonized where deemed necessary. The most comprehensive stations, super-sites act as testbeds, which operate as integrated research platforms. The infrastructure development and is made in concert with the currently on-going European infrastructure projects. Outputs of the PEEX monitoring system will be used for appropriate modeling within the PEEX domain and will be distributed to the stakeholders and public.

The PEEX toolbox includes a hierarchical station network consisting of super-sites for holistic in-situ understanding of the atmosphere-biosphere-anthroposphere continuum at the process level and, flux stations for targeted regional aspects and observations. The standard stations in turn would provide the spatial in-situ variability of the selected parameters at the ground level. A suite of satellites extends the observations to global scales and provides also the vertical structure of the atmosphere as well as data on biosphere, land-use and hydrological cycle.

A suite of models covers the processes leading to e.g. changes in the atmospheric composition, biosphere functions and cloud formation. Boundary layer modeling is utilized in analyzing the vertical structure, atmospheric stability whereas the regional chemical transport models integrate chemistry and physics of the atmosphere for specific tasks such as trans boundary pollution transport. The smaller scale modeling together with the observational data is fully utilized in global earth systems models which provide tools to assess the overall effects of feedback mechanisms and the anthropogenic influences of the environmental change.

Fig.36. The PEEX measurements provide crucial data on earth system behaviour.

SYNOPSIS. **A coherent and coordinated observation programme of the Arctic-Boreal regions needs to be built on the co-operation with the existing Arctic / boreal stations and networks, such as Stations for Measuring Ecosystem – Atmosphere Relations (SMEAR), IASOA – International Arctic Systems For Observing the Atmosphere, INTERACT - International Network for Terrestrial Research and Monitoring in the Arctic, Russian System of Atmospheric Monitoring (RSAM) Integrated Land Information System of Russia. It is essential that atmospheric, terrestrial and marine components of the PEEX observation program respond to quality objectives of international networks, such as AERONET, NDACC, TCCON or research infrastructures such as ICOS, INGOS, ANAEE, ACTRIS or GAW.**

The establishment of PEEX observing component with the long-term goal of contributing to the European Integrated Observations component of GEOS is essential. Networks and Research Infrastructures have been established in the different domains with the common objective to deliver to the scientific community high quality data documenting variability and trends of essential variables driving the atmospheric, terrestrial and marine components of the ecosystem. PEEX observations and interpretation should embrace the whole of Northern Eurasia and Arctic in order to reflect the gradient from arctic tundra to boreal forests, mires, steppes, deserts, and broadleaf forests (Kulmala et al MS). Information from satellite regions (i.e. Caucasus, Northern China, etc..) may also be of interest for the domain. PEEX continuous atmospheric and ecosystem *measurement programme* will developed in line with the on-going European Union research infrastructure development on several domains: ACTRIS (Aerosols, Clouds, and Trace gases), ANAEE (terrestrial ecosystem research), ICOS (global carbon cycle and greenhouse gas emissions), LIFEWATCH (biodiversity data and observatories), and EXPEER (terrestrial ecosystem research) (Kulmala et al. 2011). At the first phase the current on-going research activities in in Europe can provide research collaboration like providing up-to-date results on relevant research topics in the arctic regions or know-how, how to start the designing the next-generation research infrastructures in a coherent manner, or training for exploitation of infrastructure measurements. These type of arctic activities are the Nordic Center of Excellences CRAICC (Cryosphere-atmosphere interactions in a changing Arctic climate) and DEFORST (Interactions between climate change and the cryosphere) funded by Nordforsk or bilateral initiatives between Russia and EU member states such as international associated institutes (VOSTOK, YAK-AEROSIB Between France and Russia). The WMO training programs

GAW-TEC is an additional instrument for building the proper expertise for the observing program of PEEX.

Table X. An exemplary list of field data provided by the PEEX in-situ infrastructures and connecting satellite observations.

IN SITU field experiments made on ground-based stations, aircraft and ships provide data e.g. on: • **short-lived pollutant concentrations and greenhouse gas concentrations in air and biosphere and their deposition on vegetation, snow and ice surfaces *)** • **seasonal evolution of terrestrial and oceanic snow and ice cover *)** • **surface short wave and long wave radiation and heat fluxes between the compartments *)** • **cloud properties **) can be complemented with satellite observations*** • **boundary layer structures and vertical profiles of gases, aerosols and clouds *)** • **spatial variability of relevant meteorological variables** • **ecosystem functioning, e.g. primary productivity, transpiration and water use efficiency, soil respiration, nutrient cycling** • **production, exchange and fluxes of volatile organic compounds, methane, nitrous oxide between the ecosystems and the atmosphere** • **vegetation phenology, length of growth period, greening** • **chronosequences of different disturbances like forest fires** • **population migration (birds, insects, mammals, plants), species extinction, invasive species occurrence** • **transitions from woodlands to grasslands/tundra or vice versa, treeline advancement towards higher and northern latitudes**

Harmonization of PEEX data products

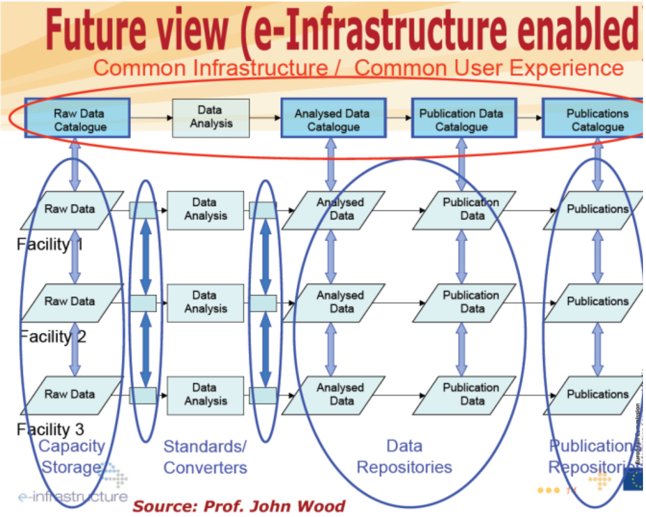


Fig.36 The PEEX research infrastructure data flows.

SYNOPSIS. The PEEX program will produce extensive amount of measurement data, publications, method descriptions and modelling results. The PEEX data product plan is built on the establishment of permanent PEEX integrated platforms documenting variability of the various components of the ecosystem (atmosphere, terrestrial, marine) utilizing state-of-the-art data management procedures incl. automatic data submission directly from the measurement sites, data processing, quality control and conversion to international user and storage communities. The PEEX data will be harmonized with the international measurements systems and data formats in collaboration with the existing Arctic and boreal infrastructure projects

The organization of databases, data products and formats will be made in collaboration of on-going European and European-USA activities. Development of instrumented sites is not trivial and will require not only the technical expertise for best measurement practices but also in parallel the development of data management capacities to utilize the scientific potential of the collected data. Data management capacities embrace all aspects that facilitate the use of data by external users, from data storage to access to both raw and processed data and data products. In this framework, the need for standardized data products is a strong request from the user communities. PEEX should therefore implement data portals, (semi) real-time automatic data processing workflow tools, data retrieval algorithms and user interface that shall facilitate use of data and, in the longer term, increase the number of users. Most relevant projects in years 2013-2020 are linked to on-going EU-FP7-projects either through the single research infrastructures already mentioned or through theFP7-ENVRI-project "Common Operations of Environmental Research Infrastructures" in Europe, a collaboration effort of the ESFRI Environment Cluster and to develops common e-science components and services for their facilities, or through FP7-COOPEUS-project "Transatlantic cooperation in the field of environmental research infrastructures" between Europe and USA. The aim of these research infrastructure projects is the identification of next generation user friendly data structures and formats that will facilitate the inter-domain and multi-disciplinary approach relevant to PEEX. The key institutes in European scale are those holding relevant data centers such as the Norwegian Institute for Air research, NILU (Norway), where major part of the atmospheric relevant dataset/ products are currently stored and distributed, or the different components of the World data centers of WMO-GAW program.

The data products and infrastructures development in environmental sector in in Europe are currently performed by European Strategy Forum on Research Infrastructures (ESFRI). As a part of building the European Union research area and to ensure Europe's competitiveness in "frontier" research EU is listing the European world class research infrastructures in the (ESFRI) roadmap. PEEX data formats will follow these new European data product and database standards.

4.1 THE PEEX HIERARCHICAL STATION NETWORK

Fig.36 An example of existing research infrastructures and activities: the Obukhov Institute of Atmospheric physics measurements (Elansky, 2012).

SYNOPSIS. The Arctic-Boreal regions are currently lacking of a coordinated, coherent in-situ observations despite its critical role in the climate system. The first step towards the coherent atmosphere-ecosystem measurements is an establishment of a Preliminary Phase Observation Network based on the already existing activities. There are already several state-of-the-art field stations which provide a pilot approach. In the full PEEX network there would be one station in every 2000-3000 km across Siberian region representing all major ecosystems.

The PEEX labelled network of field stations from Scandinavia to China with a continuous, comprehensive science program is based on a hierarchical station network (Hari et al. 2009) set up for the comprehensive measurements measuring fluxes, storages, and processes providing quantitative process understanding of the multidisciplinary system (Hari and Kulmala, 2005).

Network of hierarchical station network consists of:
a) a suite of standard stations - the upgraded weather stations
b) flux stations - similar to Fluxnet stations
c) Flag ship stations - similar to SMEAR-type supersite stations

The supersites with the comprehensive and integrative measurement capacity are capable of probing the sources and sinks for greenhouse gases and aerosols and providing ground-based validation data for the remote sensing instrumentation and airborne observations. The flag ship station data are needed to understand the climate system behaviour (Hari et al. 2009).

The supersite stations measuring meteorological factors and atmospheric composition (including both greenhouse gases and short-lived climate forcers, gases and aerosols) simultaneously together with several processes and phenomena in a forest ecosystem enable comprehensive understanding of feedbacks and connections, combining the ecosystem compartments and the surrounding atmosphere, lithosphere, cryosphere and hydrosphere in a

dynamic manner. These SMEAR-type atmosphere-ecosystem measurements include (i) carbon and nitrogen fluxes (photosynthesis, respiration, growth), (ii) trace gas exchange (reactive carbon compounds, nitrogen compounds, ozone), and (iii) hydrological fluxes. Supporting measurement points can be set up around the main stations with the aim to observe e.g. vegetation characterization characteristics and soil microbial processes, or soil atmosphere interactions (such as CO2 and other greenhouse gas fluxes, Pumpanen et al. 2013). It is crucial to have one supersite in all major ecosystem areas (Fig. 36), which in practice would mean a station in every 2000 - 3000 km in the PEEX domain.

During the PEEX preliminary phase, several targeted field experiments are performed to investigate key processes and feedback mechanisms in more details. The in situ field experiments are performed at the ground-based stations together with observations on board aircrafts and ships, utilizing also existing data sets and archives. In the second phase of PEEX, several new pan-Eurasian field stations are planned to be built to provide for improved spatial coverage. In practice, at least one supersite with a comprehensive water-soil-atmosphere-cryosphere measurement for every representative biome is needed.

Table YY. Observations in the hierarchical station network stations and the station roles in the network

STANDARD STATION	
The standard stations provide key parameters at the ground level with a dense geographical grid. The measurements include the following:	
1)	**standard meteorological parameters and their profile in the atmosphere (temperature, relative humidity, wind direction, wind speed, precipitation)**
2)	**extended meteorological parameters (solar radiation: global radiation, photosynthetically active radiation and net radiation)**
3)	**measurements on the properties of the soil and ground: temperature profiles, soil water content and tension, snow depth and water content**
4)	**aerosol particles: aerosol number concentration**
5)	**trace gas measurements: O_3 and NO_x concentrations**
6)	**ecosystem measurements: leaf area and mass, amount of soil organic matter (annually), biomass inventory (annual), deposition of nutrients, such as nitrogen, phosphorus, potasium and calcium**
FLUX STATIONS	
The aim of the flux stations is to provide information on fluxes in the ecosystem level as well as the information of the basic stations. The station capacity include:	
1)	**All measurements done at the standard stations**
2)	**micrometeorological fluxes of carbon dioxide, water, heat and momentum between the ecosystem and the atmosphere**
3)	**aerosol number size distributions**
4)	**concentration and profile measurements of CO_2, O_3, SO_2, O_3, NO, NO_2 and N_2O**
5)	**focused campaigns to determine the connections between the fluxes and environmental and ecosystem factors**
FLAG SHIP STATIONS	

The flag-ship stations provide state-of-the-art observations of the atmospheric concentrations and material and energy fluxes between the atmosphere-biosphere continuum. In the PEEX network, flag-ship stations are needed in each ecosystem types and regions in the PEEX domain. Together with all observations conducted at standard and flux stations, a more comprehensive monitoring of processes and contributing factors at high spatial and temporal resolution, such as:

1) All observations conducted in standard and flux sites
2) comprehensive characterization of trace gas concentrations (volatile organic compounds (VOC), sulfuric acid, ammonia, methane)
3) emissions and profiles of VOCs in connection to the vegetation and soil
4) atmospheric ion size distribution
5) cloud characterization (cloud radar)
6) advanced characterization of solar radiation (spectral dependency, PAR intensity within the biosphere)
7) advanced characterization of atmospheric turbulence inside the surface layer (e.g. below canopy)
8) atmosphere-biosphere-soil interactions, including monitoring of nutrients (nitrogen, phosphorus, potasium and calcium, and H+ concentrations) in soil water, and water flow in the trees, CO_2 and H_2O fluxes between the soil and the atmosphere, use of stable isotopes in studies of processes, such as photosynthesis and de-composition of soil organic matter
9) development of novel instrumentation and in-depth comparison with the existing data
10) hosting intensive field studies
11) inter-platform calibrations and verifications (in-situ, satellite, airborne).

4.1.1 CRYOSPHERIC AND MARINE PROCESSES PART OF THE OBSERVATION SYSTEM

SYNOPSIS: The cryosphere in the Arctic is changing rapidly. Observations on the cryospheric current and past conditions include deep bore holes, permafrost sites, buoy / floating stations in the Arctic Ocean, observations onboard ships, and geophysical observations onboard aircrafts. These activities are ongoing already. A good example is Nordic center of Excellence: DEFROST sites operating in Russia, Finland, Sweden, Iceland and Norway.

Fig. 37 Cryospheric observations within DEFROST.

A crucial part of the ground based network is to develop instrumentation and infrastructures for observation of fundamental cryospheric processes, improve methods of geocryologic and geoecological monitoring of natural and anthropogenic systems and conduct training of specialists for obtaining objective information about the current state of the Arctic geosystems. These are the necessary conditions for development methods and tools for maintaining the stable functionality of the Northern infrastructure supporting the high-quality living standards of the native population and newcomers.

Improving environmental geocryological forecasting is important as it has far reaching implications for geopolitics and environmental security. It is especially important to forecast the destructive processes in the natural systems that could cause environmental disasters, because of vulnerability of Arctic and Subarctic regions to the natural and anthropogenic influences. This is the area of the most dramatic interactions between the cryosphere and other geospheres affected by dynamics, thermal, and geological processes.

The PEEX marine component is based on new and existing in situ observations from the Arctic Ocean in combination with remote sensing observations on the ocean surface temperature, colour, and wave field, as well as sea ice type, concentration, extent, thickness, albedo, surface temperature, and snow on sea ice. Considering new observations in the Arctic Ocean, the most important ones will be those made at drifting ice stations and research cruises, as well as by moorings, drifting buoys, under-ice gliders, and (manned and unmanned) research aircrafts during topical field studies.

Temporal development of permafrost will be monitored using the existing subsurface temperature observatories in Eurasia. As a special additive to surface and meteorological data, borehole temperatures, which can be used for forward and inverse modelling of ground surface and subsurface temperature development, will be compiled from previous historical data sets and new observations. Selected shallow (<100 m) and deep (>1 km) boreholes will be instrumented for the long-term observations of temperatures. A set of 'borehole observatories' will be established extending from Europe to Siberia and China. This will require organized international collaboration in initiating and in running the efficient subsurface monitoring program as part of the PEEX infrastructures.

In the resources point of view, a relatively low geothermal gradient may allow the temperature-depth behaviour to be within the stability field of methane hydrates, and it is one of the essential questions in the PEEX programme to improve understanding of the potential release of methane and (other greenhouse gases) from the layers of the thawing permafrost. Prediction and modelling of the methane gas release requires well-coordinated observations systems, including a suite of shallow and deep boreholes with thermal instrumentation, estimation of the amount of gas-hydrates in situ, and application of indirect geophysical proxies for monitoring the time-dependent changes in the permafrost layers. One of the most interesting techniques would be the use of ground-based and airborne geophysical measurements utilizing the electrical conductivity contrast between frozen and thawed soil. Combining results of such surveys repeated at regular intervals (e.g., 1-5 years) with the long-term borehole and laboratory data allow covering the large areas surrounding the PEEX stations.

4.1.2 INLAND WATERS AS PART OF THE PEEX OBSERVATION SYSTEM

A comprehensive investigation of hydrophysical, hydrochemical and hydrobiological parameters of inland waters are required for understanding the water cycle in the changing PEEX domain. Particularly the large river systems discharging into the Arctic Ocean are of crucial importance. The activities include development of the system for a series of representative water bodies in the different geographical conditions and under the influence of climatic changes of varying intensity.

A comprehensive system of monitoring of physical, chemical and biological state of the inland water bodies based on in-situ and on remote sensing methods is required. The observations include parameters describing the atmosphere (temperature, pressure, humidity, wind) and the water bodies (temperature, velocity, turbidity, chemical composition, surfactant concentrations, 3 dimensional spectra of surface waves, biomass) as well as relevant exchange processes (evapotranspiration, evaporation) as well as geographically representative parameters (water body area and depth, run off and soil moisture. The in-situ observations need to be complemented with satellite remote sensing.

Tools and techniques for real-time monitoring of toxic water bloom should be developed to effectively prevent the negative effects of a toxic bloom of water bodies for improving water quality and normalization processes in the regulation of natural biological communities of blooming water bodies. For this purpose the comprehensive system of monitoring of physical, chemical and biological state of inland water bodies based on remote sensing methods should be developed, including

- **Development of the system for a series of representative water bodies in the different geographical conditions and under the influence of climatic changes of varying intensity**
- **Simultaneous ground contact measurements of atmospherically, hydro physical, hydrochemical and hydrobiological parameters of the environment for calibration of aerospace methods**
- **Assessing the extent of toxic water bloom under the pressure of climate change**

4.1.3 GROUND BASED OBSERVATIONS COMPLEMENTED BY THE REMOTE SENSING OBSERVATIONS

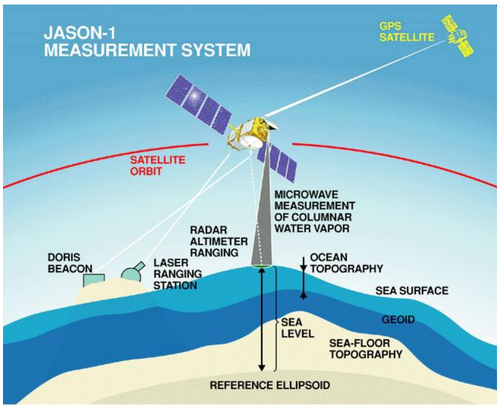
The ground based observations should be complemented by the remote sensing observations on atmospheric – land – aquatic systems. The remote observations of the land ecosystem should cover monitoring the transition from forest covered regions to tundra. The ground-based supersites provide benchmarking services to the satellite observations, both in terms of surface concentrations as well as column integrated properties.

Additionally, in connection with arctic greening and as a part of the PEEX remote sensing capabilities, an observation system of a northern socially oriented observation system network is needed. This should include monitoring transects in treeline ecotones and remote sensing studies of treeline status resulting in detailed maps of treeline ecotone at key sites and in

estimates of ecotone dynamics in the key areas, such as Kola peninsula, where advance of the treeline at various rates is already observed. Furthermore, analysis and long-term monitoring of impact of industrial activity on vegetation, exemplified by the effects by metal smelters at Monchegorsk and Norilsk could be addressed by a combination of in-situ and satellite observations. On the background of general treeline advance in Kola peninsula, the industry-related retreat of mountain treeline near Monchegorsk is estimated at hundreds of meters. Furthermore, transects already established need to be strengthened to provide for re-survey in ca. 50 years and beyond. The remote sensing monitoring will be continued and developed using new technologies including optical hyperspectral and radar data. This research should be integrated with long-term ground monitoring of treeline ecotones.

In the context of Arctic Ocean, cryosphere and hydrology, simultaneous ground contact measurements of hydrophysical, hydrochemical and hydrobiological parameters of the environment will be conducted for calibration of aerospace methods and to monitor e.g. sea ice extent. The satellite remote sensing provides also data that can be used to assess the extent of toxic water bloom under the pressure of climate change. The satellite data derived water cycle of cross-border river basin in Pan-Eurasia, to establish water budget experiments and to develop hydrological models that can be utilized in the water budget estimates for the PEEX domain as a whole.

Recent studies show substantial changes in the Arctic terrestrial hydrological system. They affect precipitation, evapotranspiration, river discharge, terrestrial water storage. Data from the Gravity Recovery and Climate Experiment (GRACE) satellite mission show long term changes in the hydrological budget of the large Siberian watersheds. A new application of the satellite altimetry originally designed for measurements of the sea level are associated with monitoring inland waters.



(Photo courtesy of CNES-website, http://www-aviso.cnes.fr)

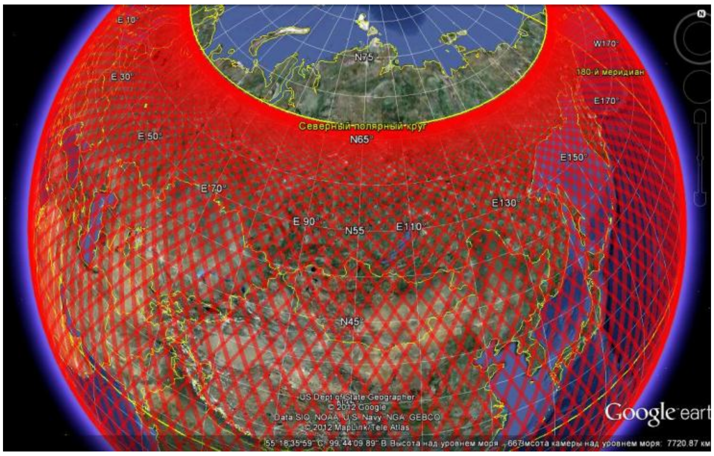


Fig. Satellite altimetry. Basic principles and positions of the ground tracks of Jason-2 alimetry satellite.

The technique is applicable at any time of day and any weather being most useful, when ground measurements are impossible due to geographical, political or economic reasons. It can be used for

- **long-period (20 years) monitoring of water level in lakes and rivers in different geographical zones of Eurasia including arid zone and permafrost zone as the indicator of climate change**
- **Comparing with air temperature, precipitation, evapotranspiration, permafrost state, etc.**

4.1.4 GROUND BASED OBSERVATIONS COMPLEMENTED BY SYSTEM ANALYSIS

The current science of global change comes down to understanding of a need of a full and verified terrestrial ecosystems full greenhouse gas account and its nuclei – Full Carbon Account (FCA). Uncertainties of previously reported estimates of the role of terrestrial ecosystems in global biogeochemistry are large (Shvidenko & Nilsson 2003), hindering scientific understanding of the problem (Schulze et al. 2002) and hampering political and economic decision making (Janssens et al. 2005). However, assessment of the uncertainties of FCA is not trivial and requires new approaches. The FCA, particularly for large territories such as the PEEX domain, is a typical fuzzy (underspecified) dynamic system (full complexity or wicked problem). It means that the uncertainties of the results obtained by any of existing methods of assessment of terrestrial ecosystems carbon cycling (i.e., landscape-ecosystem approach; process-based models; eddy-covariance; inverse modeling), if those are applied individually, are able to present only an “uncertainty within an approach” which could have a little common with “real uncertainty” (Shvidenko et al. 2010). The PEEX will provide a systems analysis and future elaboration of this problem as a whole. One of possible ways is further improvement of methodology of the FCA developed by IIASA. This methodology is based on system integration of different methods with following harmonizing and mutual constraints of intermediate and final results obtained by independent methods (Shvidenko et al. 2010, 2013).

4.2 CURRENT STATUS OF THE OBSERVATION ACTIVITIES IN THE NORTHERN PAN-EURASIAN REGION





Fig. 38. The existing field stations and field expeditions within the PEEX domain in different type of environments from left: Zotto, Tiksi, TROICA expedition on board the train.

In the PEEX domain, many different topical infrastructures exist. Here a short summary of the selected infrastructures is presented with the particular aim to illustrate their contribution to the PEEX science topics. The infrastructures include both national and distributed multi-national infrastructures.

4.2.1 IN-SITU OBSERVATION NETWORK

Finland

The network of atmospheric and ecosystem sites in Finland, namely Station for Measuring Ecosystem – Atmosphere Relations (SMEAR) network form the foundation of the PEEX in-situ network. The SMEAR network covers the boreal forest conditions in the Scandinavian part of the global band of taiga in the northern latitudes (Figure 39). The SMEAR consists of super site stations in the boreal environment. The measurements from the SMEAR station network are descriptive for conditions ranging from a remote boreal environment north of the polar circle to a more temperate boreal environment in Southern Finland. The measurements in Helsinki provide an outlook on the effect of urban emissions. As an example, the wide spatial range also provides a possibility to probe into the role of forest fires and the resulting large-scale biomass burning in Russia, with plumes aging during their transport to the SMEAR network stations (Figure 39, Table ZZ).

Figure 39. The Station for Measuring Ecosystem-Atmosphere Relations (SMEAR) atmospheric observation network. Station descriptions are listed in Table ZZ. Pallas needs to be added

Table ZZ. The SMEAR network stations and Pallas-Sodankylä GAW station.

 **Hyytiälä. The SMEAR II station in Hyytiälä (61°51’N, 24°17’E, 181 m)**	• **extensive facilities for measuring forest-atmosphere interactions operational since 1996 (Hari and Kulmala, 2005).** • **aerosol size distribution measurements with a twin-DMPS system since January 1996.** • **surrounded by Scots Pine forest, with the managed stand established in 1962 by sowing after the area had been treated with prescribed burning and light soil preparation.** • **the nearest urban pollution sites are Tampere (ca. 50 km to the southwest) and Jyväskylä (ca. 100 km to the northeast).**
 **Värriö. The SMEAR I station in Värriö (67°46’N, 29°35’E, 400 m)**	• **situated in Lapland, in a remote rural area.** • **surrounded by a Scots Pine (Pinus sylvestris l.) forest, which is over 40 years old in the station’s immediate vicinity. The measurements are performed on a hill top (Hari et al., 1994).** • **no pollution sources nearby, but emissions from industrial activities (e.g., smelters) from the Kola Peninsula area may be advected over the station.** • **aerosol size distribution measurements started in since 12/1997 in the 8–460 nm size range. In 04/ 2003 twin-DMPS system for 3-1000 nm size range. The sampling at 2 m above ground inside the forest canopy.** • **a range of atmospheric parameters, incl. trace gas concentrations along with temperature, relative humidity, solar radiation and wind speed.**
 **Helsinki. The SMEAR III station in Helsinki (60°12’N, 24°57’E, 26 m)**	• **started operations in Helsinki in autumn 2004.** • **instrumentation covers aerosol dynamics and atmospheric chemistry, micrometeorology, weather monitoring and ecophysiology of trees growing in the urban environment.** • **situated in two different locations, Kumpula and Viikki. The Kumpula site located about 4 kilometres from downtown of Helsinki.** • **measurements by a 31 meter high tower equipped with meteorological instrumentation at several heights.**
 **Puijo. The SMEAR IV station, Kuopio (62°55'N, 27°40'E, 224 m)**	• **located on the top of an observation tower.** • **continuous measurements of aerosols, cloud droplets, weather parameters and trace gases (Leskinen *et al.,* 2009, Portin *et al.*, 2009) since 2005/06.** • **station frequently located within cloud, e.g. in October (more than 40 % of days).** • **two sampling inlets for aerosol sampling: an interstitial inlet equipped with a PM1 impactor and the total air inlet with a heated inlet in order to dry the cloud droplets.** • **aerosol size distribution from both inlets with the same DMPS by using a synchronized valve system in two 6-minute cycles, giving a 12-minute time resolution for the whole measured size range.** • **difference in particle size distribution provides information on the**

	partitioning of particles between cloud droplets and interstitial particles in the cloud.
Pallas. The Sammaltunturi Global Atmospheric Watch station (67°58'N, 24°07'E, 565 m a.s.l.)	• operated by the Finnish Meteorological Institute. • situated on top of a hill in western Lapland (Hatakka et al., 2003). • vegetation in the immediate vicinity consists of mixed pine, spruce and birch forest. • above the tree line and the sampling inlet is 7 m above ground. • in the sub-Arctic region near the northern limit of the boreal forest zone. • no significant local or regional pollution sources, 20 km to the nearest town (Muonio with 2500 inhabitants). • DMPS system, operational since April 2000, size range 7–500 nm.

Scandinavia

When broadening the scope from Finland to Scandinavian and Arctic environment, a suitable connection point is "CRyosphere – Atmosphere Interactions in the Changing Arctic, CRAICC" network. These observation sites provide atmospheric and ecosystem observations in different locales, from the high arctic locales to the hemiboreal environment in Denmark (Figure 40).

Fig. 40. The in-situ station network for the Nordforsk funded Center for Excellence on "Cryosphere – Atmosphere Interactions in the Changing Arctic" (CRAICC).

Europe

Within Europe there are many suitable environmental research infrastructures that contribute to the science pertinent to the PEEX. There are already harmonized structures in place both for greenhouse gases (Integrated Carbon Observation System, ICOS, Integrated Non-CO2 Greenhouse gas Observation System, INGOS) and short-lived climate forcers (Aerosols, Clouds, and Trace gases Research InfraStructure Network, ACTRIS, Fig. 41). The global perspective is

provided by Global Atmospheric Watch, GAW, which is operated by the Weather Meteorological Organization. This infrastructure offers atmospheric observations with a global perspective, but however lacking in the high arctic and Russia.

In terms of ecosystem observations, relevant infrastructures are “Experimentation in Ecosystem Research”, EXPEER and “Analysis and Experimentation on Ecosystems”, ANAEE. These structures increase understanding on the ecosystem behaviour of the terrestrial and aquatic biomes in the PEEX domain.

The SMEAR supersites and in particularly SMEAR-II in Hyytiälä is a specific component on all of the above research infrastructures. This underlines the strength of the supersite concept and the hierarchical station network approach utilized in the PEEX. The PEEX adaptive etwork of stations and in particularly the PEEX supersite network can contribute to the thematic and topical research questions in the PEEX domain and contribute to the increased understanding of the earth system behaviour in the global scale.

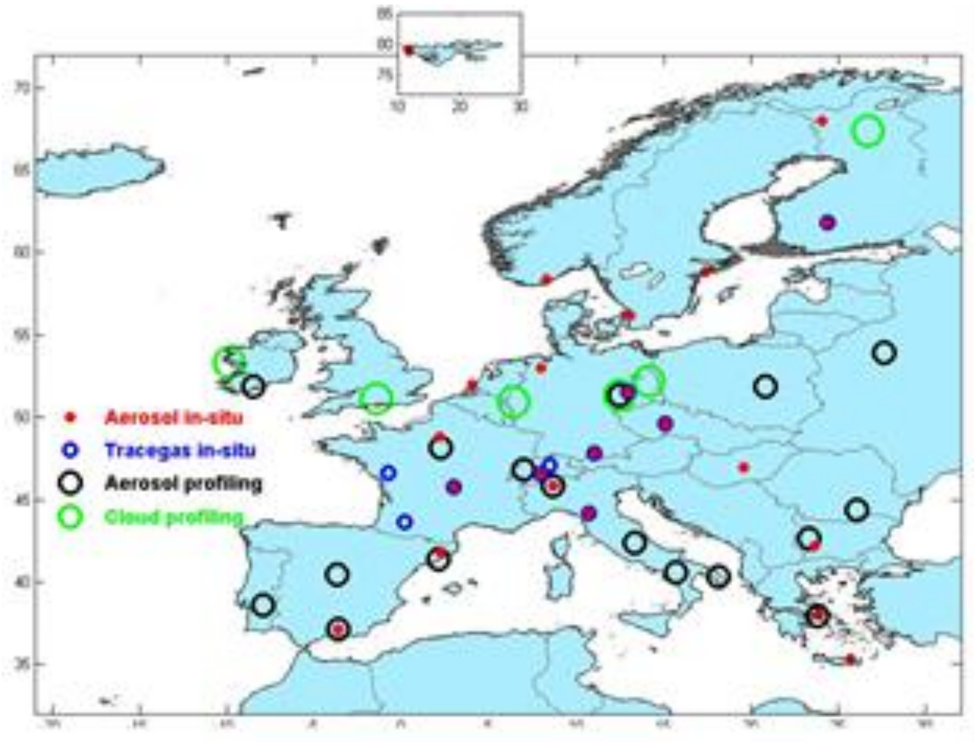


Fig 41. Aerosols, Clouds, and Trace gases Research InfraStructure Network, ACTRIS provides harmonized observations on in-situ and remote sensing data on aerosol particles as well as cloud profiling and concentration data on volatile organic compounds and nitrogen oxides.

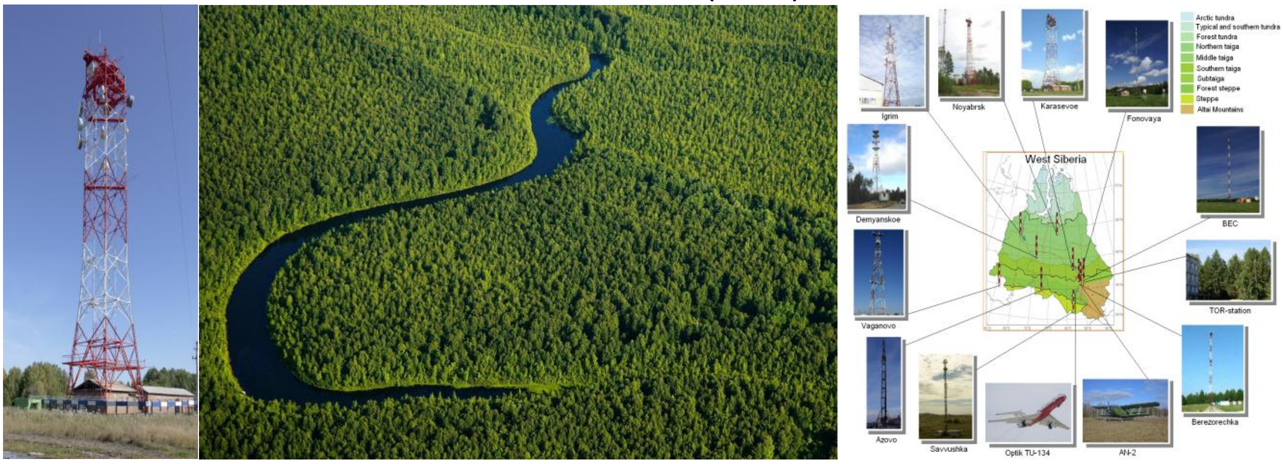


Fig 42. Joint Japan-Russia Siberian Tall Tower Inland Observation Network (JR-STATION, NIES&IAO SB RAS) for Greenhouse gas monitoring.

Russia-Siberia

At the moment the spatial coverage of the station network and other research infrastructure is unevenly distributed in the Pan Eurasian region. There are several long-term measurement stations, towers and masts equipped with a diverse instrumentation providing data on multiple gas and particle parameters and intensive campaign-based measurements have been carried out in the past.

The main problems of the existing atmospheric monitoring in Siberia are deterioration of the instruments, insufficient development of the maintenance capabilities that would allow to upkeep and control the quality of measurements, lack of continuous observations for a large fraction of its territory, insufficient equipment with means of data processing and transmission, and its incompatibility with the existing international observation networks. At present, reconstruction of the Russian System of Atmospheric Monitoring (RSAM) is on the way. It includes both the modernization of research equipment and a broader use of remote sensing methods with prospects that in the future RSAM will be a part of the Integrated Global Earth Observing System.

In the first phase the PEEX observation network as a whole consists of existing intensive stations and their measurement programs and quality analysis and data dissemination procedures developed in other projects. In order to ensure long-term sustainability and comparability, these measurements need to be connected to international networks wherever possible. The existing ones should be equipped with the missing instrumentation so that they can contribute to the PEEX science mission efficiently. The minimum setup should consist of tools for the measurement of fluxes and concentrations of aerosols and trace gases including greenhouse gases, short lived climate forcers, snow/ice cover, surface radiation budget components, and, finally, supporting meteorological quantities. Continuous data obtained from satellites need to be be complemented with in-situ measurement data from air-craft, trans-Siberian railway and research vessels and aircrafts.

China

In the China region an example of the on-going actives is the measurement and research platform Station for Observing Regional Processes of the Earth System (SORPES-NJU) developed by the Institute for Climate and Global Change Research (ICGCR) and Nanjing University since

2009. The overall objective of this platform is to characterize the temporal variation of key parameters related to climate change and to understand the interactions of different regional processes of the Earth System in the East China, a region strongly influenced by monsoon weather and by intensive human activities (Ding et al., 2013ab). In Fig 43 the footprint area calculated with a trajectory analysis of the last 20 days that contributes to the data observed at SORPES-NJU and Hyytiälä are presented. The PEEX domain is within these footprint areas.

SORPES-NJU is in the process of being developed into a SMEAR (Station for Measuring Ecosystem-Atmosphere Relations) type measurement station. It mainly focuses on the impact of human activities on the climate and on the environment system in a rapidly urbanized and industrialized Yangtze River Delta region. Considering the geography, climate, and the environment characters in East China, SORPES-NJU focuses on four major processes: land-surface processes, air pollution-climate interaction, ecosystem-atmosphere interaction, and hydrology and water cycle. The entire platform will be developed to an integrated observation network with a "flagship" central site, few “satellite” sites and mobile platforms in the vicinity.

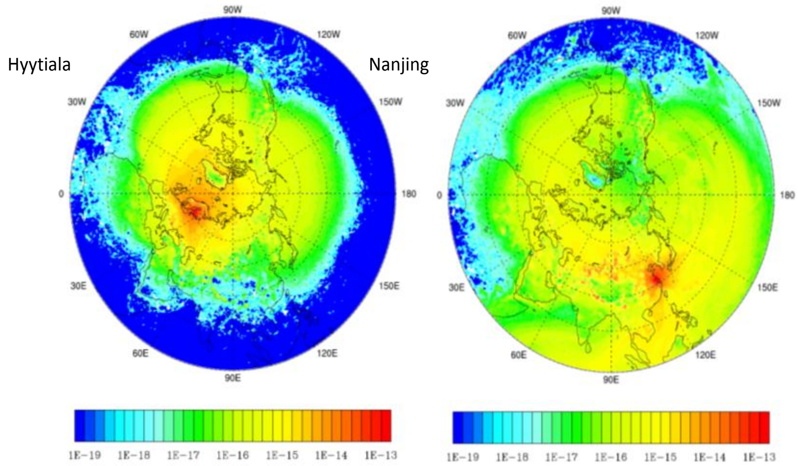


Fig 43. Annual mean "footprint" retroplume plots for Hyytiala and SORPES-NJU site based on 20-day backward Lagrangian dispersion simulation for the year 2012 using HYSPLIT trajectory model. The methodology is presented in Ding et al. 2013c.

4.2.2 SATELLITE MONITORING

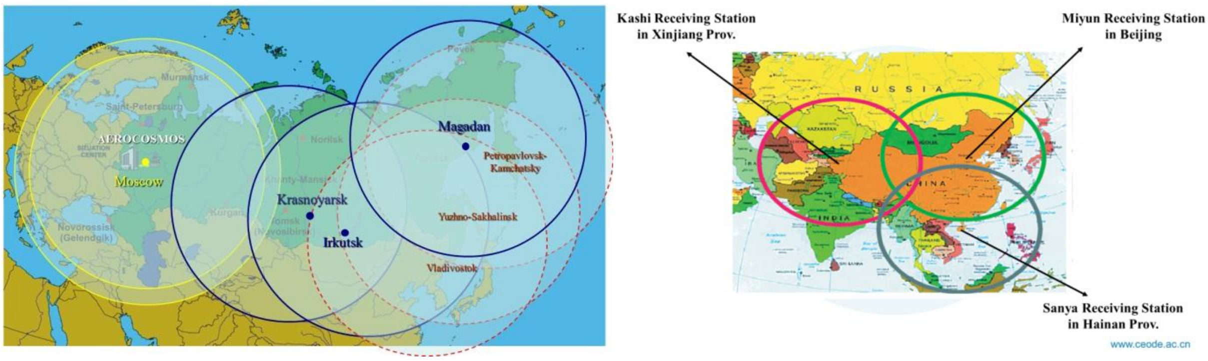


Fig.44. Areas of space information reception by Aerocosmos ground stations (left) and CHINA-Satellite receiving stations (right).

Satellite remote sensing provides data on atmospheric composition, land and sea surface properties, snow, ice, vegetation, etc. The principle parameter measured is the radiation at the top of the atmosphere (TOA), broadband or spectrally resolved, ultraviolet (UV), visible, infrared, microwave parts of the electro-magnetic spectrum. Radiation measured at wavelengths in the UV, visible and infrared spectral bands provides information on atmospheric composition: aerosol properties (primary Aerosol Optical Depth (AOD) at several wavelengths, Ångström exponent, absorbing aerosol index; information on aerosol physical and optical properties is used in AOD retrieval which in principle defines aerosol properties such as fine mode fraction, aerosol composition, single scattering albedo, etc.); cloud properties (e.g., cloud fraction, cloud optical thickness, clout top height, cloud droplet effective radius, liquid water path, etc.); concentrations of trace gases (e.g. O_3, NO_2, CO, NH_3, H_2O, VOC's, halogens) and greenhouse gases (e.g. CO_2, CH_4).

Information on land surface properties which can be obtained from satellites includes land use, vegetation (vegetation index, leaf area index), fire counts, burned area, fire radiative power, soil moisture, glaciers. Information on ocean properties includes sea surface temperature, salinity, ocean colour, sea ice extent, sea levels and wave information.

All this information is available on a global scale with a frequency and spatial resolution which depend on the instrument and the platform (satellite). In some cases the data are available for a period of over three decades. In other cases, such as aerosols and clouds over polar regions, the retrieval is in its initial state of development due to problems arising in discrimination between snow/ice, the reflectance of which overwhelms that of aerosols or clouds.

On-going satellite monitoring activates
RUSSIA: **-AEROCOSMOS: near real time fire monitoring; assessment of carbon monoxide emission; global ocean surface temperature distributions; monitoring of terrestrial ecosystems; forestry, forest pathology, forest resources; revealing and estimation of wildfire damage; forest certification; lumbering monitoring; reforestation estimation, detecting areas with intensive anthropogenic load** **-Moscow State University geoportal (http://www.geogr.msu.ru:8082/api/index.html). Over 20 of such Russian centres have now joined in the Consortium of University Geoportals (UNIGEO).** **-Institute of Space Research RAS (http://smiswww.iki.rssi.ru/) reception of open remote sensing data, such as Terra/Aqua MODIS, and thematic processing of this and other imagery, own receiving station for MODIS.** **CHINA:**

-RADI: Comparison Study of Remote Sensing for Global Environment Change from four countries including Australia, Brazil, Canada and China, covering total continental lands of the world, with the typical global environment change phenomena.
-RADI: Drought, fires, flooding monitoring and assessment in Asian region,i.e., East Asia, Middle Asia, Southern Asia, West Asia, southeast Asia under the CAS-TWAS projects.
-RADI: Pan-Eurasia and Arctic aerosol satellite retrieval and dynamic; Pan-Eurasia snow/ice and permafrost satellite retrial and dynamic.
-RADI: Aerosol-cloud atmosphere-Hydrosphere processes of earth system and characteristics of Extreme Precipitation events simulation in spatial and temporal scales (AHEP) supported by CAS.
-RADI:Pan-Eurasia spatial and temporal land use/cover change and phenology detection with multi-satellite data
-RADI:Pan-Eurasia Forest/grassland/wetland carbon dynamic under extreme climate event based on integrated remotely sensed data and ecological model
-RADI: Satellite water cyle of cross-border river basin in Pan-Eurasia

4.2.3 GROUND BASED REMOTE SENSING OBSERVATIONS

To complement in-situ observations and satellite based remote sensing capabilities, the ground based measurement sites need to be equipped with active remote sensing from the ground. Within Europe the ground based active remote sensing is done in ACTRIS infrastructure project. A suite of lidars is well equipped to derive profiles of aerosol properties. Depending on instruments different sets of aerosol products can be obtained.

Ideal aerosol profile instrument fit: Consists of a three-wavelength Raman lidar with depolarization measurement capability (3 elastic backscatter channels + 2 N2 Raman channels, + depolarization at one wavelength) and an AERONET sunphotometer (Heese et al., 2010), running continuously every day of the year, together with ceilometer (Vaisala CL51) and in-situ instrumentation. This configuration provides spectrally resolved aerosol extinction and backscatter profiles together with the particle depolarization ratio. Aerosol typing and the retrieval of microphysical particle properties are possible.

Backscatter lidars and ceilometers. Lidars which cannot measure a pure molecular return signal (Raman or Rayleigh) need an assumption on the extinction-to-backscatter ratio (lidar ratio) for aerosol retrievals (Binietoglou et al., 2011). Accurate extinction profiling is not possible with such instruments. When operated in the UV or visible spectral range, calibration is possible in aerosol-free regions of the atmosphere. Reliable backscatter profiles are obtained when these lidars are combined with a sunphotometer to constrain the aerosol optical depth of the atmosphere. Ceilometers can be regarded as low-power backscatter lidars and operate at 905 or 1064 nm. Because of the low signal-to-noise ratio, only layers with high aerosol load (PBL, pollution or dust plumes) can be observed.

Hierarchy of potential aerosol products
1. attenuated backscatter profile: range-corrected and calibrated atmospheric backscatter profile. (O' Connor et al., 2004) 2. aerosol mask: atmospheric regions with enhanced aerosol load (Binietoglou, et al.,

2011)

3. PBL height, aerosol layer boundaries: upper boundary of the aerosol layer that is in touch with the surface and of top and bottom heights of lofted aerosol layers

4. particle backscatter-coefficient profile (at one or several wavelengths): quantitative, i.e. calibrated and attenuation-corrected, description of 180° volume backscattering caused by aerosol particles (in m^{-1} sr^{-1}) (Böckmann et al. 2004, Pappalardo et al. 2004).

5. particle linear depolarization-ratio profile (at one or several wavelengths): quantitative, i.e. calibrated, description of the depolarization of linear-polarized laser light caused by (non-spherical) aerosol particles

6. particle extinction-coefficient profile (at one or several wavelengths): quantitative description of atmospheric extinction caused by aerosol particles (in m^{-1}, derived from a pure molecular return signal, i.e. with a self-calibrating method) (Böckmann et al. 2004, Pappalardo et al. 2004).

7. aerosol type/target classification: discrimination of major aerosol types (such as dust, maritime aerosol, smoke, pollution, volcanic ash) from depolarization ratio, lidar ratio, and/or Angström exponent (color ratio) (Pappalardo et al. 2004).

8. particle microphysical properties (e.g., effective radius, volume size distribution, refractive index) derived from spectral extinction and backscatter coefficients.

The hierarchy of products is coupled to the instrument capabilities (from simple ceilometer to advanced multiwavelength Raman lidars). Products 1) – 4) are possible with simple backscatter lidars. Products 5) – 8) are only possible using the ideal setup. (Böckmann, et al. 2004)

Observing cloud and precipitation processes

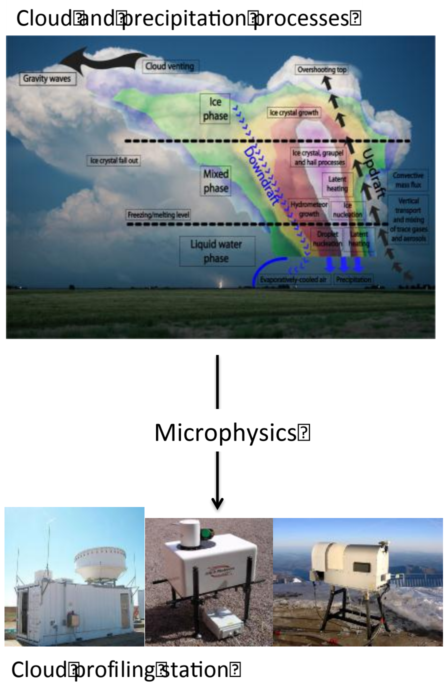


Fig 45. Ground based remote sensing of aerosols and cloud processes.

Advances in understanding the role of cloud processes are critical to reducing the uncertainty in precipitation and water cycle prediction -- a key component of the global climate system, as well as in understanding aerosol cloud interactions. To understand and map the continuum of climatically important cloud regimes, from heavy rain to light drizzle and snowfall a number of cloud and precipitation profiling station in the PEEX domain are needed. The observing stations should document cloud regimes that are representative of the region, i.e. deep convection, shallow cloud systems, frontal systems and orographic precipitation enhancement.

To record cloud and precipitation processes comprehensive measurements of cloud and precipitation microphysical properties are needed. A combination of cloud radars, microwave radiometers and lidars are needed to achieve this (Illingworth et al., 2007).

Hierarchy of cloud and precipitation profiling station products
Raw products
• Radar reflectivity factor and Doppler velocity (Cloud radar)
• Lidar-attenuated backscatter coefficient (Lidar)
• Microwave radiometer brightness temperatures and liquid water paths (MWR)
From those observations a number of meteorological products can be derived, such as:
• Liquid water content
• Ice water content
• Drizzle flux and drizzle drop size from radar and lidar
• Ice effective radius from radar and lidar
• TKE dissipation rate from radar Doppler velocity
• Precipitation rate and type

4.2.4 MARINE OBSERVATIONS

Fig.46 On a field expedition in the Arctic Ocean.

SYNOPSIS. The PEEX marine component is based on new and existing in situ observations from the Arctic Ocean and on the remote sensing observations on the ocean surface temperature, colour, and wave field, as well as sea ice type, concentration, extent, thickness, albedo, surface temperature, and snow on sea ice. These observations will be utilized in and supported by atmospheric, ocean, and sea ice re-analyses. The observational activities will be closely connected with integrative activities applying process models, operational models, as well as regional and global climate models. Considering new observations in the Arctic Ocean, the most important ones will be those made at drifting ice stations and research cruises, as well as by moorings, drifting buoys, under-ice gliders, and manned and unmanned research aircrafts.

The PEEX observations in the marine area are conducted with drifting stations, buoys and by satellite remote sensing. The measurement activities are complemented by scientific

expeditions onboard research ships. The ground based measurement network provides a link of the marine observations to the coastal areas in key areas, such as Tiksi. In the Arctic, another connecting point is Svalbard Integrated Arctic Earth Observing System, SIOS.

Buoys + ship measurements **RUSSIAN DRIFTING STATIONS "NORTH POLE – 41…"**
• Participants: Arctic and Antarctic Research Inst., Inst. of Oceanology RAS, Main Geophysical Observatory, St. Petersburg University, Center for Environmental Chemistry, RPA "Typhoon" (Russia), AWI (Germany) ESRL NOAA (USA), NPI (Norway) **• Meteorology /Oceanography /Hydrochemistry and greenhouse gases exchange /Dynamic and morphometry of sea ice cover /Sea ice biology, plankton and benthos communities/Investigations of sediments in snow-ice cover /Validation of satellite data** **• Sea Level and Climate Change Coordinated by the ENEA, IT and the KNMI, NL** **• Changes in the Hydrological Cycle in collaboration with HyMex Coordinated by the CNR and the ENEA, IT**

4.2.5 AIRBORNE OBSERVATIONS

Fig.47 Optik TU-134 aircraft laboratory

The PEEX airborne observations are based on ongoing measurement activities and new initiatives are engaged. One of the main advantages of airborne research platforms consists in the fact that aircraft enables in situ measurements to be carried out in the atmosphere over vast areas. Furthermore, it can track atmospheric phenomena under study within a long range, and if the aircraft is well-equipped it allows complex measurements of the atmosphere and underlying surface to be performed simultaneously. The main disadvantage is a high cost of the flights; nevertheless airborne method is very useful to explore the Arctic, where it is difficult to establish a dense surface observational network. Furthermore, the aircraft measurements provide a link between the PEEX ground based supersites by providing data between the stations.

RUSSIA

- Belan B.D., Arshinov M. Yu., Panchenko M.V. Institute of Atmospheric Optics SB RAS, Russia, Tomsk
- CAO (Central Aerological Observatory (CAO) of the ROSHYDROMET) Opportunities in ground-based and airborne investigations of atmospheric composition (Borisov Yu. A)
- Dyukarev E.A., Krutikov V.A., Kabanov M.V.Institute of monitoring of climatic and ecological systems SB RAS, Russian Federation, Tomsk
- Optik TU-134 Aircraft Laboratory. Research capabilities: in situ measurements of CO_2, CH_4, CO, O_3, black carbon, aerosol scattering coefficient, aerosol size distribution, ambient temperature and humidity, navigation parameters, as well as filter sampling and lidar sensing of aerosols. More detailed information can be found in Antokhin et al. (2012), where the scientific complex deployed on the previous airborne platform was described, except for Picarro G2301-*m* analyser recently installed and new generation eye safe CIMEL lidar to be installed in 2014.

Fig 48. Aircraft measurements in Tomsk area.

On-going airborne activities

- CNRS, FR & IAO SB RAS: "Airborne Extensive Regional Observations in Siberia – YAK-AEROSIB"
- NIES, JP & IAO SB RAS: "Measurements of greenhouse gases affected by Siberian ecosystems"

Fig 49. Airborne observations in China.

CHINA:

- Airborne Remote Sensing Centre of RADI operates two Cessna Citation S/II Airplanes and have two new advanced Airplanes ARJ 21-700ER with 10 new sensors.
- Two new Remote Sensing Aircrafts: Equipped with 10 state-of-the-art remote sensors: visible, infrared, and microwave remote sensors and a high-performance data processing

- system, including Airborne atmospheric laser radar, Digital CCD camera, Airborne whiskbroom imaging spectrometer
- (0.45µm-12.5µm); Airborne 3-D light detection and ranging, Airborne X-band interferometry SAR, Airborne pushbroom imaging spectrometer (0.45µm-2.5µm).

4.2.6 LABORATORY

Fig.49 Large Aerosol Chamber (IAO SB RAS).

SYNOPSIS. Research within PEEX benefit from comprehensive field observations but also from laboratory experiments. Experimental work is conducted in various laboratories in Europe but also in Russia and China. As an example, aerosol emissions from Siberian boreal forest fires are crucial for understanding of the environmental and climate impacts in subarctic regions and Arctic. The ability of biomass burning aerosol to absorb/scatter incoming radiation as well as act as cloud condensation nuclei strongly depends on optical, microphysical, chemical and hygroscopic characteristics, regional database for which is highly sparse.

Laboratory experiments that are important in the PEEX domain are conducted e.g. in CLOUD-chamber in CERN (Kirkby et al. 2011). These experiments shine light into the initial steps of secondary aerosol formation (Schobesberger et al. 2014) that is a regional phenomenon in the boreal environment (Kulmala et al. 2004). Also the work in Paul Scherrer Institute chamber has underlined the importance of organic vapors to the initial clustering (Riccobono et al. 2012). Important laboratory experiments are conducted also in various laboratory facilities in Russia and China.

The comprehensive investigations of biomass burning aerosols are currently performed under controlled conditions in a Large Aerosol Chamber of IAO SB RAS (1800 m^3), equipped with modern devices for measurements and definitions of: i) radiative-relevant optical- microphysical characteristics - aerosol scattering coefficients, mass concentrations of aerosol and Black Carbon, BC fraction, single scattering albedo (SSA) in the visible region, particle size distributions, ii) sampling of aerosol particles on filters and metallic substrates for subsequent gravimetric definition of PM10/ PM2.5, and iii) for chemical analysis of the biomass burning aerosols.

Fig.50. Laboratory facilities at IAO SB RAS in Tomsk.

Size distributions of smoke particles and its complex index of refraction, Ångstrom parameters on scattering and absorption, single scattering albedo, and emission factors of size-selected aerosols are studied using methods of polarization spectronephelometry of scattered radiation, aethalometry, photoelectrical particle counter and gravimetry. Comprehensive characterization of physico-chemical properties of combustion aerosols is performed, including morphology, elemental composition, surface chemistry, carbon and ion content, organic carbon / elemental carbon content, organic/inorganic and selected organic compounds (levoglucosan, mannosan and dycarboxylic acids). Scanning electron microscopy coupled by energy-dispersive X-ray spectroscopy, Fourier Transform Infra-Red spectroscopy, capillary electrophoresis, thermo-optical technique and chromatography are proposed for characterization.

The main processes of biomass burning in Siberian boreal forests: smoldering, open fire, and mixing state (both above-mentioned types) are considered to simulate different properties of aerosol emissions in dependence on type of fuel (pine, debris and others), combustion conditions, and aging in the atmosphere. Various characteristics of smoke aerosols are proposed are classified and empirical models of their verification are suggested. Special attention is emphasis on identification of microphysical, morphological and chemical micro-markers of combustion aerosols assigned to Siberian boreal wildfires. Individual particle characterization supported by cluster analysis allows the quantification of smoke structure and major types of particles with purpose to discriminate between the different biomass burning and identify morphological and chemical micromarkers.

Aerosol absorption and scattering emphasis the radiative-microphysical properties of smoke, and BC generation for smoldering, open fire, and mixing burning. BC fraction, SSA, emission factors, OC/EC, ions, molecular markers (anhydrosugars) reveal the dramatic differences in aerosol composition as a function of combustion phase. The largest emission of organics and levoglucosan occurs during the smoldering phase. Studies show the importance of obtaining the optical and chemical profiles for dominant component in PM in order to permit the assessment of contribution of Siberian biomass burning to atmosphere pollution and aerosol/climate system through PM characterization and molecular marker approaches.

4.3 MODELLING AND ANALYSIS INFRASTRUCTURES

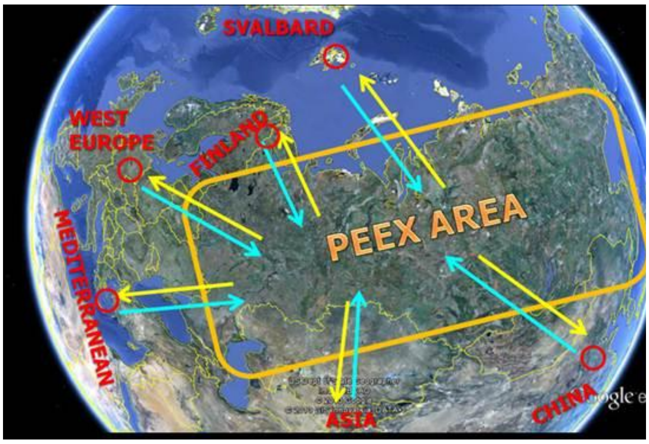


Fig. 51. The PEEX domain and its interactions and connections with the surrounding areas.

SYNOPSIS. The PEEX modelling platform (MP) is characterized by a complex integrated Earth System Modelling (ESM) approach in a combination with specific models of different processes and elements of the system acting on different temporal and spatial scales. The PEEX takes an ensemble approach with the integration of modelling results from e.g. different models, participants and countries. The PEEX utilizes full potential of a hierarchy of models; analysing scenarios; inverse modelling; modelling based on measurement needs and processes. The models are validated and constrained by PEEX in-situ and remote sensing data of various spatial and temporal scales by data assimilation and top-down modelling. The analysis of anticipated large data volumes coming from PEEX models and sensors should be supported by developed dedicated virtual research environment.

As the part of the PEEX initiative, for the purpose of supporting the PEEX observational system and answering on the PEEX scientific questions, a hierarchy/ framework of modern multi-scale models for different elements of the Earth System integrated with the observation system is needed.

One of the acute topics in the international debate on land-atmosphere interactions in relation to global change is the Earth System Modeling (ESM). The question is whether the ESM components actually represent how the Earth is functioning. The ESMs consist of equations describing the processes in the atmosphere, ocean, cryosphere, terrestrial and marine biosphere. ESMs are the best tools for analyzing the effect of different environmental changes on future climate or for studying the role of the processes in the Earth System as a whole. These types of analysis and prediction of the future change are especially important in the Arctic latitudes, where climate change is proceeding the fastest and where near-surface warming has been about twice the global average during the recent decades.

The processes, and hence parameterizations, in ESMs are still based on insufficient knowledge of physical, chemical and biological mechanisms involved in the climate system and the resolution of known processes is insufficient. Global scale modeling of land-atmosphere-ocean interactions using ESMs provides a way to explore the influence of spatial and temporal variation in the activities of land system and on climate. There is a lack, however, ways to forward a necessary process understanding effectively to ESMs and to link all this to the decision-making process. Arctic-boreal geographical domain plays significant role in terms of green-house gases and anthropogenic emissions and as an aerosol source area in the Earth System.

Added value of the comprehensive multi-platform observations and modeling; network of monitoring stations with the capacity to quantify those interactions between neighboring areas

ranging from the Arctic and the Mediterranean to the Chinese industrial areas and the Asian steppes is needed. For example, apart from development of Russian stations in the PEEX area a strong co-operation with surrounding research infrastructures in the model of ACTRIS network needs to be established in order to obtain a global perspective of the emissions transport, transformation and ageing of pollutants incoming and exiting the PEEX area.

To meet challenges related to growing volumes of global and PEEX domain environmental data archives creation of virtual research environment (VRE) is required. This should enable researchers to process structured and qualitative data in virtual workspaces. VRE should integrate data, networks and computing resources providing interdisciplinary climatic research community with opportunity to get profound understanding of ongoing and possible future climatic changes and their consequences for the targeted region.

4.3.1. EARTH SYSTEM MODELS

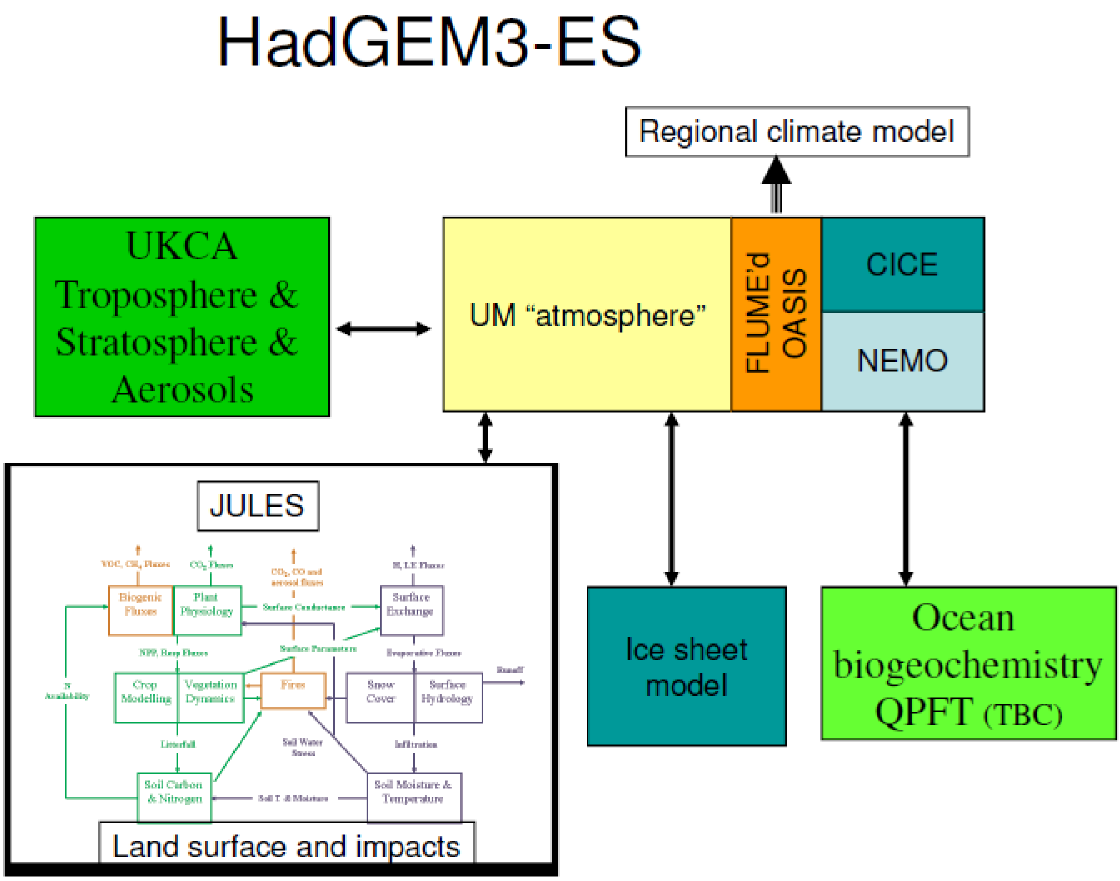


Fig.52 The PEEX interests: interactions and feedbacks between boreal forests, aerosols and climate, TOOLS: Process models and ESMs. NEEDS: Long term / multi annual, co-located observations of vegetation and atmosphere properties across Eurasia.

SYNOPSIS. There has been criticism that the processes, and hence parameterizations, in the Earth System Models (ESMs) are based on insufficient knowledge of physical, chemical and biological mechanisms involved in the climate system and the resolution of known processes is

insufficient. We lack ways to forward the necessary process understanding effectively to the ESMs. Within the PEEX we tackle this issue.

The PEEX-MP aims to simulate and predict the physical aspects of the Earth system and to improve understanding of the bio-geochemical cycles in the PEEX domain, and beyond (Fig 52). The environmental change in this region implies that, from the point-of-view of atmospheric flow, the lower boundary conditions are changing. This is important for applications with immediate relevance for society, such as numerical weather prediction. The PEEX infrastructure will provide a unique view to the physical properties of the Earth surface, which can be used to improve assessment and prediction models (Fig 53). This will directly benefit citizens of the North in terms of better early warning of hazardous events, for instance. On longer time-scales, models of the bio-geochemical cycles in the PEEX domain absolutely need support from the new monitoring infra-structure to better measure and quantify soil and vegetation properties.

In the most basic setup, the atmospheric and oceanic Global Circulation Models (GCMs) are connected to each other, sharing e.g. fluxes of momentum, water vapor and CO_2. Traditionally, the land compartment has been an integral part of the atmospheric model, but in most modern ESMs the land model has been clearly separated. In most cases, the GCMs are complemented by other additional sub-models covering, for example, atmospheric chemistry and aerosols, biogeochemistry or dynamic vegetation. Although the models can communicate also directly with each other, usually a separate coupler is used as an interface between different sub-models.

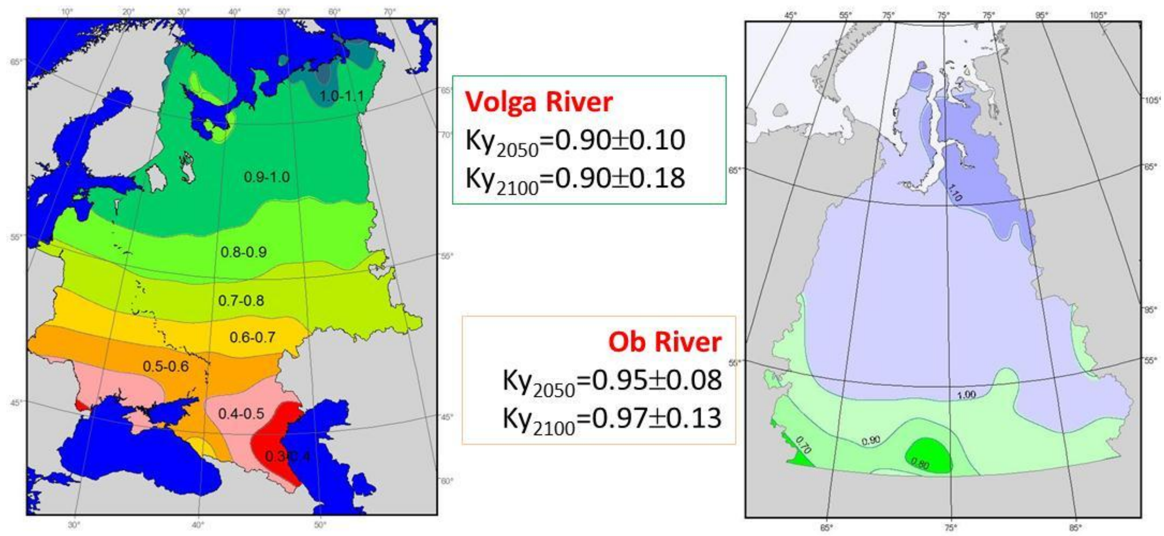


Fig.53. Regional climate modelling: Relative changes of a runoff (Ky2050) in the PEEX domain based on the CMIP3 ensemble at the middle of XXI century.

Evaluation of process-models to improve GCM parameterizations

One of the main PEEX modelling activities is to evaluate process-models of chemistry-biota-atmosphere interactions in Pan Eurasian region and to improve GCM parameterizations. PEEX scientific plan is designed to serve as a research chain that aims to advance our understanding of climate and air quality. It can be seen through a series of connected activities beginning at the

molecular scale and extending to the regional and global scales. Past variations in climate in Pan Eurasian region and corresponding forcing agents would be revealed by analysis of firn and ice cores in glaciers and ice sheets.

A combination of direct and inverse modelling will be applied to diagnosing, designing, monitoring, and forecasting of air pollution in Siberia and Eurasia (Penenko et al., 2012). Regional models coupled with the global one by means of orthogonal decomposition methods allow one to correctly introduce data about the global processes onto the regional level where environmental quality control strategies are typically implemented (Baklanov et al., 2008).

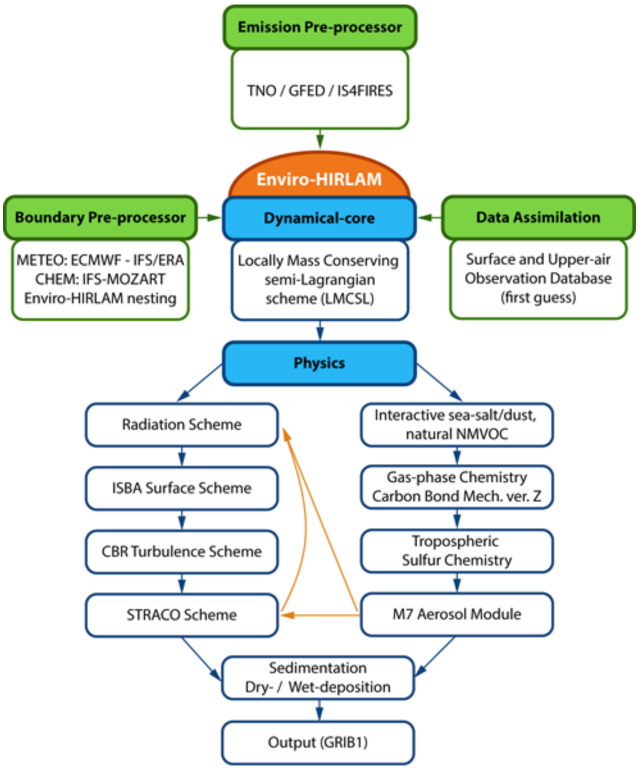


Fig.54. A concept of "one-atmosphere" as two-way interacted meteorological and chemical processes - strategy of new generation integrated chemistry-climate modelling systems for predicting atmospheric composition, meteorology and climate change.

Proceeding from the above mentioned limitations, a new concept and methodology considering the concept of 'one-atmosphere' as two-way interacted meteorological and chemical processes is suggested (Baklanov et al., 2011; Zhang et al., 2012). The atmospheric chemistry transport models should include not only health-effecting pollutants (air quality components), but also green-house gases (GHG) and aerosols effecting climate, meteorological processes, etc. Such concept requests a strategy of new generation integrated chemistry-climate modelling systems for predicting atmospheric composition, meteorology and climate change. The on-line integration of meteorological/ climate models and atmospheric aerosol and chemical transport models gives a possibility to utilize all meteorological 3D fields at each time step and to consider feedbacks of air pollution (e.g. aerosols) on meteorological processes and climate forcing, and further on the chemical composition (as a chain of dependent processes) (Fig. 54). This promising way for future atmospheric simulation systems (as a part of and a step to ESMs) will be considered in PEEX. It will lead to a new generation of models for climatic, meteorological, environmental and chemical weather forecasting (EuMetChem, 2012: www.eumetchem.info) providing tools for environmental risk assessment and strategy optimization.

SCIENCE QUESTIONS, THE INTEGRATED ESM APPROACH

• An urgent question to address as northern latitude regions are expected to experience temperature changes higher than the global mean while being large enough to feedback to regional and global climate systems. Our understanding of the relevant physical processes has been hampered by a lack of concurrent measurements of aerosols, clouds, radiation, snow, and sea-ice processes.

• How can we describe BVOC emission responses to of air chemistry related impacts (CO_2 impact, ozone induction, nitrogen dependency) mechanistically considering the phenological and physiological state of the plant as well as immediate climatic conditions?

• How can we quantify the deposition of air pollutants (i.e. ozone) into the vegetation and how can we distinguish explicitly between stomatal- and non-stomatal deposition (incl. chemical deposition by BVOC emission, ozone impact on stomata)?

• What are the current and future effects of biomass burning /wild forest fires / ship emissions on radiative forcing and atmospheric composition in the Arctic and Siberia?

4.3.2 SOCIO-ECONOMIC MODELS

Socio-economic development of the region depends upon a number of global and macro-economic processes such as future development of the world's energy production and consumption, the national and global demand on natural resources, specifics of the national policies in developments of northern territories, or policies with respect to small ethnic communities. Expected climate changes will play a substantial role in the overall socio-economic predictions and assessments, as will the existing climate policy that already influences economic development. The post-Soviet period of dynamics of the regions was characterized by many negative social tendencies and processes like substantial migration of population from the northern regions, decline of thousands of taiga settlements due to the collapse of the soviet forest industry, destruction of transport connections, substantial worsening of social services like medicine and education, supply of first-necessity goods etc., particularly in remote territories.

The crucial prerequisite of socio-economic development of the region, particularly in high latitudes, is transition to sustainable development aiming at creation of acceptable standards of human life and maintenance of environment and regional stability of the biosphere. In Russia, this transition is declared as a starting point of national and regional policies of natural resources management. However, the reality is far from such declarations. The ecological and environmental situation in large regions of Northern Eurasia should be characterized as the ongoing severe ecological crisis initiated by unregulated anthropogenic pressure on nature and explosive increase of production and transport of natural resources, mostly fossil fuel. Altogether, this results in the decreasing quality of major components of environment – air, water, soil, and vegetation, - and generates many risks. The region is one of the most vulnerable regions of the globe.

Taken complexity and uncertain character of predictions of the socio-economic development of the region, PEEX will widely use with this respect integrated modeling as a major modeling tool. Integrated modeling combines consideration of problems of different nature – economic,

ecological and social. One of the planned ways is use of integrated clusters like IIASA ESM Integrated Modeling Cluster (http://www.iiasa.ac.at/web/home/research/researchPrograms/EcosystemsServicesandManagement/Integrated-Model-Approach.en.html). The cluster integrates different models – economic model GLOBIOM (Havlik et al., 2011), forest specialized model G4M (Rametsteiner et al., 2007), agricultural model EPIC (Izaurradle et al., 2006) and others, which are combined in a common modeling framework. The cluster could be modified and adapted for the region's conditions and problems.

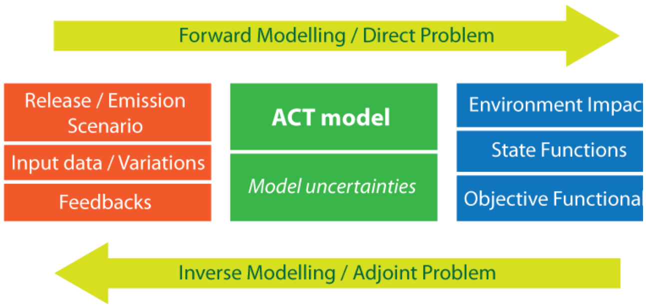


Fig. 55. A scheme of environmental risk assessment and mitigation strategy optimization basing on forward/inverse modeling. ACT - atmospheric chemical transport models (Baklanov et al., 2012).

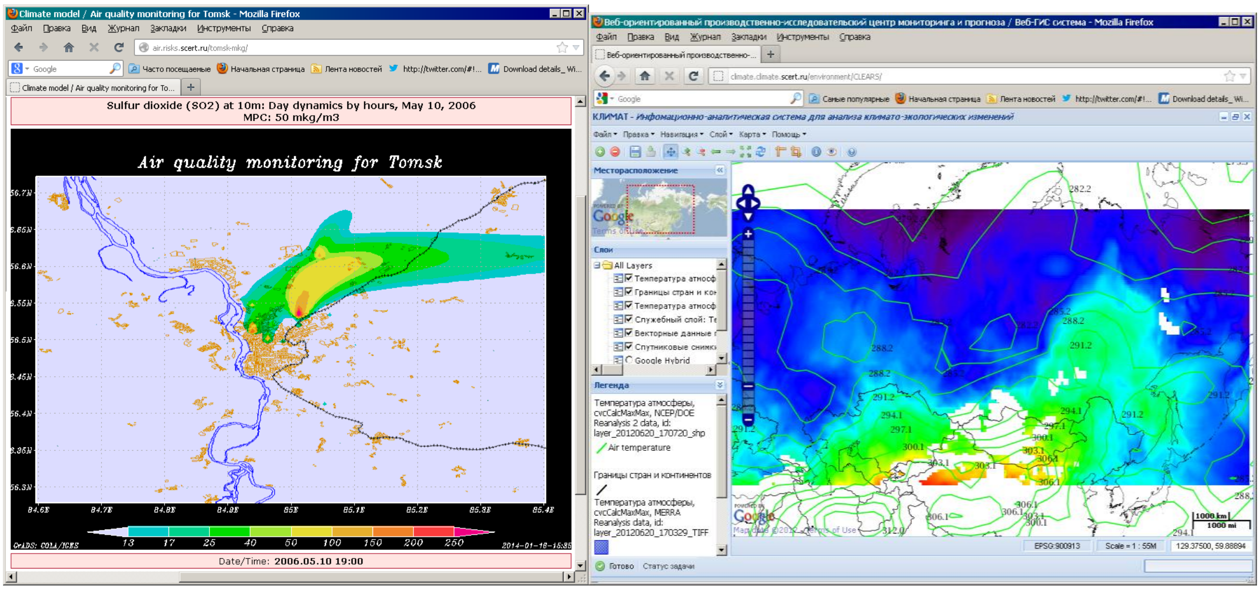
The another promising approach deals with the application of combining agent-based and stock-flow modeling approaches in a participative analysis of the integrated land system that allows to illustrate various paradigms in studying the complexity of ecological-social systems. In essence, an agent-based model is a system designing a collection of individual, heterogeneous decision-makers referred to as agents, who consider their options in their respective environment to form decisions on the basis of a pre-defined set of rules working in an environment of on internal and external factors and different scenarios. Finally, taking different perspectives of different stakeholders or decision-makers, other techniques of socio-economic modeling and research will be examined, particularly using real options modeling for investigating the impact of uncertainty emerging from a lack of information. In questions relating to adaptation and mitigation strategies and development, a variety of social science methods will be employed in order to gain a better understanding of how these political processes take place and how they can be best supported. This includes a variety of participatory methods to include relevant stakeholders.

4.3.3 ELEMENTS OF VIRTUAL RESEARCH ENVIRONMENT FOR REGIONAL CLIMATIC AND ECOLOGICAL STUDIES SUPPORT

Volumes of environmental data archives are growing immensely due to recent models, high performance computers and sensors development. It makes impossible their comprehensive analysis in conventional manner on workplace using in house computing facilities, data storage and processing software at hands. One of possible answers to this challenge is creation of virtual research environment (VRE), which should provide a researcher with an integrated access to huge data resources, tools and services across disciplines and user communities and enable researchers to process structured and qualitative data in virtual workspaces (De Roore and Goble, 2007). Thematic VRE should integrate data, network and computing resources providing interdisciplinary climatic research community with opportunity to get profound understanding of ongoing and possible future climatic changes and their consequences.

First steps of development of PEEX domain VRE elements aimed at regional climatic and ecological monitoring and modeling as well as at continuous education and training support were done in course of FP6 EC Eviro-RISKS project (Baklanov and Gordov, 2007, Fig 56). The interactive web-system for regional climate assessment on the base of standard meteorological data archives was developed and launched into operation (http://climate.risks.scert.ru). On this basis the experimental software and hardware platform "Climate" was recently developed aimed at integrated analysis of heterogeneous georeferenced data (http://climate.scert.ru; Gordov et al., 2013; Shulgina et al., 2013; Okladnikov et al., 2013). It can be used as a PEEX VRE element prototype and approach test bench. Currently the VRE element is accessible via developed geoportal at the same link (http://climate.scert.ru) and integrates the WRF and «Planet Simulator» models, basic reanalysis and instrumental measurements data and support profound statistical analysis of storaged and modeled on demand data. In particular, one can run the integrated models, preprocess modeling results data, using dedicated modules for numerical processing perform analysis and visualize obtained results. New functionality recently has been added to the statistical analysis tools set aimed at detailed studies of climatic extremes occurring in Northern Asia. The VRE element is also supporting thematic educational courses for students and post-graduate students including relevant trainings (Gordova et al., 2013). Developed VRE element "Climate" provides specialists involved into multidisciplinary research projects with reliable and practical instruments for integrated research of climate and ecosystems changes on global and regional scales. With its help even a user without programming skills can process and visualize multidimensional observational and model data through unified web-interface using a common graphical web-browser.

PEEX VRE to be developed should integrate on the base of geoportal distributed thematic data storages, processing and analysis systems and set of models of complex climatic and environmental processes run on supercomputers. VRE specific tools should be aimed at high resolution rendering on-going climatic processes occurring in Northern Eurasia and reliable and found prognoses of their dynamics for selected sets of future mankind activity scenario.



(a) (b)

Fig56. (a) Enviro-RISKS web portal Climate site (http://climate.risks.scert.ru/) providing an access to interactive web-system for regional climate and environment assessment on the base of meteorological and air quality (sulfur dioxide concentration; Tomsk, Russia) data; (b) Example of user interface of the "Climate" platform supporting multidisciplinary Earth/Environmental Sciences regional study (Merra data, Maximal temperature, 850mb, June 1990, rasterNCEP2, contour) EvgenyGordov SCERT/IMCES SB RAS.

Taken into account the diversity and integrated character of research which intends to be done by PEEX, it is relevant to have a solid georeferenced basis which would contain all available accumulated information about landscapes, terrestrial ecosystems, water bodies, biological productivity of the biosphere and its interaction with the lower troposphere, etc. Such a base will be realized in form of an Integrated Land Information System (ILIS) for Northern Eurasia (Schepachenko et al. 2010) as a multi-layer GIS with corresponding attributive databases. The georeferenced background of the ILIS is represented by a hybrid land cover which is developed by using multi-sensor remote sensing concept and all available ground information (forest and land state accounts, monitoring of disturbances, verified data of official statistics, measurements in situ etc.). The basic resolution of the ILIS is 1 km^2. Finer resolution could be used for regions with rapid change of land cover. Initial version of the ILIS will be developed by state for 2011. The ILIS is planned to be used: (1) for introduction of a unified system of classification and quantification of ecosystems and landscapes; (2) as a benchmark for tracing the dynamics of land-use land cover; (3) for empirical assessment of fluxes of an interest (CO_2, CH_4, VOC, NOx, aerosols, etc.); (4) for use in different models and for models' validation; (5) for understanding of gradients for up scaling of "point" data.

The methodology for multidisciplinary probabilistic environmental risk and vulnerability assessments elaborated in ArcticRisk-NARP and FP6 Enviro-RISKS projects (Baklanov et al., 2006abc; Mahura et al., 2005, 2008) can be refined and applied as a web-based tool for evaluation of potential impact on environment and population in the PEEX region. The GIS and Google-Earth components of such tool could provide a more valuable representation. On an on-line web-request, for selected geographical locations of continuous emissions, accidental releases, planned constructions and operations, etc. the short- and long-term (ranging from a day up to several days, months, and up to one year) simulations with trajectory and dispersion modeling approaches can be used to construct various indicators of potential impact. These can include dominating atmospheric transport pathways, airflow probabilities, maximum reaching distances, fast transport, precipitation factor, time integrated air concentration, dry, wet, and total deposition patterns as well as other indicators. The results of these simulations are also applicable for integration and input for further evaluation of doses, impacts, risks, short- and long-term consequences for population and environment from potential sources. Risks evaluations and mapping will be important for decision making processes and for analysis of environmental, social, economic, etc. consequences for different geographical areas and various population groups taking into account social-geophysical factors and probabilities, and using demographic and administrative databases. All these can be provided through the web-portal.

5. PEEX SOCIETY DIMENSION (F-3)

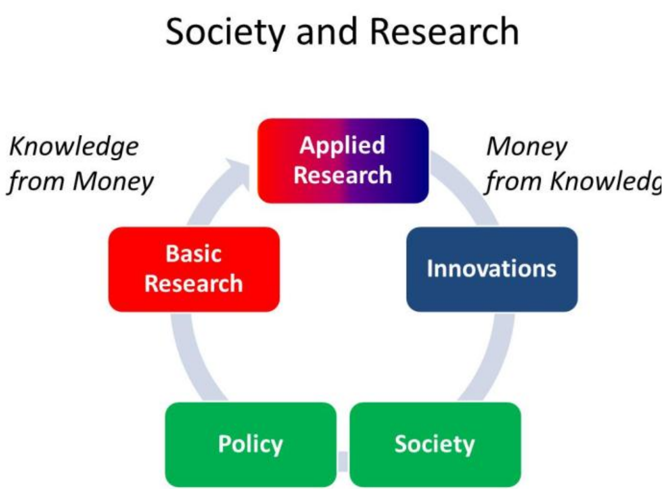


Fig. 49

SYNOPSIS. PEEX research agenda provides information for mitigation and adaptation strategies, which will be made in collaboration with stakeholders through different mechanisms. Reliable climate information is crucial for the planning and adaptation for climate change impacts on the society in the coming decades. The future plans by various societal stakeholders require scientific information of the physical and social processes in order to avoid the most harmful risks and take sustainably advantage of new opportunities. The innovations like measurement techniques, predictions of extreme events are of great value for diverse social groups, providing improved knowledge and scenarios of climate phenomena.

PEEX research agenda provides information for mitigation and adaptation strategies, which will be made in collaboration with stakeholders through different mechanisms. PEEX Society Dimension (F-3) integrates the outcomes of the Research agenda (F-1) and Infrastructure (F-2) and delivers different types of scenarios on the effects of climate change and air quality on human population, society, energy resources and capital flow. An adequate response to these environmental challenges requires social transformations regarding how human activities are organized. Basic research, as well as applied research, is important for policy- making and society as a whole.

5.1 MITIGATION AND ADAPTATION

Mitigation of greenhouse gases and adaptation to the impacts of climate change are the two societal responses to climate change. Activities in mitigation include changes in the ways that energy is produced and consumed in societies, whilst measures in adaptation are taken to ensure that risks and vulnerabilities arising from the impacts of climate change are avoided as much as possible. Both include changes in the energy systems, agriculture, built environment and forestry. The activities taken also overlap within mitigation and adaptation.

There are number of ways to advance the society dimension within PEEX and these will be developed in collaboration with the PEEX research agenda (F-1) and the PEEX infrastructure (F-2) plans. The strategy is two-fold. First, within the research agenda attention is paid to the societal needs of the PEEX region when formulating the research questions and this has already been taken into account in this science plan. Further explorations of this are carried out when more detailed research projects are launched as part of PEEX. This is particularly relevant to the research questions addressing the anthropogenic system. Second, society dimension is taken into account when addressing the needs related to research infrastructure and the role of societal actors in this. A

number of interactive methods can be employed here, ranging from stakeholder workshops to participatory research. These will be further explored and developed according to needs as the PEEX science plan will become realised.

Fig. 50 In Mongolia, Kazakhstan and Buryatia the main source of emission by the traditional land use is firewood using (pot Kasimov , Bityukova)

5.1.1 MITIGATION – KEY ASPECTS

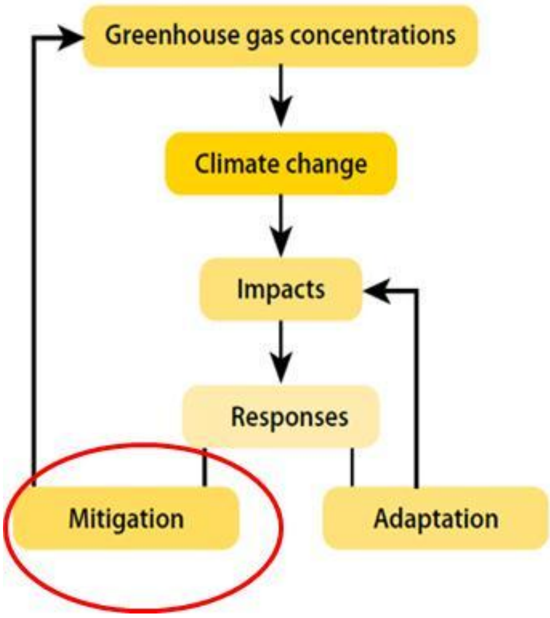


Fig. 51. Mitigation is understood as activities to protect nature from society (Stehr et al. 2005) ref. Juhola

SYNOPSIS: The primary aim of the mitigation plans/strategies is towards low-carbon societies in an Arctic-boreal region. Future actions are needed stabilize greenhouse gas concentrations from agriculture and forestry, energy production and manufacturing. For the GHG stabilization we need to develop new technologies, management practices, urban planning and increase the use of renewable energies (wind). Furthermore, the land use actions related to agriculture and forestry and protection of ocean ecosystems are needed to protect the natural carbon sinks.

PEEX addresses the following main topics of mitigation

(i) Sustainable agriculture and forestry

The major part of the territory used for extensive agriculture in Eurasia is located in its northern part (sub regions of Russia, Ukraine and Kazakhstan where the positive impact of climate change is expected). Intensification of agriculture and implementation of efficient agriculture technologies in these zones can multiply the outcome of the agriculture sector in the region. Multiplication of the efficiency of agriculture, in combination with the operation of new Eurasian transport

infrastructures, will essentially raise food security in Eurasia (ref. IIASA). Important topics of studies of forestry are the following: negative institutional shifts in Russian forestry in the 1990–2000s and their impact on forestry managing and adaptation to natural change (Kuzminov, 2011); forecast of the frequency of forest fires due to the climate change and with account of negative institutional shifts.

(ii) Safe energy production, energy efficiency and manufacturing

Industrial activities such as energy production and manufacturing are one of the key anthropogenic activities regarding contribution to the environmental change. The main environmental outcomes of these activities are pollution, land transformation and intense use of natural resources, whilst industrial activity is vital part of the economic sector of contemporary society. One of the challenges of the forthcoming decades is to optimise industrial activities in order to minimise its impacts to the environment without reduction of productivity. PEEX will contribute to this problem examining the feedbacks between anthropogenic activities and the environment. PEEX will conduct local case studies of the interactions between regions' ecosystem and industrial infrastructure in order to build an efficient model of such interaction, which is a necessary step in optimising human presence in the environment. Raising energy efficiency implies saving scarce energy resources, reducing the pressure on the environment, supporting the technology transfer, and promoting technological innovations. The implementation platform may employ modifications of cooperation and corporate instruments of the post Kyoto developments (ref. IIASA). (Renewable energies)

Both Russia's North and East possess abundant mineral resource potential. The resource orientation of northern and eastern Russia's economy, which had not changed for centuries, only increased in the post-Soviet period and was influenced primarily by the product market. The natural resource development sector of the economy (mining together with forestry) will continue to prevail in the majority of these territories for the next decades. But serious socio-ecological problems remain. In the post-Soviet period, the criteria of profitability have become dominant in the decision making of enterprises and federal/regional governments, but it has not incorporated socially responsible and ecological criteria as well. Consequently, the local population is now faced with grave ecological problems in places of industrial natural resource utilization. There is also social and ecological conflict between industrial exploitation of natural resources and traditional forms of nature management (i.e. reindeer breeding, etc.). Processes aimed at mitigating the negative impacts of resource utilization are weak because the federal government takes too much tax gained from the locations where the resources are exploited. Consequently, local authorities cannot fund adequate social and environmental protection measures.

(iii) Coordination in management of water resources and ecosystem services

Industrial infrastructure produces great amount of impacts to the environment as well as it consumes natural resources intensively. Unbalanced use of natural resources and uncontrolled production transform the environment severely which in turn affects ecosystems and society in the most unpleasant ways. Hence, a great deal of control and coordination is needed in order to optimise the interactions of industrial infrastructure and the environment.

Coordination in management of water resources and ecosystem services is highly important for both maintaining economic growth and preventing destabilization of the environment. Northern Eurasia accumulates tremendous water resources and ecosystem services (particularly the biggest over the

globe boreal forests - Siberian taiga) which operate as important components of the global biotic regulation mechanism and very likely will be under substantial risk (northern Siberia alone contains in frozen ground up to 900 Pg C; warming and thawing of permafrost may provide destructive impacts on the Earth System, surviving of boreal forests, life of many smaller peoples, and have grave consequences on national and global economies). Understanding of systems interactions between current and future hydrological regimes, dynamics of permafrost and functioning the arctic and boreal ecosystems is a corner stone of satisfactory socio-economic developments of huge territories. Working out balanced recommendations for transition to sustainable management of water resources and ecosystems in Eurasia has an extraordinary meaning for strategic planning and will be an innovative research task of systems analysis (ref. IIASA).

(iv) Urban design

Urban areas are among the major contributors to climate change through the emissions of greenhouse gases. The potential for reductions of emissions in urban areas is great and many cities have already taken advantage of this by pursuing low carbon initiatives. Within PEEX, the research agenda in the urban context focuses on identifying the best possible strategies for reduction of greenhouse gases with keeping in mind the interactions between land use and the atmosphere.

For example, present-day Russian territorial and urban planning almost does not take into account the results of research works and forecasts of possible future natural change and hazards. There is no Master-Plan of spatial development of Russia. At the same time there is profound geographic information of this kind that could be incorporated into interdisciplinary studies. PEEX program should become a source of reliable data on zoning of the territory Arctic and boreal Pan-Eurasian region according to 40-years forecast.

(v) Eurasian transport corridors

Development of new Eurasian transport corridors (across land and Northern Sea Route) can initiate rapid growth in commodity circulation in the region, raise employment, promote implementation of technological innovations in the transport and infrastructure sectors, and lead to economic and social approach. An important research task will be assessment of energy efficiency and socio-ecological consequences of the new transport corridors and optimization of the future transport flows at both the Eurasian and sub-regional scales (ref. IIASA)

(vi) Protecting the natural carbon sinks

Protecting the natural carbon sinks includes natural resources management, ecological safety and new ecological standards of life, protecting biodiversity and resource management of the Russian coastal zones

(Vii)Living conditions of the northern people

Northern reindeer husbandry along with sea and river fishery is one of the main branches of the traditional north economy and the main occupation of the nomadic Northern people. This is a source of sustainability of the northern indigenous societies. The number of wild and domestic reindeer has dramatically declined in post-soviet period (Gray 2000, Hiyama and Inoue, 2010, Litvinenko 2013). Field studies in North Yakutiya revealed that availability of drinking water (stored as ice in winter), availability of bio-fuels (mainly wood), pasture and land productivity, and patterns of animal reproduction and hunting are changing (Hiyama and Inoue, 2010). The migration routes of wild reindeer are changing in relation to new environmental conditions. MODIS satellite data showed that reindeer move along rivers and through zones of better vegetation, while avoiding increasingly

common forest fires. Interviews with indigenous people, keepers of domestic reindeer, revealed that current climate change has not severely damaged their operations and they have been able to successfully adapt to changes in climate, while, on the contrary, they were severely impacted by social changes following the collapse of the Soviet Union (http://www.chikyu.ac.jp/rihn_e/project/C-07.html).

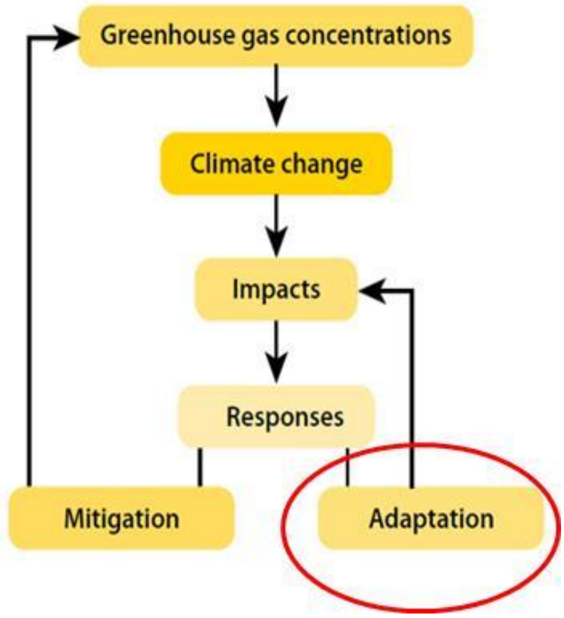
(viii) Geoengineering

Geoengineering and remediation are methods of artificial transformation of the environment, such as: technical removal of contaminants, isolation of hazardous wastes and solar radiation management. Generally geoengineering is proposed as another separate option for the mediation of climate change effects, but it is also perceived as an additional technique for adaptation and mitigation strategies (Wigley, 2006). Main critique of those methods are that they lack control and predictability, since modern science cannot yet reach certain level of understanding of all the feedbacks between the Earth systems it cannot predict with certainty the long term effects of such methods. And as it was pointed out: we cannot seriously propose to conduct any geoengineering efforts regarding climate change until we will fully understand our earlier contributions to this change (Matthews et al., 2009). In that sense PEEX contributes to exploring geoengineering technologies by providing necessary information on diverse interactions in climatic system.

In the coming decades certain geoengineering technologies can be developed and used to countervail the change. Before any real-time experiences it is important to quantify and analyse the impact of their implementation on sensitive Arctic ecosystems by modelled scenario studies. Under PEEX research domain, the future research would aim to encompass new things like ice sheet – ocean interaction simulation. Also, the sea ice models can be used to study deliberate modification by shipping on early season ice cover, and to do ESM simulations of albedo type modification of land surface in the Eurasian Arctic region. These modelling efforts can provide important knowledge on which to base more detailed future studies.

- **Wigley, T. (Oct 2006) "A combined mitigation/geoengineering approach to climate stabilization" *Science* 314 (5798): 452-454**
- **Matthews, H. D.; Turner, S. E. (2009) "Of mongooses and mitigation: ecological analogues to geoengineering" *Environmental Research Letters* 4 (4): 045105**

5.1.2 ADAPATION – KEY ASPECTS



SYNOPSIS. The PEEX research agenda supports the planning for adaptation through the provision of scientific knowledge of natural and climatic processes in order to assess the extent of climate risks in the future. PEEX will accumulate scientific knowledge of how societies in the PEEX area are able to adapt to climate change and what issues can hamper these processes.

Fig.52 ***Adaptation represents activities understood as protecting society from nature (Stehr et al. 2005) ref. Juhola***

PEEX addresses the following topics of adaptation:

The development of adaptation strategies is a political process within which decisions are made in terms of what kinds of measures can be taken to reduce these vulnerabilities to climate change. In these processes, the production and dissemination of scientific information is crucial is steering the society towards optimal solutions. Adaptation strategies are essential for federal, regional and local authorities in addition to the specific plans in various branches of economy in the face of climate change impacts. Climate change impacts will have an effect on all regions but the ways in which the different regions respond to these changes is depended on their specific characteristics. A region's vulnerability to climate impacts is not only determined by the exposure to climate stimuli but also by its sensitivity to the impacts in questions and its adaptive capacity. Sensitivity to impacts is considered to be the specific elements of a society that are, for example sensitive to a specific impact such as a coastal city to sea level rise. Adaptive capacity is defined as the ability to change and adapt to the impacts that are likely to occur due to climate change i.e. the ability of the city to build flood defenses. Adaptation can be considered to take place through long-term structural changes in society, as well as through shorter term changes as a result of unexpected shocks. For the former, longer term political strategies are necessary, whilst the latter requires different kinds of early warning systems through which information of climate impacts can be fed into the shorter term management of economic resources and other societal activities.

The development of adaptation strategies is a political process within which decisions are made in terms of what kinds of measures can be taken to reduce these vulnerabilities to climate change. Adaptation can be defined as either planned adaptation that is taken by the state and that aims to ensure reduction of vulnerabilities through political processes. These processes have normally take place at the national level with different ministries engaging planning for adaptation. Similarly adaptation can take place through autonomous measures whereby different actors in society engage

in changing their behavior due to climatic stimuli. These actors, including the private and the third sector, can change their practices in order to reduce the risks from climate change.

Complex mitigation and adaptation strategies should be worked out for federal, regional and local authorities in addition to the specific plans in various branches of economy. It would be rather important to explore the interaction between environmental change and post-Soviet transformation of natural resource utilization in North Eurasia to assess the complexity of their socio-ecological consequences at regional and local levels. The population dynamics in regions of Northern Russia in 1990–2012 and the linkage between intra-regional differences in population dynamics and spatial transformation of natural resources utilization and ethnic breakdown of the population should be clarified. Mechanisms of interaction between regional environmental change and post-Soviet transformation of natural resources utilization at both regional and local levels are of special importance in this sense (Litvinenko, 2012). The local peoples' (indigenous people and newly arrived people) adaptation and response to both environmental and economic changes would improve evaluation of socio-ecological fragility and vulnerability. It would be desirable to develop an "early warning system" for timely mitigation of negative socio-ecological effects of both environmental and natural resources change. Such system would be useful for federal, regional and local authorities, as well as for local communities.

5.2 CLIMATE POLICY MAKING

Fig.56

SYNOPSIS. PEEX will work closely with influential organisations such as the Intergovernmental Panel for Climate Change (IPCC), the International Council for Science (ICSU) Global Environmental Change (GEC) programmes (IGBP, DIVERSITAS, WCRP, IHDP), the emerging international global sustainability initiative Future Earth, and Digital Earth. Future Earth is being developed by ICSU, the United Nations, the International Social Science Council (ISSC), and the Belmont Forum, and it will merge most of the ICSU GEC programmes over the next few years and become a major player in the international global change research field. Digital Earth is a global initiative aimed at harnessing the world's data and information resources to develop a virtual 3-D model of the Earth in order to monitor, measure, and forecast natural and human activity on the planet.

PEEX project goal is to provide tools for scientists to produce results that can diminish the uncertainty in scientific knowledge that policy makers are utilizing in policymaking process in PEEX

region. Also, PEEX project improves the tools that scientist have in communication with policy makers. Scientific uncertainty is still the prevailing fact regarding the research domain of PEEX. As our knowledge on PEEX science domain increases, perceptions of the types and levels of scientific uncertainty may increase or decrease. Assessment of risk and uncertainty in PEEX science domain therefore involves a degree of subjective judgment that PEEX scientists, in multidisciplinary way, try to clarify and provide for policy makers to be used in successful climate policy making. Different policy sectors and scientific disciplines will be invited to join the PEEX project in order to be able to respond to the challenges that require multidisciplinary approach.

PEEX will contribute to solving major global challenges and contribute significantly to socioeconomic issues related to global sustainability and ecosystem-atmosphere-society interactions: examples include the interactions between climate changes and the terrestrial, coastal, and marine environment and agriculture, forestry, energy consumption, urban planning, and extreme events. Among the main themes will be sustainable managed environments and the mixed anthropogenic (sulphur and nitrogen) and biogenic (BVOCs) input to cloud and aerosol processes. PEEX will answer to the needs of policy-makers in the region by producing assessments and policy briefs of relevant topics and by maintaining an open dialogue with stakeholders and policy-makers: PEEX will create communication channels internationally and within each individual country and ensure that the new scientific understanding will be available and ready to use at policy level. Internationally, PEEX will work closely with influential organisations. such as the Intergovernmental Panel for Climate Change (IPCC), the International Council for Science (ICSU) Global Environmental Change (GEC) programmes (IGBP, DIVERSITAS, WCRP, IHDP), and the emerging international global sustainability initiative Future Earth. Future Earth is being developed by ICSU, the United Nations, the International Social Science Council (ISSC), and the Belmont Forum, and it will merge most of the ICSU GEC programmes over the next few years and become a major player in the international global change research field. The key concept in Future Earth science is co-design of research plans with stakeholders, scientists, and funders together to produce knowledge necessary for societies to cope with global change and to transition to sustainable economies and practices.

PEEX is endorsed by the IGBP core project iLEAPS (Integrated Land Ecosystem-Atmosphere Processes Study) that has its international project office in Helsinki and daily contacts with PEEX leaders. ILEAPS will bring visibility especially to the ecosystem-atmosphere interactions research within PEEX and, as part of IGBP and the emerging Future Earth, Digital Earth, iLEAPS can act as one channel for PEEX results to reach the policy level in different PEEX countries. Via iLEAPS, PEEX is linked to the Future Earth initiative that will re-organise ICSU's GEC programmes to act in an integrated way towards global sustainability research: this requires the integration of social science and economics with natural sciences at all levels of research, from planning the research to implementing it and interpreting the results. Finding the best way to get these different communities to work together is challenging, but PEEX is well equipped to take the first steps in the Pan-Eurasian region on the road to solving the equation of one Earth and a growing human population

In each country, scientists have their own channels through which to reach out to policy-makers. PEEX engages the local scientific leaders and, with their experience, creates the multiple pathways necessary for an effective science-policy dialogue: in Finland, PEEX has direct links with the National Climate Panel; to the Forum of Environmental Information (www.ymparistotiedonfoorumi.fi) that

produces scientific information for policy-making; and to Future Earth, the international initiative on global sustainability led by ICSU, ISSC, and UN (www.icsu.org/future-earth) and to the Digital Earth forum.

6. KNOWLEDGE TRANSFER

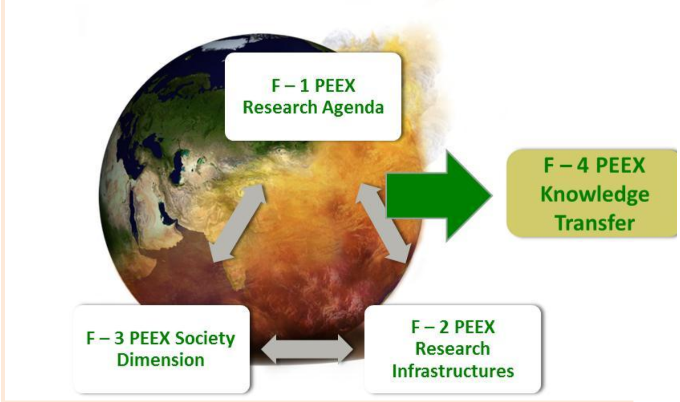


Fig.53

SYNOPSIS. PEEX will establish different level and type of educational activities. PEEX will also promote the distribution of scientific information to the general public as well as to the science teachers of primary and secondary schools.

6.1 EDUCATION PROGRAMME ON MULTIPLE LEVELS

Fig.54

SYNOPSIS. One of the first activities of PEEX will be the establishment of PEEX Education programme. Main emphasis is on facilitating dissemination of existing education material and collaboration of national and regional programs. PEEX training targets on training of researchers' throughout their career from master and Ph.D. level studies to expert, professor and research institute leaders with actions fitted to the different levels. Building bridges between natural sciences as well as with social sciences is one of the most important goals of the international and interdisciplinary education collaboration.

PEEX education programme is founded on lifelong learning at multiple levels and targets from raising the awareness of the general public to training expert skills of scientists and disseminating PEEX scientific outcomes to stakeholders.

Objectives of the training and promotion of the research career: 1) to educate a next generation of researchers and specialists in atmospheric research, 2) to establish future collaboration between PhD students with national and international parties involved in atmospheric / Earth system

research and technology, 3) to provide transversal training addressing all aspects of the atmospheric and Earth system observation, from instrument development, data provision to data application in numerical models and 4) to provide transferable skills applicable on a wide range of scientific and expert tasks in the society.

MSc level	PhD level	Postdoc level	Professor level
• Specializing in one topic • Learning general scientific practices	• Further specialization, learning independent research • Getting the big picture	• Establishing own research • Obtaining funding • Building research group	• Building and maintaining international networks and research consortia • Top-level initiative preparation
• Joint programmes • Local programmes • International courses	• Joint programmes • Local / national programmes • Workshops • International courses	• Science workshops • Teacher workshops • International courses	• Science workshops • Teacher workshops • International courses

PEEX EDUCATION PROGRAMME addresses the following themes:

(i) Training of multidisciplinary skills and knowledge transfer skills

Research of climate change and air quality as well as development of adaptation and mitigation plans requires combination of mastering core expertize (from master to Ph.D. level), multidisciplinary (Ph.D. level) and possession of supplementing soft skills (Ph.D. post doc to professor level). The PEEX Education program will engage Ph.D. students, post docs, technical staff and experts in knowledge transfer both by horizontal knowledge transfer during courses held by the world experts in different fields of science as well as lateral cross disciplinary training by peers. The doctoral students involved in PEEX are enrolled in local and national doctoral programmes involved in the project. Courses with specialist lectures and tackling key research questions transfer knowledge from professors to students, and also among the professors and experts in the different

PEEX fields of science that cover many topics and promote fresh views on the complex multidisciplinary research questions.

(ii) Opening already existing courses at PEEX institutes

PEEX education plan includes collaboration by opening already existing courses at PEEX institutes for PEEX students. The courses held regularly at the other universities can be included into the curriculum of individual students at the PEEX institutes. Courses can also be tailored to share special expertise and fit the needs of an institute e.g. an institute specialized in in-situ observations can arrange for satellite observation training from another institute. The education also targets on peer to peer knowledge transfer trough expert and professor exchange and interdisciplinary workshops focusing on the PEEX scientific questions.

(iii) Cross discipline collaboration and promoting mobility

PEEX institutes possess world leading expertize on climate change in the arctic and boreal regions and the knowledge transfer facilitates peer support and buildup of expert network of Pan-Eurasian experts. Training of soft and supporting skills is part of the knowledge transfer program. The student exchange program facilitates cross discipline collaboration and promotes mobility within Eurasia, specifically nations within the Arctic and boreal region: North Europe, Russia and China. Mobility both nationally and internationally is done on four levels: (i) between PEEX sites; (ii) between research fields (ecology-physics-technology-chemistry-meteorology-geography, in situ observations–remote sensing observations); (iii) between research methodologies (theory-modeling-experiments-observations); and (iv) between universities, research institutes and business. The mobility is carried out by organizing joint courses and workshops, and through researcher secondments.

(iv) Recognizing the importance of career development

The master and doctoral training is organized through national education programmes and the aim of PEEX is to facilitate the education collaboration of national and regional programs as well as individual universities. PEEX recognizes the importance of career development, and the education structure aims to covers all the academic levels from Ph.D. students to professors and institute leaders, thus also involving the idea of lifelong learning.

The actions supporting the creation and existence of the positive feedback loop in education include: (i) supporting formation of formal and informal interdisciplinary and international supervision and peer support (ii) facilitation of cross-supervision involving supervisors from two or more research groups ; (iii) organizing annually several joint, international courses and workshops to directly support the students' research, and providing both core and transferable skills; and (iv) transparency and open information flow, contributing institutes post adverts on courses through a web portal. The specific transferable skills provided to both the students and postdoctoral researchers include e.g. skills in working with the field measurements; instrument technology; data analysis, data mining, modeling, presentation, teaching and knowledge transfer, project management; public outreach; commercialization of scientific ideas; and entrepreneurship.

(vii) Training next generation research infrastructures experts (best practices, twinning)

PEEX will engage the larger international scientific communities also by collaborating with, utilising, and advancing major observation infrastructures such as the SMEAR, ICOS, ACTRIS, and ANAEE networks in addition to building its own in the Pan-Eurasian region. PEEX will promote standard methods and best practices in creating long-term, comprehensive, multidisciplinary observation data sets and coordinate model and data comparisons and development; PEEX will also strengthen the international scientific community via an extensive capacity building programme. Knowledge transfer and training, including facilitating open discussion based on mutual respect among networks initially built for different fields of science and building bridges between the communities behind the major observation infrastructures in the PEEX domain. Training actions aimed specifically at the support of infrastructure and PEEX observation network include international courses on core topics, and workshops were best practices are agreed on, taught and refined. Experts are encouraged to continue lifelong learning, to refresh and upgrade core and transferrable skills. Staff exchange and secondments is an essential part of expert training and exchange between institutes, within and between research and monitoring infrastructures, are promoted. Knowledge transfer actions are is bidirectional and experts are expected to share their knowledge with their peers as well as to lecture and teach the next generation.

Twinning activities where field stations in PEEX domain are upgraded and expanded to become multidisciplinary observation infrastructures. Twinning involves two partners one is the expert, e.g. field station or data processing facility, which shares their experience with the developing partner. Both partners commit by signing an agreement to the long term process where the infra and protocols of the experienced partner are adapted to the conditions of the facility that is expanding its scope of expertize. Support in twinning is purely immaterial and funding for development of instrumental and facilities is obtained from other sources. In addition to twinning, PEEX promotes multi-institute peer support and peer knowledge transfer and acknowledges that a person can be expert giving lectures on one topic and a novice who needs training on another topic.

(viii) Integration of research and education activities into larger frameworks

PEEX will promote and strengthen the productive supradisciplinary research environment while being an active player in science policy by deepening the scientific understanding of the multi-scale concept and participating in the construction of PEEX region environmental research infrastructures with an open data access and visualization of data. PEEX initiative is promoted by University of Helsinki, Finland, also leading Centre of Excellence in Atmospheric Science – From Molecular and Biological Processes to the Global Climate (ATM) that is actively proposing and participating in European level initiatives on doctoral training, e.g. Erasmus Mundus programmes and FP7 Marie Curie Initial Training Networks (CLOUD-ITN, CLOUD-TRAIN, HEXACOMM). Other doctoral training initiatives that PEEX involved institutes take part in include bilateral and regional programs.

PEEX EDUCATION AND TRAINING: EXAMPLES OF TARGET GROUPS, AIMS AND ACTIONS

Secondary school teachers and pupils	Increase the awareness of Public	Dissemination of PEEX topic material
Master and Ph.D. students	Educate next generation of scientists in PEEX domain	Local/regional programs, International courses and workshops
Young scientists	Technical experts retraining. Maintenance of infrastructure.	Best practices. International courses and workshops. Twinning.
Education of potential business applicators	Commercial use of PEEX outcomes.	International courses and workshops.
Data operators	To meet data standards.	Best practices. International courses and workshops. Twinning.
Senior scientist	To enforce interdisciplinary understanding.	International courses and workshops.
Stakeholders	Disseminate specific outcomes on mitigation / adaptation.	Policy papers on PEEX scientific outcomes.
Economy sectors	Regional awareness on PEEX observation system.	Contact node, information dissemination.
General public	General awareness about Arctic climate change.	Transparent dissemination of PEEX scientific outcomes trough web portal.

6.2 ESTABLISHING FUTURE RESEARCH COMMUNITY

Fig. 55

SYNOPSIS. PEEX will add to the building of new, integrated Earth system research community in the Pan-Eurasian region by opening its research and modelling infrastructure and inviting international partners and organisations to share in its

development and use. PEEX will be a major factor integrating the socioeconomic and natural science communities to working together towards solving the major challenges influencing the wellbeing of humans, societies, and ecosystems in the Arctic-boreal region.

Diversity exist on many levels and PEEX supports mutual respect, building bridges and trust among hard natural sciences and social sciences, recognition of regional and national circumstances and promotes gender balance.

- **Diversity of knowledge is essential for tackling grand challenges. It requires combining knowledge of multiple natural science as well as social sciences. Building bridges over fields of science are a necessity for open discussion, trust and respect among scientists from different disciplines.**
- **Diversity of solutions is essential, to get things working. Regional circumstances, ranging from climate and geography to culture and legislation, must be taken into account while making decisions. One shoe does not fit all feet and thus PEEX aims at giving recommendations and best practice protocols, but accepts diverse solutions that fit to the regional circumstances. PEEX facilitates joint education and training and promotes mutual recognition among the involved institutes, while the requirements of the training programmes and degrees obtained therein comply with the legislation of each participating country.**
- **Diversity of persons is present any time when more than one person is involved. We are all different and PEEX acknowledges that people are different and personal growth, education and training requires different actions and support. PEEX does not accept any kind of discrimination and supports the promotion of equality, including gender balance and positive discrimination actions. PEEX aims at gender balance in decision making boards and equal pay for equal work.**
- **Diversity of cultures is encountered among nations, fields of science and even in the working culture between and inside institutes. PEEX promotes acceptance and equal appreciation of different cultures and facilitates discussion between different cultures.**
- **Diversity of innovation is needed for turning the PEEX ideas and solutions into commercial services and products. Novel ideas rise from diverse mix of people, cultures, knowledge's and solutions.**

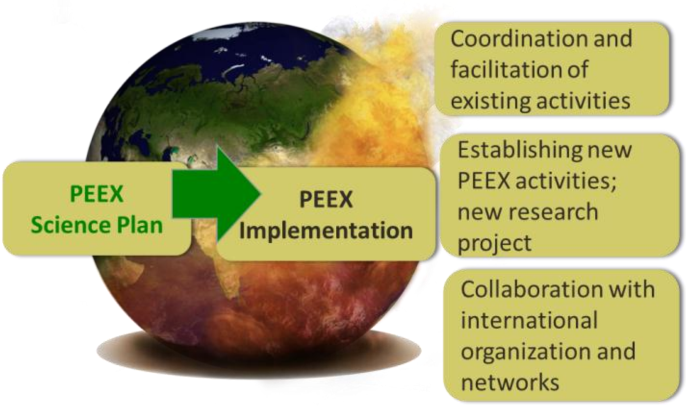
6.3 RISING THE AWARENESS OF GLOBAL CHANGE AND ENVIRONMETAL ISSUES

Climate change is exposing Artic natural resources, and objective information on the impact of global change on the Arctic is essential to make the rising industrial and commercial activities sustainable and responsible. In addition to decision makers, the general public needs reliable, unbiased estimates on the impacts of the new Arctic activities as well as information on the

consequences of the commercial actions. PEEX involved institutes can provide this information and the strong involvement of social sciences aims at raising the awareness of the impacts different consumer behaviors on global change as well as on the societal change that is occurring at the PEEX domain.

PEEX promotes the distribution of scientific information to the general public as well as to the science teachers of primary and secondary schools. Actions include distributing outreach material and e-learning courses provided by EGU such as Geosciences Information For Teachers (GIFT, egu.eu/outreach/gift/) and webGeology flashed teaching resources from the University of Tromsø, Norway (ansatte.uit.no/webgeology/). PEEX also facilitates use of distant learning such as the training offered by WMO to its members (www.wmo.int). In addition PEEX promotes massive open online courses (MOOCs) that are online course aimed at unlimited participation and open access via internet. Metadata of image archives, already established by UNIGEO members, are being openly available, to establish ways for exchange of the data for scientific and educational use.

7. IMPLEMENTATION



PEEX implementation will consist of three components: Coordination and facilitation of existing activities (C-1), establishing new PEEX activities (C2) and collaboration with international organization and networks (C-3).

Coordination and facilitation of existing activities

PEEX will start the implementation of Science Plan by establishing a process towards Pan-Eurasian Observation Networks and PEEX Education program. Pan-Eurasian Observation Networks will be, in the first phase, built on existing stations network infrastructure and existing remote sensing activities. The detailed plans for the technical requirements, instrument setup, data storage, data distribution will be made together with the PEEX contributing research institutes as a bottom up approach. Detailed design of the PEEX modelling platform will be jointly with the observation network. As the first outcome of the PEEX Modelling Platform Preliminary Phase, the PEEX modeling team will make an inventory of available modeling tools fitting the PEEX purposes, illuminate the main existing gaps in the modeling tools and suggest a plan for their developments and improvements.

The first activities of the PEEX Education Programme will be the first PEEX labelled courses provided by the PEEX Contributing institutes and web based education module.

Establishing new PEEX activities

PEEX Science Plan - Research Agenda is a thematic umbrella specific PEEX research funding applications and new research projects. PEEX will actively apply funding from multiple sources in national, Nordic and European scales the first funding applications will be targeted to the opening calls of Nordfrosk, EU-JPI-Climate, EU-Horizon-2020 Programme and Russian research funding programme.

Collaboration with international organization and networks

PEEX will collaborate with several international organization and networks. Important research collaborators will be the Nordic Centers of Excellence (CRAICC and DEFROS) and IIASAIIASA - International Institute for Applied Systems Analysis. The research infrastructure development will be made with the interaction with the *Global Earth Observation System of Systems* (GEOSS). The GEOSS connects PEEX to the GEO Cold Regions activity. At the moment PEEX is listed along with the international programs enhancing the Arctic Data-Information coordination for Cold Regions within global research infrastructures and programs such as the Sustaining Arctic Observation networks (SAON), The Svalbard Integrated Earth Observing System (SIOS), WMO Global Cryosphere Watch (WMO GCW),The International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT), The Conservation of Arctic Flora and Fauna (ABDS-ABA/CAFF) and The Monitoring the Climate Change in the Cryosphere (Cryoclim).

PEEX coordination and management

PEEX activities are coordinated by the PEEX International Project Office (IPO) located at the University Of Helsinki, FINLAND. PEEX-IPO is supported by the code of contacts of the PEEX-Moscow and PEEX- Beijing offices. PEEX IPOs are coordinating PEEX fundraising, outreach activities and assisting the PEEX preparatory Phase Committee. PEEX Preparatory Phase committee consists of representatives of the most active PEEX Contribution Institutes in Europe, Russian and China (APPENDIX-2).

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