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PAN EURASIAN EXPERIMENT (PEEX) – A RESEARCH INITIATIVE MEETING THE GRAND CHALLENGES OF THE CHANGING ENVIRONMENT OF THE NORTHERN PAN-EURASIAN ARCTIC-BOREAL AREAS

ABSTRACT. The Pan-Eurasian Experiment (PEEX) is a new multidisciplinary, global change research initiative focusing on understanding biosphere-ocean-cryosphere-climate interactions and feedbacks in Arctic and boreal regions in the Northern Eurasian geographical domain. PEEX operates in an integrative way and it aims at solving the major scientific and society relevant questions in many scales using tools from natural and social sciences and economics. The research agenda identifies the most urgent large scale research questions and topics of the land-atmosphere-aquatic-anthropogenic systems and interactions and feedbacks between the systems for the next decades. Furthermore PEEX actively develops and designs a coordinated and coherent ground station network from Europe via Siberia to China and the coastal line of the Arctic Ocean together with a PEEX-modeling platform. PEEX launches a program for educating the next generation of multidisciplinary researcher and technical experts. This expedites the utilization of the new scientific knowledge for producing a more reliable climate change scenarios in regional and global scales, and enables mitigation and adaptation planning of the Northern societies. PEEX gathers together leading European, Russian and Chinese research groups. With a bottom-up approach, over 40 institutes and universities have contributed the PEEX Science Plan from 18 countries. In 2014 the PEEX community prepared Science Plan and initiated conceptual design of the PEEX land-atmosphere observation network and modeling platform. Here we present the PEEX approach as a whole with the specific attention to research agenda and preliminary design of the PEEX research infrastructure.

KEY WORDS: climate change, air quality, the Arctic, boreal forest, the Arctic Ocean, atmosphere-biosphere-cryosphere interactions, permafrost, greenhouse gases, anthropogenic influence, natural hazards, research infrastructures.

BACKGROUND

The dynamics between demographic trends, the changes in the demand of natural resources, globalization and climate change and their interactions and feedbacks are the driving forces for the next 40 years megatrends taking place on the northern latitudes and the Arctic regions [Smith 2010]. The Arctic has warmed more than twice the global-average rate during the recent decades, and the summers 2005, 2007, 2010 and 2011 were probably warmer than any other summer during the past 600 years in high northern latitudes [Tingley & Huybers 2013]. The most recent report by Intergovernmental Panel on Climate Change [IPCC 2013] concluded that this pattern will continue, and the Artic regions will warm from 2, 2 ± 1, 7 °C up to 8, 3 ± 1, 9 °C by the end of this century, depending on the selected future emission scenario. To cope with the consequences of the climate change in a global scale the transformation of the civilization and natural ecosystems are one of the ultimate challenges of the 21st century. It is expected that the northern regions, land and ocean areas lying 45 °N latitude or higher, will undergo consequential change during the next 40 years [IPCC 2013].

The warming will affect the demography trends and urbanization and, consequently, the migration to the Northern regions is expected increase. One of the major environmental consequences of the warming is thawing of permafrost and melting of ice over the Arctic Ocean [Christensen et al., 2004; IPCC, 2013]. The thawing of permafrost in the Boreal and Arctic regions will impact the exploration and extraction of large sources of non-renewable natural resources such as oil and natural gas in diverse ways. Navigation in and the transport through the Arctic will increase, if the Northern Sea Route between the Atlantic and the Far East will stay open for shipping for a longer summer-autumn period than presently [Kerr, 2012]. Considering the utilization of the natural resources, while the exploitation will be easier as the permafrost is thawing, instability of frozen ground will generate higher potential risks of accidents, for example, on transportation of oil and gas via pipelines.

One of the major impacts of the Northern Pan-Eurasian region on the climate system is related to the changing dynamics of the Arctic-boreal ecosystems. The changes in ecosystem distribution and productivity, surface energy balance, albedo and in the production volume of the aerosol precursors and greenhouse gases can be significant and probably will play a vital role. The Eurasian area holds a large pool of recently stored-carbon within the biota and an inactive soil carbon pool in permafrost areas, but also a vast storage of fossil carbon storage in the form of oil and gas deposits [Groisman et al., 2013]. Due to these large storages, small changes in the carbon dynamics, release and emissions can have global climate consequences [Piao et al., 2008; Zimov et al., 2006]. The expected shifting of the bioclimatic zones towards Arctic together with replacement of boreal forests in the southern ecotone of the forest zone makes substantial changes in land cover over the Siberian regions [Buermann et al., 2014; Walther et al., 2002; Tape et al., 2006; Elmendorf et al., 2012; Shvidenko et al., 2013; Tchebakova et al., 2009]. The boreal forests can be considered as a tipping element as they may enter into unstable state, where relatively small changes of environment may lead to a nonlinear feedback in functioning of forest ecosystems and death of its components with the least adaptation capacity [Lenton et al., 2008]. These changes are reflected to woody biomass accumulation and net primary productivity (NPP) of northern terrestrial ecosystems [Rustad et al., 2001; Melillo et al., 2002] and may, on the other hand, lead into a negative feedback between climate warming and the terrestrial ecosystems in a form of secondary aerosol formation [Paasonen et al., 2013].

In addition to the land ecosystems – atmosphere processes, understanding planetary boundary layer (PBL) mechanisms has a significant role in the Earth system dynamics. The PBL is the lower, essentially turbulent atmospheric layer immediately affected by the interactions with the underlying land, biosphere, urban, water, ice or snow surfaces, and usually subjected to pronounced diurnal temperature variations. Physical and chemical processes in the PBL control local features of weather and climate, as well as the outdoor and indoor air quality. The PBL is intensely turbulent in contrast to the free atmosphere, where turbulence is significantly weakened due to the dominantly stable stratification [Zilitinkevich et al., 2013]. Shallow stably-stratified PBLs amplify consequences of thermal impacts e.g. from local changes in the land-use or the global climate change and increase the level of air pollution at given intensity of emissions [Zilitinkevich et al., 2007; Zilitinkevich & Esau, 2009;

Esau et al., 2013]. Deep convective PBLs typical of unstable stratification strongly influence weather and climate through ventilation (turbulent entrainment) at the PBL upper boundary, and essentially control air quality and development of convective clouds [Zilitinkevich, 2012].

A new large-scale research initiative "Pan Eurasian Experiment", PEEX was launched in Helsinki, Finland, in October 2012. A group of Russian, Chinese and European research institutes established a process towards writing a science plan underling the most urgent research topics and related to climate change on the Arctic boreal environments and societies of Northern Pan-Eurasian regions (Fig. 1). It was established that the research agenda needs to be complemented with the development of observation networks and data systems, establishing education activities and fast procedures for the Northern societies to cope with the environmental change.

PEEX OBJECTIVES

PEEX is a next generation research initiative, contributing to the future environmental, socio-economic and demography development of the Arctic and boreal regions. Furthermore, PEEX aims to form a strong science community, which coordinates and builds novel observation and data infrastructures in the Northern Eurasian region.

The objectives of PEEX are:

1) to understand the Earth system as a whole and in particular to understand the influence of environmental and societal changes in pristine and industrialized Northern Pan-Eurasian environments.

- to determine the processes relevant to the climate change in the Pan Eurasian region.

2) to establish and sustain long-term, continuous and comprehensive ground-

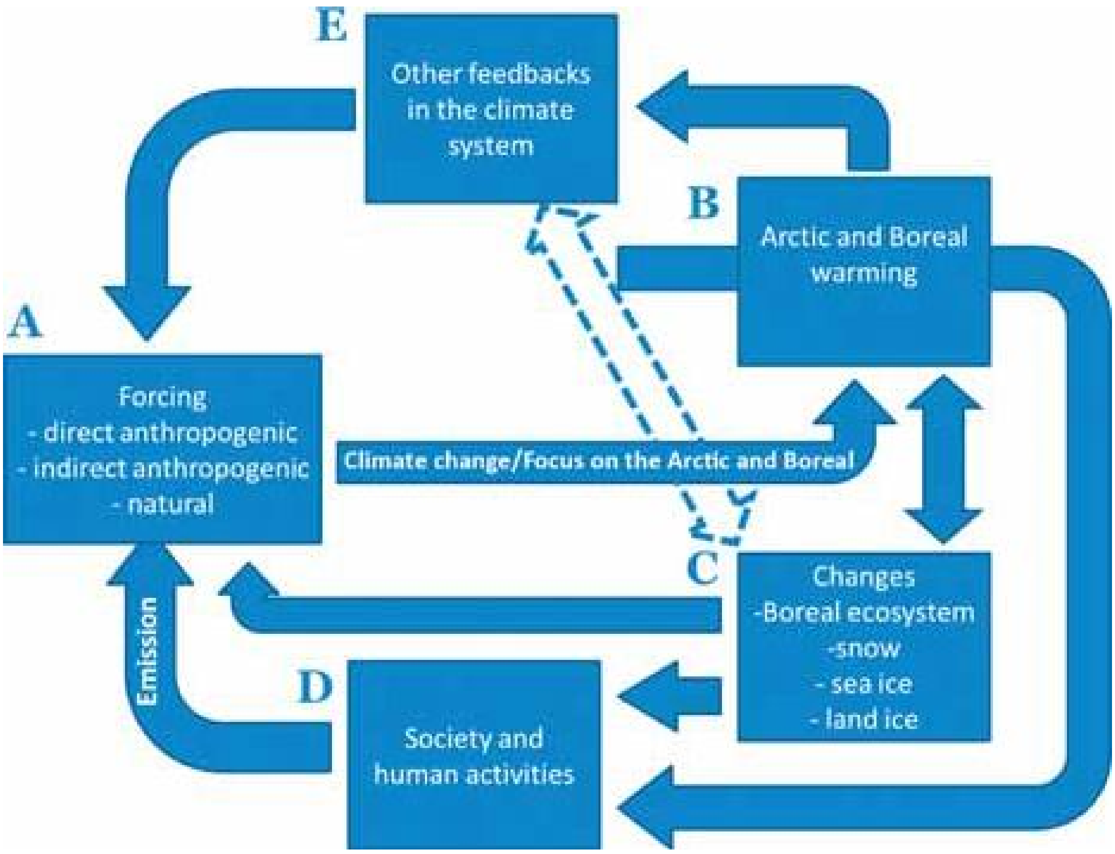

Fig. 1. PEEX large scale schematics addresses the strong role of the Arctic and boreal regions (adopted form Nordic Center of Excellence "Cryosphere-atmosphere interactions in a changing Arctic climate" (CRAICC)-project).

based airborne and seaborne research infrastructures, and to utilize satellite data and multi-scale model frameworks supporting comprehensive earth observations.

3) to contribute to regional climate scenarios in the Northern Eurasia and China, and to determine the relevant factors and interactions influencing human and societal wellbeing.

- to assess the natural hazards (floods, forest fires, extreme water events, risks for structures built on permafrost) related to cryospheric changes in the Northern Pan-Eurasian arctic-boreal regions
- to provide information for the adaptation and mitigation strategies for sustainable land-use, energy production and human well-being.

4) to promote dissemination of the state-of-the-art scientific results and strategies in the scientific and stake-holder communities and policy making.

5) to educate the next generation of multidisciplinary global change experts and scientists.

6) to increase the public awareness on the climate change impacts in the Pan-Eurasian region.

RESEARCH METHODS

The PEEX research agenda is built on large-scale research questions of the main PEEX components: land-atmosphere-aquatic-systems including the key questions of the human activities and society and feedback and links between the systems. The method solving the topical research questions and complex feedbacks, is adopted from the EU-FP6 – "Integrated Project on Aerosol, Cloud, Climate, and Air Quality Interactions" (EUCAARI), the atmospheric aerosol project [Kulmala et al., 2009; Kulmala et al., 2011] and it is based on integration of scientific knowledge from nano- to global scale with multidisciplinary science approach (Fig. 2).

The PEEX research approach covers different spatial and temporal components, where PEEX is investigating various types of natural ecosystems and urban environments. The large scale systems covered by the PEEX approach are the land-system, atmospheric-system, aquatic-system and the human activities on this system as a whole. Each system can be divided into smaller sub-components. For example, the land-system

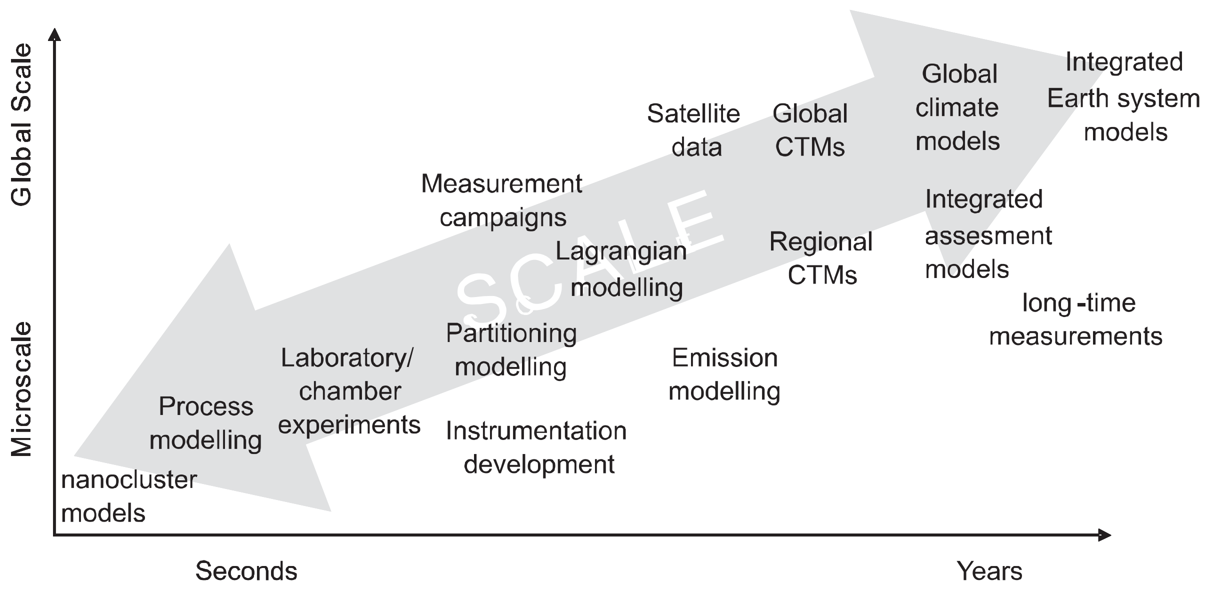

Fig. 2. The "EUCAARI arrow" servers as a methodological concept for connecting scientific results from molecular scale processes with the global scale effects by using integrated measurements, modelling and theory (Kulmala et al., 2009).

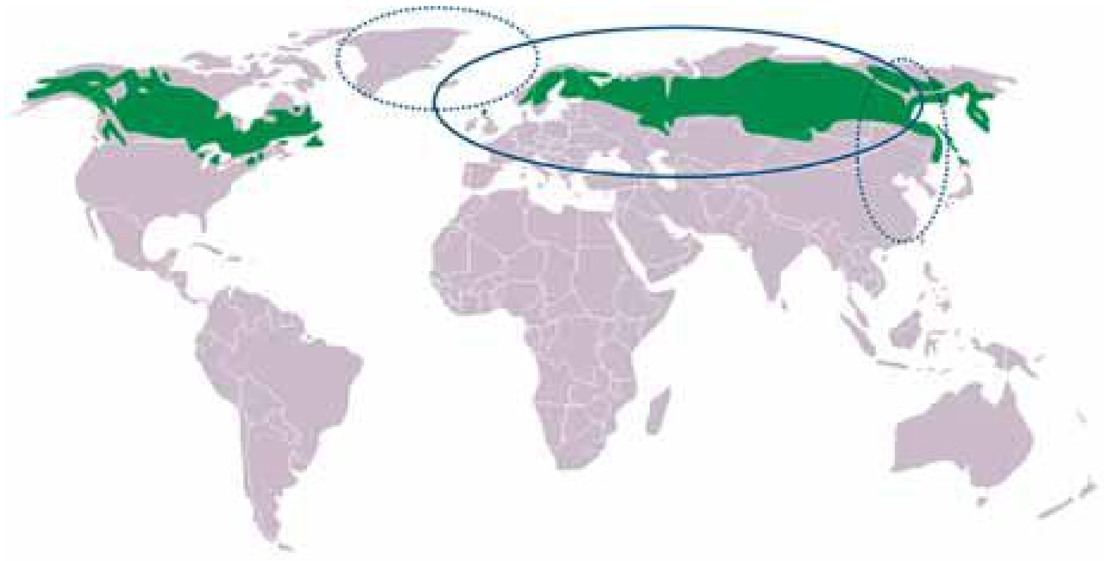

Fig. 3. Geographical boundaries of PEEX domain (inside the dotted line). The PEEX covers the Arctic-boreal areas of Pan-Eurasian region including major remote areas of Greenland and the important long-range air pollution, China (map http://en.wikipedia.org/wiki/File:Distribution_Taiga.png).

is divided into boreal forests, burnt or clear-cut areas, grasslands, tundra and peatlands, whereas the Aquatic-system is divided into the Arctic Ocean, freshwater lakes and rivers, and associated catchments, shores, continental shelves and pelagic regions. The Atmospheric-system is classified into boundary layer, troposphere, stratosphere and the human activities include the anthropogenic impact, environmental risks and social transformations.

Geographically, Northern Europe, Siberia and Far East are the ecoregions of the PEEX domain (Fig. 3) with related hydrological areas and catchment areas. China is included as an important source area for the atmospheric PEEX component.

LARGE-SCALE RESEARCH QUESTIONS

PEEX community has identified 15 large scale research questions (Q) pertinent for each subsystem for the next 10 years. Each of the large scale research questions is connected to one of the key topics of the PEEX research agenda. The key topics are introduced in the PEEX Science Plan in more detail.

LAND SYSTEM

Q-1 How could land regions and processes that are particularly sensitive to climate change be identified, and what are the best methods to analyse their responses the future changes?

Key Topic: Shifting of vegetation zones, Arctic greening

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

Key Topic: Risk areas of permafrost thawing

Q-3 What are the tipping points in the changing Pan Eurasian ecosystems in the future?

Key Topic: Structural changes of the ecosystems

ATMOSPHERIC SYSTEM

Q-4 What are the critical atmospheric physics and chemistry processes with large-scale climate implications?

Key Topic: Atmospheric composition and chemistry

Q-5 What are the key feedbacks between air quality, climate and weather at northern high latitudes and in China?

Key Topic: Urban air quality, megacities and changing PBL

Q-6 How will atmospheric dynamics in different scales, such as synoptic scale weather and planetary boundary layer, change in Arctic – boreal regions?

Key Topic: Weather, general atmospheric circulation

AQUATIC SYSTEMS INCLUDING THE ARCTIC OCEAN

Q-7 How will the extent and thickness of the Arctic sea ice, terrestrial snow cover change in the future?

Key Topic: Arctic Ocean as part of the climate system

Q-8 What is the combined effect of Arctic warming, pollution load and acidification on the Arctic marine ecosystem, primary production and carbon cycle?

Key Topic: The Arctic maritime environment

Q-9 What is the future role of the Arctic-boreal lakes, wetlands and large river systems in the biogeochemical cycles including thermokarst lakes and running waters of all sizesand how will future changes affect the society in general, and livelihood, agriculture, forestry and industry in particular?

Key Topic: Lakes, wetlands and large river systems in Siberian region

ANTHROPOGENIC ACTIVITIES

Q-10 How will human actions such as land-use change, energy production, efficient use of natural resources, and use of energy sources influence further environmental changes in the region?

Key Topic: Anthropogenic impact

Q-11 How do the changes in physical, chemical and biological state of the different ecosystems, inland water and coastal areas affect the economies and societies in the region and vice versa?

Key Topic: Environmental impact

Q-12 In which ways are socio-economic areas vulnerable to climate change, how can their vulnerability be reduced and their adaptive capacities improved and what responses can be identified to mitigate and adapt to the climate change?

Key Topic: Mitigation, climate change, natural hazards

FEEDBACKS – INTERACTIONS

Q-13 How will the changing cryospheric conditions and the following ecosystem changes feedback to the Arctic climate system and to the weather and do they pose an increasing risk via natural hazards?

Key Topic: Changing permafrost and associated natural hazards

Q-14 What are the net effects of various feedback mechanisms connecting e.g. (i) land cover changes (ii) photosynthetic activity, (iii) GHG and BVOC emissions (iv) aerosol and cloud formation and radiative forcing varying with the climate change in the regional and in global scales?

Key Topic: Negative and positive feedback mechanisms in the changing environment

Q-15 How intensive urbanization and related processes are changing the local and regional climate and the environment in general and how can this be foreseen via an early-warning system in connection to increased risk for natural hazards and air quality issues?

Key topics: Atmospheric composition change, biogeochemical cycles; water, carbon, nitrogen, phosphorus, sulphur, natural hazards, air quality

THE STRUCTURE OF THE PEEX INITIATIVE

Research agenda

The main goal of the PEEX research agenda is to solve locally and globally important science questions associated with the Arctic and boreal regions. The PEEX large-scale research questions, listed above, are focused on understanding the key processes of the land-atmospheric-aquatic-anthropogenic systems and on the identification and the quantification of the main feedbacks in the Pan-Eurasian Arctic-Boreal region. The large scale research questions (Q-1–Q-15) are linked to the main research topics of the PEEX initiative.

The key to understand the Earth system behaviour and future climate is on the identification and quantification the feedback mechanisms in the land – atmosphere – aquatic – anthropogenic continuum. The scientific outcome of PEEX is to fill current gaps of knowledge in the process understanding, feedbacks and links within and between the systems and in biogeochemical cycles in the Arctic-boreal context. The PEEX research agenda is designed to catch the most relevant processes in each of these systems subsequently integrating them into a holistic understanding of the Earth system. PEEX is interested in the so called COBACC (Continental Biosphere–Aerosol–Cloud–Climate) – hypothesis by Kulmala et al. [2004] (Fig. 4) and CLAW (Feedback loop between ocean ecosystems and the Earth's climate)-hypothesis by Charlson et al. [1987].

The COBACC – hypothesis suggests two loops related to the ambient temperature and gross primary production (GPP). First one is a negative climate feedback mechanism whereby higher temperatures and CO_2-levels boost continental biomass production leading to increased biogenic secondary organic aerosol (BSOA) and cloud condensation nuclei (CCN) concentrations tending to cause cooling [Paasonen et al. 2013]. The second, a positive feedback loop, connects the BSOA to the increasing

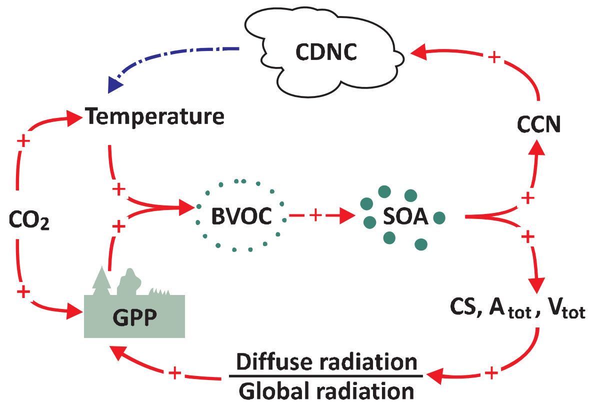

Fig. 4. The two feedback loops associated with the COBACC feedback. BVOC = biogenic volatile organic compounds, SOA = secondary organic aerosol, CS = the condensation sink, A_{tot} = total aerosol surface area, V_{tot} = total aerosol volume, CCN = cloud condensation nuclei, CDNC = cloud droplet number concentration, and GPP = Gross Primary Productivity, which is a measure of ecosystem-scale photosynthesis (Kulmala et al., 2014 in press).

condensation sink that affect the ratio between diffuse and direct radiation and enhancing GPP [Kulmala et al. 2004, Kulmala et al. 2014].

The CLAW-hypothesis connects ocean biochemistry and climate via a negative feedback loop involving CCN production due to sulphur emissions from plankton [e.g. Quinn & Bates, 2011]. These global-scale feedback hypotheses are closely linked to biogeochemical cycles, which are still inadequately understood and have many feedback loops 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] while some are related to emissions and atmospheric chemistry of biogenic volatile organic compounds [Grote & Niinemets 2008; Mauldin et al., 2012], subsequent aerosol formation and growth [Tunved et al., 2006; Kulmala et al., 2011a] and aerosol direct forcing and aerosol-cloud interactions [Lihavainen et al., 2009; McComiskey & Feingold 2012; Penner et al., 2012;Scott et al., 2014]. 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

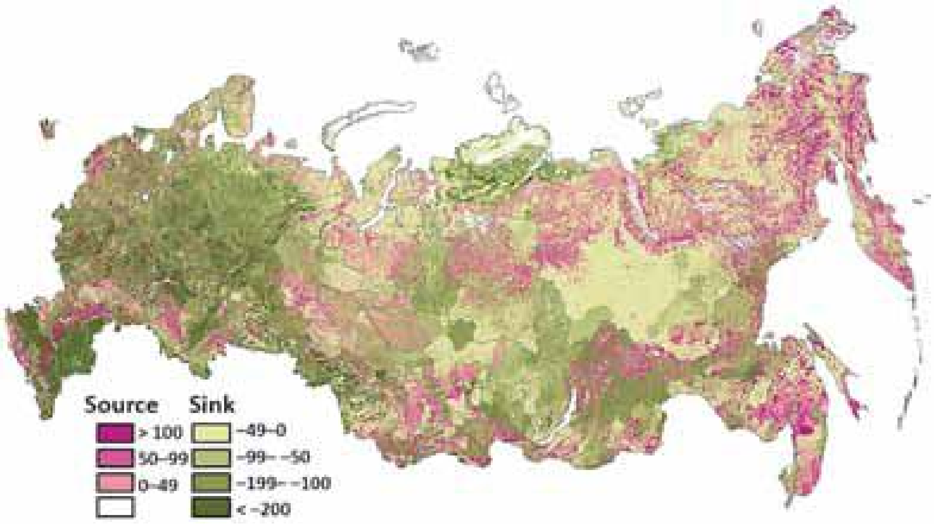

Fig. 5. Net Ecosystem Carbon Balance of Russian terrestrial ecosystem (2009). Dimension in the legend g C m^{-2} year^{-1} (Dolman et al., 2013).

productivity, and to take into considerations that there may be previously unknown sources and processes [Su et al., 2011; Kulmala & Petäjä, 2011; Bäck et al., 2010].

As an example, understanding the complex processes and links of the carbon cycle is crucial for estimating the carbon budget in the Russian region. In spite of a wide distribution of natural and human-induced disturbances, terrestrial ecosystems in Russia served as a net sink of carbon with Net Ecosystem Carbon Balance of 550–650 Tg C yr^{-1} during the last decade out of which above 90% was provided by forests [Dolman et al., 2012; Shvidenko & Schepaschenko, 2013b]. While the overall sink of the terrestrial ecosystems is high, substantial areas serve as a source as well, typically associated with permafrost and with disturbed forests (Fig. 5). The major feedbacks need to be analysed whether they will lead to the decreasing carbon sink by the 2030s which can be substantial by end of this century [Shvidenko, 2012].

The human activities in inland areas can considerably alter the hydrological and hydrogeochemical conditions of downstream lakes, wetlands and coastal waters [Meybeck, Vörösmarty, 2005]. Intensive changes in the human activities within some parts of the Eurasia both in semi-arid and boreal corridor require a new vision to link hydroclimatic, hydrological and hydrogeochemical research with a special focus on the climatic and human change sequences. According to Kasimov, [2013], basin-scale distributions of pollution sources, transport pathways as well as times from the pollution sources and resulting loads after retention along the pathways, through the coupled atmosphere – surface water – groundwater systems to downstream recipients have to be studied.

As whole, Northern Pan-Eurasian Arctic-Boreal geographical regions cover a wide range of human-natural system interactions and feedback processes, with humans acting both as the source of climate and environmental change and as 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 [Galloway et al., 2003]. The observed changes in the hydrological cycle and biogeochemical cycles are needed to construct and parameterize the next generation of Earth System models.

Natural hazards

A crucial task of PEEX will be to prepare the mitigation and adaptation plans, including forecasting tools to minimize the foreseen risks of natural hazards such as forest fires, floods and landslides and infrastructure (buildings, roads, energy distribution systems) damages due to thawing permafrost and extreme weather events (droughts, storms, heat waves). Due to forest succession and associated accumulations of forest biomass major risks are expected to take place in dark coniferous forests ecosystems. Changing disturbance regimes could lead to dramatic increase of wildfire and outbreaks of forest pests. This generates a high probability of a significant positive feedback between the warming and escalation of wildfire regimes. The increase in the atmosphere CO_2 concentration will extend the prolonged dry periods that will cause the expansion of the fire area and fire severity and lead to a considerable increase in greenhouse gas emissions due to deep soil burning. In turn, as a result of climate change the increase in carbon emissions will potentially increase the risk of fires [Shvidenko 2013a, Kuzminov, 2011].

One area of specific interest is the climate projection of weather hazards with the state of the art classification. Meteorological and climatological classifications are wildly used in weather forecasting. In recent decades, the usage of classifications has widened due to new computer techniques. Now it is considered to be two fundamental approaches of investigating the link between the large-scale circulation and environmental variables [Cannon et al., 2002; Smedsrud et al., 2013; Zhang et al., 2013; Zhou et al., 2013]. In the framework of the first one, so-called the "circulation – to environment" approach, arrangement of the circulation data of interest (e.g. sea level pressure, geopotential height, etc.) is carried out to group them into circulation types (CTs) according to a selected methodology (clustering, principal component analysis (PCA), regression, etc.). Then, one looks for relations of CTs with the local-scale environmental variable (e.g. storm waves). Such an approach has already tested, for example, over the PEEX geographical domain [Surkova et al., 2013; Zhou et al., 2013].

Atmospheric pollution

Atmospheric pollution is one of the key environmental problems in Russia and China that needs to be resolved. The geographical distribution of pollutants is not uniform over the Russian territory and it considerably depends on the strength of the emission source and the emission composition [Baklanov et al., 2012, Bityukova & Kasimov, 2012, Goncharuk & Lapshin, 2012]. Urban emissions changing the gas and aerosol content [Chubarova et al., 2011, a, b] and their adverse effects on the environment and human health [Malkhazova et al., 2012a, b; Malkhazova 2013; Chubarova & Zdanova, 2013] are currently studied in Russia. China's air pollution in 2013 was at its worst for some 52 years, with 13 provinces hitting record-high levels of air pollution. Increasingly, more cities are now monitoring air quality in real time using meteorological towers and remote sensing from satellites to track pollutants [e.g. Ding et al., 2013]. 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 hospitalized. 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. Awider research observation infrastructure plan of air quality within the PEEX framework will made in order to contribute to the sustainable development of the PEEX area and for the well-being of the population.

INFRASTRUCTURE

General concept of the PEEX in-situ land-atmosphere station network

The main aim of the PEEX land-atmospheric observation network is to fill the current in-situ observational gap in the Siberian and Far East regions and bring the observation setup into international context with standardized or comparable procedures. PEEX serves as a basis for the long-term continuation of advanced measurements on aerosols, clouds, GHGs, trace gases and biosphere processes in the Northern Eurasian and China to be operated by educated scientific and technical staff capable of answering the research questions arising from the PEEX science community.

The PEEX Observation Network program will include the following tasks:

– to identify the on-going measurement routines of the ground stations,

– to analyze the end-user requirements of the global and regional-scale modeling communities,

– to provide an outline for the PEEX labeled network incl. the measurement and data product – archiving – delivery requirements for each station category,

– to identify the most important gaps in the initial phase observational network including long-term observational activities in Europe, in Russia, in China and globally,

– to initialize harmonization of the observations in the PEEX network following e.g. accepted practices from World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) programmed and the European observation networks,

– to carry out inter-platform inter-comparisons between the ground-based and satellite observations,

– to establish education program on the measurement techniques and data-analysis for young scientists and technical experts,

– to establish connections to Northern America.

The PEEX research infrastructure (RI) will consist of a comprehensive field station network in the region covering Scandinavia, Finland and the Baltic countries, Siberia and China, complemented by satellite observations and corresponding integrated modeling tools. The vision of the Pan-Eurasian network will be based on a hierarchical SMEAR-type (Station for Measuring Forest Ecosystem–Atmosphere Relations) integrated land-atmosphere observation system [Hari et al., 2009]. This means that some of the stations will have a minimum instrument setup and data processing for atmospheric monitoring, but providing spatial coverage, whereas the most advanced stations will cover a full setup of instruments and data systems for monitoring energy flows in the land-atmosphere-aquatic continuum providing an integral and comprehensive view.

The PEEX network is based on existing infrastructure representing different environments and different types of stations: (i) standard stations, (ii) flux stations and (iii) flag ship stations with comprehensive ecosystem-atmosphere measurements. For example, the current weather stations like typical meteorological station maintained by Rosrydromet, could represent the standard stations. There are about 1000 weather stations in Former Soviet Union with time series started usually from 1936 (Fig. 6) and which archived data are freely available from World Data Centers (RIHMI-WDC, Obninsk, Russia or NCDC-NOAA, Ashville, USA).

At the beginning the PEEX observation system is based on the currently existing infrastructures, supplemented by a flag ship station network. A flag ship station measures meteorological and atmospheric parameters together with ecosystem-relevant processes

Fig. 6. Maps of weather stations at PEEX domain area. Pink dots – WMO stations, brown – GSOD (global summary of the day) data (adapted from Climate Data Online NCDC NOAA (http://www.ncdc.noaa.gov/cdo-web/)).

(incl. carbon, nutrient and water cycles, vegetation dynamics, biotic and abiotic stresses). Ideally, the PEEX network will contain one flag ship station in all major ecosystems, in practice a station in every 2000–3000 km from each other. The in-situ infrastructure will be completed by aircraft and satellite observations, having also an important role in validation, integration and full exploitation of satellite data for Earth system studies. 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 virtually no in situ observations.

Preliminary setup of the PEEX in-situ observation network

In 2013–2014, a suite of ground stations has already been selected for the PEEX Observation network. These stations includes the SMEAR-type stations (Measuring Atmosphere–Ecosystem Interactions) in Finland (SMEAR-I (N 67° 45.295′, E 29° 36.598′)-II (N 61° 50.845′, E 24° 17.686′)-III (-IV stations (N 60° 12′, E 24° 58′) and Estonia (SMEAR-Järviselja) In addition to SMEAR-stations, the network includes: Pallas-Sodankylä-GAW station (Finland), TIKSI-regional–GAW station (Russia), and selected stations in Russia (Nizni Novgorod, Moscow-Borok, Zvenigorod – Obninsk cluster, Tomsk, Kola Arctic / White Sea, Tiksi, Novosibirsk, Zotino, Tjumin, Baikal – Irkutsk – Ulan Ude) and in China (Changbai Mountain Research Station of Forest Ecosystems 42°4′ – 42°36′N, 126°55′ – 129°8′ E, Kashi Satellite Data Receiving Station China Remote Sensing Satellite Ground Station 75.83°E, 39.50°N, Station for Observing Regional Processes in the Earth System (SORPES) E118°57′9″, N32°7′13″, Beihai Ecosystem Station, CERN

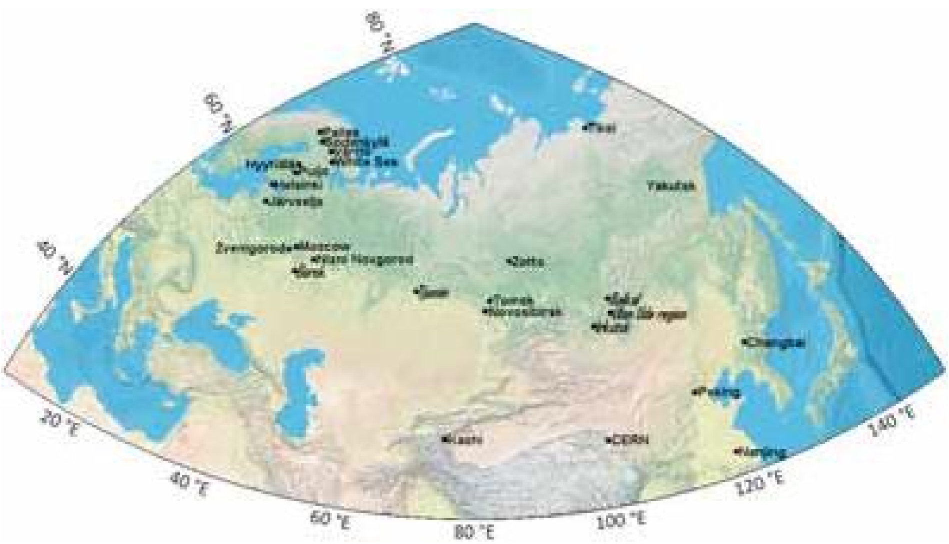

Fig. 7. The first set of the PEEX labeled in situ atmospheric stations across the Pan-Eurasian region.

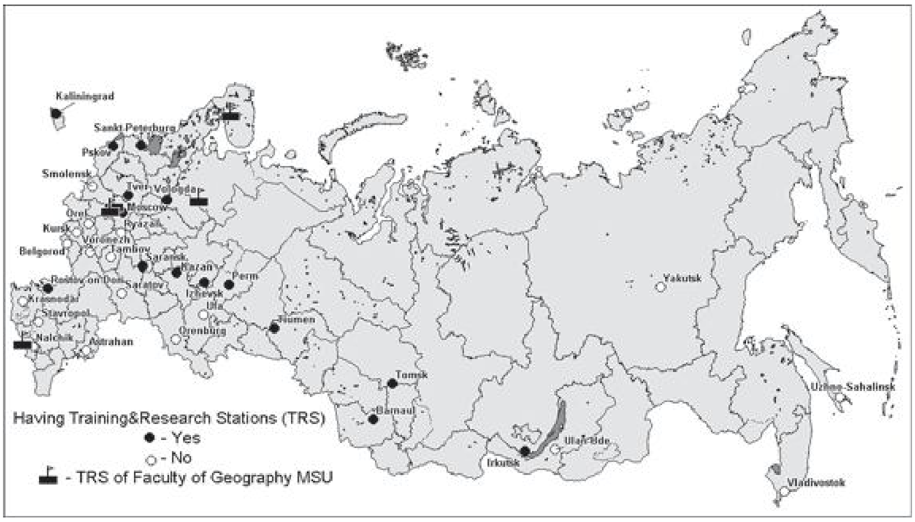

Fig. 8. Research and training field stations (TRS) in Universities of Russia.

Network Station N37°37', E101°19'). These stations are situated in different vegetation and climate zones representing hemi-boreal, boreal, arctic and sub arctic regions (Fig. 7). The Russian PEEX core stations can be supported by the research and training station network of Russian Universities., This network may widen an geographical scope of the PEEX environmental observation in the future [Kasimov et al, 2013] (Fig. 8).

The preliminary set of PEEX stations will be expanded in the future. Good candidates are e.g. the set of remote stations hosted by Russian Academy of Sciences (RAS). Altogether, 30 institutes of the RAS Department of Earth Sciences and the RAS Department of Biological Sciences have indicated that they are ready to contribute the PEEX observation program (Fig. 9). The contribution of RAS institutes will allow a planning of combined

Fig. 9. A map showing positions of the RAS institutes and their field bases or branches. Red circles are institutes, and blue ones are field bases.

observational programs with the ground and aircraft observations and revealing existence of Russian observational stations with instrumentations rather similar to the SMEAR-type stations. For example, the forest station "Spasskaya Pad" of the Institute of Biological Problems of cryolithozone of Siberian Branch of RAS (Yakutsk), is the only station in the world where the observation methods used in Asia and Europe are compared (CarboEurope, AsiaFlux, and ScanNet projects).

PEEX aims to have a special observational program on the comparison of the ecosystem states in such distant areas as North Europe (Finland) and Yakutiya (East Siberia). Zuev Institute of the Atmosphere Optics of the RAS Siberian Branch has own rich observational network including ground stations and aircraft. Central Aerological Observatory of Roshydromet has recently received new aircraft that also may be considered as one of possible platforms for the PEEX.

Preliminary concept of the aquatic observations in the surrounding seas

Similar to the in-situ land – atmosphere observation network, a network of hierarchical stations in the surrounding seas will be established in collaboration with major oceanographic research programs. The Preliminary concept of the Aquatic Observations in a surrounding seas would consist of (A) Simple buys, (B) Sophisticated buoys, (C) Research vessels and (D) Flagship stations (Fig. 10.).

The Category-A refers to buoys deployed on sea ice or in the open ocean with measurements of the location, atmospheric pressure, as well as air and surface temperature. The buoys transmit the data via satellite links. Successive observations on the location yield the ice drift or ocean current vector, in the case of ice and open ocean buoys. Category-B refers to buoys that include more devices that allow measurements of at least snow and ice thickness, temperature profiles through the upper ocean, sea ice, and snow, as well as profiles of ocean currents and salinity. Category-C, research vessels, allows a wide range of measurements on the physical, chemical, and biological properties and processes in the ocean, sea ice, snow, and atmosphere. Research vessel cruises in the Arctic typically take place in summer, include ice stations, and seldom last longer than three months. Hence, they are only temporary stations, but allow numerous measurements that cannot be made by stations in categories A and B; these include turbulent fluxes of momentum, heat, moisture, CO_2, CH_4, as well as many biological and chemical measurements.

Category-D, Flagship stations, includes manned drifting ice stations and manned permanent coastal/archipelago stations. These allow the same kind of measurements as conducted from research vessels, but the Flagship stations have a longer duration and allow much more measurements on sea ice, its snow pack, and the ocean below the

Fig. 10. Schematic illustration on the potential station network in the Arctic Ocean. There are presently a lot of stations of categories A (black dots) and B (red dots), and mostly in summer also some of category C (blue boxes) but their locations are continuously changing and each individual station has a limited operation time. For category D (red stars), the figure only provides a vision for the future; the number and locations of the stations are open, except that the station in the Baltic Sea is already in operation.

ice. Further, the Flagship stations provide a basis for operation of (i) Unmanned Aerial Systems for atmospheric measurements and mapping of the sea ice and ocean surface properties, and (ii) autonomous under-ice gliders for oceanographic measurements (e.g. water temperature, salinity and dissolved oxygen). Such methods will significantly extend the area covered by observations. The measurements of water and air CO_2 concentrations, temperature and photosynthetically active radiation (PAR) are introduced to the standard buoys used in the studies of oceans.The flagship stations include measurements of CO_2, VOC and DMS profiles in water and in the air; temperature, light intensity and ion concentration profiles, phytoplankton mass profiles, fluxes of CO_2, VOC and DMS, sedimentation, ice cover in the surrounding area up to 500 km, reflected radiation, profiles of key enzymes of photosynthesis and synthesis of VOC and DMS.

Eurasian coastal and archipelago stations for sea ice and ocean observations will be essential Flagship stations. One of them is already in operation in Utö in the northern Baltic Sea. The Utö station is a member of the HELCOM (Baltic Marine Environment Protection Commission) marine monitoring network and a founding member of the European ICOS network. The station has long records in physical observations (water salinity and temperature measurements since 1900), and is currently under further developments for greenhouse gas (concentrations and air-sea fluxes of CO_2 and CH_4) and marine biogeochemistry observations, the latter including chlorophyll, nutrient, and fluorescence. Another Flagship station will be constructed in Severnaya Zemlya by AARI.

Satellite observations

One of the key PEEX objectives is to address climate change in the Pan-Eurasian region using remote sensing data from both airborne and satellite observations, together with ground-based in situ and remote sensing data and model, simulations of physical aspects of the Earth system.

The main advantages of airborne and satellite observations are:

- The same type of instrument and technique are used across the globe for extended period of time spanning several decades, providing consistent data sets (on condition that successive instruments provide consistent data sets; it is noted that inconsistencies may exist between like data sets, even from similar instruments).

- Up-to-date information e.g. on atmospheric composition, land surface properties and water environment with extensive spatial coverage.

- Ability to acquire environmental properties and data on various spatial and temporal scales both horizontally and vertically.

- Wide field of view and high level of detail allows studies of processes and phenomena on local, regional and global scales.

- High data reliability (especially together with ground based measurements).

Remote sensing data together with ground-based measurements and numerical modeling outcomes provide information on land, atmosphere and water system properties, as well as on the spatial and temporal changes of their components. It enables to accumulate statistical data, model dynamic processes in different environments, and in addition provides precise guidelines of the data products for ecology departments and agencies and for other consumers.

Satellite observations provide information complementary to the local in situ observations on the spatial distribution of atmospheric composition (aerosols, trace gases, greenhouse gases, clouds) [Burrows et al.; 2011], land surface properties including surface albedo, land cover (vegetation, phenology, tree line, burned area; fire detection) and soil moisture, ocean surface properties such as ocean colour (Chlorophyll, algae blooms), waves, sea surface temperature (SST), salinity and sea ice mapping, snow properties (cover, albedo, snow water equivalent) and lakes (area, biomass, water quality). Vice versa, the PEEX infrastructure has an important role in validation, integration and full exploitation of satellite data for Earth system studies.

The principal quantity measured with the remote sensing instruments is electromagnetic radiation. The radiation is measured at wavelengths spanning from the ultraviolet, visible, infrared to microwaves provide information on:

– atmospheric composition:

- aerosol properties (primary Aerosol Optical Depth (AOD) at several wavelengths, Ångström exponent (AE), absorbing aerosol index (AAI); 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. [Kokhanovsky & de Leeuw, 2009; de Leeuw et al., 2011; Holzer-Popp et al., 2013; de Leeuw et al., 2014];

- cloud properties (e.g., cloud fraction, cloud optical thickness, cloud top height, cloud droplet effective radius, liquid water path, etc.) [Kokhanovsky et al., 2011];

- concentrations of trace gases (e.g. O_3, NO_2, CO, NH_3, H_2O, VOCs, halogens) [Burrows et al., 2011];

- concentrations of greenhouse gases (e.g. CO_2, CH_4) [Buchwitz et al., 2014].

Table 1 contains list of some measured parameters and types of research conducted based on the remote sensing data.

In case of 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. Nevertheless, progress has been made [Istomina et al., 2011; Mei et al., 2013a, 2013b].

Information on the land surface properties that can be obtained using remote sensing data includes land cover, vegetation (e.g., above ground biomass, leaf area index, fAPAR, GPP), fire counts, burned area, air pollutant emission volume, soil moisture, glaciers [Bondur, 2010; 2011b]. It is crucial to study bodies of water including seas and oceans while analysing climate change in Pan-Eurasian region. Information on ocean properties which can be gained using satellite methods includes sea surface temperature, salinity, ocean colour, sea ice extent, sea level, wave information, water environment pollution etc. [Bondur, 2011 a]. Dynamics of short surface waves (including nonlinear waves) and their interaction with oceanic/atmospheric processes (internal waves, long surface waves, non-uniform currents, turbulence, etc.), mechanisms of slick formation on the sea surface [Troitskaya et al, 2012], as far as generally investigation of inland waters is a new area of remote sensing data application within PEEX domain.

The satellite observations provide information on regional to global scales with a spatial resolution varying from meters to tens of km, depending on the instrument and technique used. Likewise, the spatial coverage and repeat time depend on the swath width and orbit. In the context of PEEX, ice, snow, ocean, land, lakes and atmospheric observations are all of interest. In addition to remote marine observations also the remotely and on-situ data from main inflows, e.g. on-going observational network with associated multi-scale approach in the largest freshwater reservoir Baikal Lake should be included [Chalov et. al, 2014]. The remote observations are needed for investigation of large-scale transport of substances through

Table 1. List of satellite parameters measured and research conducted

Instrument/satellite	Parameter	Types of research conducted
MISR (Terra) MODIS (Terra/Aqua) (A)ATSR/SLSTR MERIS/OLCI POLDER CALIPSO SeaWiFS AVHRR (NOAA) --------------- SCIAMCHY OMI (Aura) GOME-2	Aerosol Optical Depth (AOD), and other aerosol properties --------------- Aerosol index (AI)	Effects of emissions from wildfire, megacities and other anthropogenic sources, versus natural emissions on atmospheric aerosol (mapping and vertical profiles generating); of interest for climate and air quality
OMI (Aura) AIRS (Aqua) TIRS(Landsat-8) AATSR(SLSTR NPP MODIS	Cloud properties (layer column cloud liquid water, albedo, Cloud Ice/Water flag)	Cloud cover monitoring for regional climatology needs (cloud cover and precipitation mapping); of interest for climate and aerosol-cloud interaction (precipitation, hydrological cycle)
OMI (Aura) GOME-2 MLS cura) AIRS (Aqua) MOPITT (Terra) TES (Aura)	Atmospheric gases (SO_2, CO, NO_2, O_3, HCHO, BrO, OClO, ClO, H2O, HCl, HCN, HNO3, HO2, HOCl, N2O, OH, CH4, NH3)	Monitoring of gas content in the atmosphere during volcanic eruption (gas distribution mapping) Wildfire areas research Studies in the sphere of global climate change (mapping of harmful contaminants distribution in atmosphere, vertical profiles generating)
AVHRR (NOAA)	Latent heat flux	Latent heat flux monitoring during starting volcanic activity (mapping)
AIRS (Aqua) TES (Aura) AVHRR (NOAA) MODIS (Terra/Aqua) ASTER (Terra) TIRS (Landsat-8) (A)ATSR/SLSTR	Surface temperature (Surface skin temperature)	Monitoring during starting volcanic activity Wildfires detecting (mapping) Climate (Land temperature and SST)
MLS (Aura) TES (Aura) AIRS (Aqua)	Air temperature (atmospheric temperature, surface air temperature, vertical profiles of temperature)	Research of surface air temperature and middle and upper atmosphere for resolving global climate change problems (mapping and vertical profiles generating)
MERIS/OLCI SeaWiFS MODIS	Ocean color	Oceanic biological cycle, climate

river basins which counteracts the current trend of decreasing occurrence and availability of global hydrological and hydrogeochemical measurement data. At the moment there is a risk of biased large-scale estimates of hydrological and hydrogeochemical fluxes. The three-year framework of Swiss-Russian collaborative research initiative involves the development and deployment of a novel multispectral and hyperspectral remote sensing platform optimised for the sensing of land and water surfaces from an ultralight aircraft in Baikal Lake environment [Akhtman et al., 2014].

Some data are already available for an extended period of more than three decades (e.g. from AVHRR and TOMS) allowing for the detection of trends and the response to changes in climate and mitigation strategies. They also serve as input to models or, vice versa, for model evaluation. The information on aerosols [e.g., de Leeuw et al., 2013], trace gases [e.g. Mijling & Vander A., 2012], GHG or clouds retrieved from satellite observations is complementary to that from the RI stations in that they cover a large spatial area, but usually with less detail (due to lower information content in the satellite data requiring assumptions to retrieve the relevant information) and with lower accuracy. As for the flag ship stations, techniques are being developed to derive information on the emission of atmospheric

Fig. 11. Satellite imagery coverage in Russia and adjacent countries using UniScanT receivers (data from http://www.geogr.msu.ru/science/projects/geoportal)

components from natural and anthropogenic sources as well as forest fires using inverse modelling. As part of ESA's Data Users Element (DUE) programme, this is applied to emissions of aerosols, NO_2, SO_2, CO, isoprene, VOCs (cf. http://www.globemission.eu/index.php), while satellite-derived GHG emissions are provided as part of the Copernicus project MACC-II (http://www.ecmwf.int/research/EU_projects/MACC/). The EU FP7 projects Marco Polo and Panda studying emissions over China will serve as pilots for the PEEX region (www.marcopolo-panda.eu).

The PEEX satellite infrastructure includes data from all open-access data sources (ESA, NASA) as well as from Russian and Chinese satellites with restricted access. The PEEX RI further includes receiving stations in Russia, China and Europe, including a very fast delivery service in Sodankylä (Finland) covering the western part of the PEEX area and a Near Real Time (NRT) service for forest fire data (AEROCOSMOS), and data centres providing access to processed and / or interpreted data. Ground-based and airborne remote sensing facilities complement the satellite observations.

The potential of the national systems of remote sensing data are also involved, e.g. Russian network of receiving centers provided by Scanex (Fig. 11) or UNIGEO (http://www.unigeo.ru/) association which merge capabilities of Russian Universities in remote sensing applications.The ground-based and airborne remote sensing facilities complement the satellite observations.

China's Earth observation system is composed of satellites aimed e.g. at characterizing resources, environmental variables, meteorology and oceans. As an example Beidou navigation satellite program has been formed providing a wide range of services for the nation's economy [Guo, 2013]. China's network of ground stations for remote sensing satellites is one of the world's highest capacities for receiving, processing, and distributing satellite data. With over 3, 3 million images of satellite data accumulated on file since 1986, it is regarded as the largest Earth observation satellite data archive in China. At present, the nationwide ground station network for land observing satellite data is taking shape. Miyun, Kashi, and Sanya stations can receive data simultaneously from satellites covering the whole territory of China and 70% of Asia. At the same time, efforts have been made to construct stations in China's southwest and northeast, and in Polar Regions. To provide users with top-notch data products of Earth observation satellites in the world, the station has built up systems to process data from state-of-the-art satellites such as LANDSAT, SPOT, RADARSAT, ENVISAT, RESOURCESAT and THEOS.

Modelling platform

For 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 and data system is needed

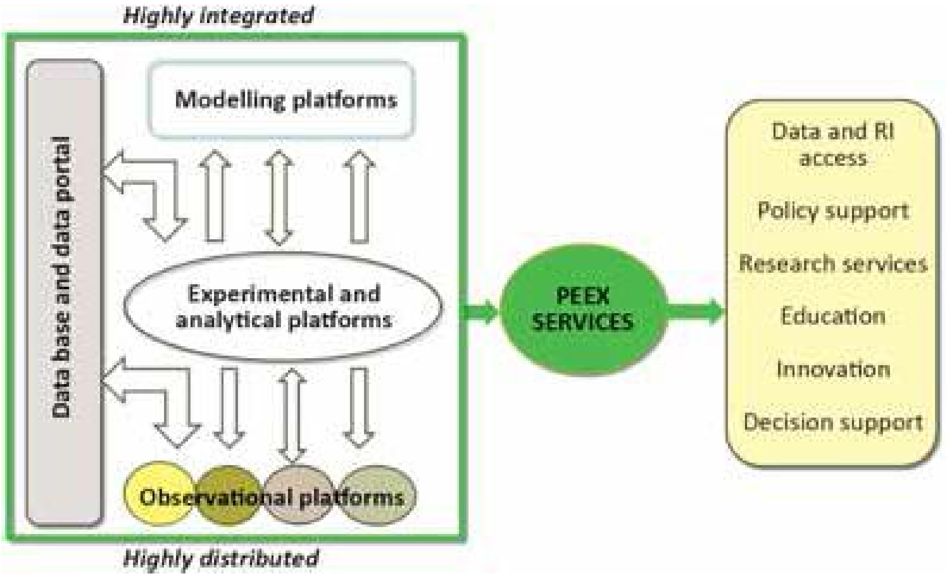

Fig. 12. PEEX data – modelling – service structure.

(Fig. 12). The PEEX-Modelling Platform aims to simulate and predict the biological and physical aspects of the Earth system and to improve understanding of the bio-geochemical cycles in the PEEX domain, and beyond. 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, air quality forecasts and climate projections. 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. 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 integration with and support from the new monitoring infra-structure to better measure and quantify soil and vegetation properties.

The PEEX Modelling Platform (PEEX MP) is characterized by:

- Complex integrated Earth System Modelling (ESM) approach in combination with specific models of different processes and elements of the system on different time and space scales.

- An ensemble approach with the integration of modelling results from different models, participants, countries, etc.

- A hierarchy of models; analyzing scenarios; inverse modelling; modelling based on measurement needs and processes; from molecular level to global climate and climate-air quality interactions

- Model validation with in-situ observation network, remote sensing data and assimilation of satellite observations to constrain models to better understand processes, e.g., emissions and fluxes with top-down modelling.

- Geophysical/chemical model validation with experiments at various spatial and temporal scales.

- Assimilation of measurement data by models.

- Analysis of anticipated large data volumes coming from PEEX models and infrastructures need to be supported by a dedicated virtual research environment.

Processes that control short-lived climate forcer (SLCF) abundances, ecosystem-climate interactions, aerosol-cloud interactions and boundary layer processes in the PEEX domain are all poorly constrained by observations.

Evaluating Earth system models and process models in this region presents a significant challenge, but is necessary to ensure our confidence in model predictions of future environmental change and its impacts at high latitudes and throughout the Northern Hemisphere. Models are generally unable to capture abundances and seasonality of SLCFs at high latitudes at the surface, with a large range in skill [Shindell et al., 2008]. Aerosol model biases in the North American and European Arctic are highly sensitive to washout processes [Browse et al., 2012], and knowledge of local emissions from sources such as gas flaring [Stohl et al., 2013]. The extent to which model biases persist over the Siberian Arctic and boreal regions is unknown. Interactions between the biosphere and climate system are also poorly understood. Model simulations suggest that boreal fire may be an important source of SLCF [Wespes et al., 2012] and that this source will likely change under future climate [Spracklen et al., 2009]. The boreal forest is also an important source of BVOCs with impacts on aerosol and cloud properties [Tunved et al., 2006; Spracklen et al., 2008] a potentially important sink for Eurasian tropospheric ozone [Engvall & Stjernberg et al., 2012], with potential consequences for the carbon sink [Sitch et al., 2007] and hydrology [Lombardozzi et al., 2012].

PEEX will undertake an unprecedented evaluation of Earth system models, ecosystem models, weather and atmospheric chemistry models, exploiting new observations from the PEEX measurement infrastructure. Model simulations from existing model comparisons, such as POLMIP [Monks et al., 2014], AQMEII [Alapaty et al., 2012] and HTAP [Shindell et al., 2008], will be evaluated in the PEEX domain to assess their ability to simulate processes important for atmospheric composition and climate, and the range in model skill in this region.

Envisioned PEEX Data harmonization

The PEEX infrastructure will deliver critical long-term datasets for climate and air quality research, including evaluation of weather forecast, air quality and climate models. The strategic focus is to ensure a long-term continuation of advanced measurements on aerosols, clouds, GHGs, trace gases, land – and sea surface characteristics and snow and ice properties in Northern Eurasian area. Procedures for improved data quality, including standardization of instruments, methods, observations and data processing, will be developed in coherence to "The European Strategy Forum on Research Infrastructures" (ESFRI) process. Linking PEEX RI approach to the European RI development together with satellite information and the scientific contribution ensures the optimal use of the observational data towards Earth System modelling.

We envision PEEX to collaborate e.g. with the "Integrated Carbon Observation System" research infrastructure (ICOS-RI), "Aerosols, Clouds, and Trace gases Research InfraStructure Network" (EU-FP7-ACTRIS-I3 project), "Analysis and Experimentation on Ecosystems" (EU-FP7-Preparatory Phase of AnaEE), Life Watch (European research infrastructure on biodiversity) and Svalbard Integrated Earth Observing System (SIOS). PEEX willbenefit from Space Agency programmes such as ESA's Climate Change Initiative (CCI), Data Users Element (DUE) and similar initiatives by NASA and the Chinese and Russian Space Agencies. PEEX will also benefit from Space Agency programmes such as ESA's Climate Change Initiative (CCI) [Hollmann et al., 2013], Data Users Element (DUE; http://www.globemission.eu/) and similar initiatives by NASA and the Chinese and Russian Space Agencies. Ground-based remote sensing infrastructure [e.g. Tomasi et al., 2014] will be used to complement and validate satellite measurements over the Arctic region.

In general, 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. 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.

The PEEX data initialization, cross-checking and harmonization process will start with the already existing datasets from the Siberian region. For example, datasets of the International Polar Years (1882/1883, 1932/1933, and the last and largest one in 2007/2008) experiments are available in scientific literature and can give a good basis for understanding changes taking place for a period longer than a century. Extensive database on atmospheric chemistry over continental Russia has been collected during unique train-based TROICA (Transcontinental Observations Into the Chemistry of the Atmosphere) experiments in 1995–2010. Furthermore, a series of large international recent programs such as TOWER FLUXNETWORK, and Russian–Swedish–British Project "Climate warming in Siberian Permafrost Regions; tracing the delivery of carbon and trace metals to the Arctic Ocean" may significantly enrich our investigations in the PEEX domain.

A part of the PEEX data initialization is development of a unified information background in form of the Integrated Land Information System (ILIS) for the PEEX region [Schepaschenko et al., 2010; Shvidenko et al., 2013]. The ILIS is based on integration of all relevant sources of remote sensing and ground data and is presented as a multi-layer and multi-scale GIS which will contain geo-referenced comprehensive information about landscapes and ecosystems, their condition, dynamics and stability, and will serve as a benchmark, system background for integrated modelling and depository of all knowledge over the region.

In addition to the land-atmospheric data processing, PEEX will establish a harmonization process towards aquatic observations. RAS Research centers for the realization of the observations on in-situ stations in Kola–Karelian Region as a pilot area, covering e.g. the White Sea and great lakes and their watersheds in Russia west of Ural Mountains, will take part of the PEEX aquatic-observations approach. INKO-Copernicus project ICA2-CT-2000-10014 Sustainable Management of the Marine Ecosystem and Living Resources of the White Sea, State Federal program of "World ocean, Sub-project White Sea", 2007–2011 and RFBR project "The response of water objects to climate change" (No. 10-05-00963), 2010–2012 have already preformed multidisciplinary studies of the White Sea and watershed; sub-satellite and satellite observations of water quality parameter (with NIERSC) and created a database and GIS for the region (include historical many years hydrometeorological observations on stations of Roshydromet. Furthermore, numerical model of water ecosystems of White Sea and Great Lakes and their watersheds and scenario development of water ecosystems under climate change and anthropogenic impacts have been developed and realized multidisciplinary socio-ecological-economical studies in the region.

SOCIETY DIMENSION

Changing socio-economic condition in PEEX domain

The dynamics of the Earth system and the Northern societies are rapidly changing. Within next 40 years, the Northern Eurasian, especially the Artic, will be a region of increased human activity, higher strategic value, and greater economic importance compared to today [Smith, 2010]. The future status of the Northern societies are driven by (i) demographic changes (human population growth and mitigation trends), (ii) natural resources demand (finite and renewable assets, gene pool), (iii) globalization trends (the set of economic, social, technological processes making world interconnected and interdependent) (iv) climate change (global mean temperature increase) and (v) technological breakthroughs (geoengineering, in bio- and nano- and environmental technology) [Smith 2010].

Referring to the demographic changes, the main part of the Arctic and boreal region of PEEX domain is situated in North and East of Russia characterized by very differentiated in socio-economic conditions. Both Russia's North and East have small and diminishing population, mainly due to migration outflows in the 1990s. 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 million people, and the population of Russia's Arctic zone decreased nearly by one third (500 000), 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%. 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 depopulated significantly [Litvinenko, 2012, 2013]. When assessing the effects of climate 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 impacts. Detailed studies of the effects of different climate parameters on health, incidence of diseases, adaptation potential, age and gender structure of population are needed.

One crucial part of the PEEX approach is to make future socio- economic assessments for the Arctic-boreal regions and provide early an early warning system for timely mitigation for local and regional authorities.

Referring to natural resources and the expected increase of industrial activities in the PEEX area, it is important to pay attention to traditional livelihoods of the area and their future position in the Arctic region. 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].

Both Russia's North and East possess abundant mineral resource potential. The sector of the natural resource economy (mining together with forestry) will continue to prevail in the majority of these territories for the next decades. 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 the aspect of the sustainable social and ecological development. The local population is now facing 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 husbandry, etc.).

Mechanisms of interaction between regional environmental change and post-Soviet transformation of natural resource utilization at both regional and local levels are of special importance [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.

PEEX Stakeholders

There is a pressure to ensure that the latest scientific results are effectively available to society. Societies within the PEEX region will have to continue their efforts to reduce greenhouse gas emissions through mitigation efforts, by increasing energy efficiency and exploitation of renewable energy. Simultaneously, there is a need to begin to adapt to the on-coming changes by assessing the vulnerability of the society. To ensure the most efficient use of its research outcome and services PEEX is developing contacts to all major stakeholders in the Arctic and boreal regions and in China. The most relevant end-users here are found in different stakeholder sectors: (i) research communities, research infrastructures and platforms (iii), policy makers and governments, (iv) Northern societies and China (v) non-governmental organizations and (vi) companies. As an example, PEEX relevant stakeholders are the research communities of Nordic Centers of Excellence and IIASA, the research infrastructures and platforms of Global Earth Observation System of Systems (GEOSS) and Digital Earth; the Future Earth (ICSU) and IPCC and the Nordic societies via the Arctic Council.

During the first years of the activity PEEX has already started contact building with GEOSS, Future Earth and China Air quality initiatives. For example, GEOSS connects PEEX to the GEO Cold Regions activity. There 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), 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).

The IGBP core-projects like iLEAPS are bringing PEEX to an international policy level and opens up opportunities to respond to the Future Earth initiative and Digital Earth programmes. These initiatives 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.

The PEEX activities in China are associated also with Beautiful China. In 2013 China's "two sessions" mapped out concrete steps toward a "beautiful China", which is an initiative stemming from an agenda-setting report to the 18th National Congress of the Communist Party of China (CPC) Congress. China is now actively seeking new environmental solutions that cost less, produces more benefits, leads to reduced emissions and contribute to sustainability, speeds up the construction of a resource-conserving and environment-friendly society, and strives for improving the level of ecological conservation and quality of life [IEAS, 2012].

KNOWLEDGE TRANSFER

The shift from a discipline-tied fundamental education towards multi-disciplinarity is an imperative for a successful career in climate and global change science [Nordic Climate Change Research, 2009]. Therefore PEEX has adopted this approach in the education of the next generation of scientists, instrument specialists and data engineers in a truly multidisciplinary way of thinking and holds this as the chief educational and knowledge transfer goal.

PEEX Education programme addresses the following themes:

– training of multidisciplinary core skills and transferable skills applicable in a range of tasks both on public and private sector;

- opening already existing courses at PEEX institutes to the whole community;
- promoting cross-disciplinary collaboration as well as international and interdisciplinary mobility;
- recognizing the importance of career development;
- training the next generation of research infrastructure experts (best practices, twinning); and
- integrating research and education activities together as part of a larger knowledge framework.

Participatory action research has been acknowledged as the main tool to achieve the goal. We also emphasize the recognition of the research career as a whole. Following the CBACCI (Nordic-Baltic Graduate School on Biosphere-Carbon-Aerosol-Cloud-Climate Interactions) Education Structure [CBACCI, 2003], dedicated work on the national and regional scale has been carried out to develop the multidisciplinary training at all levels. PEEX will bring this task to a more international level including Europe, Russia, and China.

PEEX involves several fields of science, such as chemistry, physics, meteorology, mathematics, biology, agricultural and forest sciences, geosciences, technology and social sciences, combining qualitative and quantitative research methodologies, observations, experimentation and modelling. In such a framework it is crucial that observations are based on unifying theoretical framework and are carried out with various techniques supporting each other. Furthermore, observations should be tested against field and laboratory experiments, and process understanding should be tied to theoretical and modelling development work.

The practical knowledge transfer actions in PEEX involve:

- dedicated training programmes on MSc and PhD level following the Bologna process [The European Higher Education Area, 1999], including Innovative Training Networks and international joint degree programmes;
- targeted training for the technical staff;
- joint coordination of training courses and events for the PEEX community;
- a joint PEEX database of courses (field courses, summer and winter schools);
- active development and utilization of modern technologies supporting learning e.g. learning platforms, online visualization applications and data portals [see Vesala et al., 2008; Junninen et al., 2009];
- use of innovative teaching and learning approaches such as collaborative action research and horizontal learning [Paramonov et al., 2011]; and
- outreach activities for specific target groups (policymakers, journalists and reporters etc.) and for the general public.

PEEX will distribute information for the general public to build awareness of climate change and human impact on different scales of climate and air quality issues, and increase visibility of the PEEX activities in Europe, Russia and China. A major challenge is to explore the means to make PEEX research useful with clear messages to the 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.

The PEEX community organizes intensive field courses several times a year, and they have proven to be of great interest to both students and researchers. The forms of working during intensive courses include lectures, interactive exercise sessions, seminars, discussion sessions, field work as well as social activities. Very often the emphasis is placed on intensive work in small groups consisting of students, instructors (usually more advanced postgraduate students), and supervisors (usually senior scientists). From a pedagogical point of view, the intensive courses often represent a form of problem-based learning (PBL; see e.g. Duch et al., 2001]. This instructional strategy has been adopted in order to emphasize the students' own responsibility of their learning process, with support from the instructors and supervisors. The goals for the courses are often set in the beginning of the course, after a few introductory lectures. The teachers take the role of facilitators rather than lecturers. Collaborative learning is carried out throughout the courses. This allows for the social construction, sharing of information and cognition, and finally improves the metacognitive skills of the students which, in turn, enhance self-directed learning skills. We have also noted that motivation and sociability is blossoming in these small groups, which allows the students to easily adopt the studied issues and open their minds for creative problem-solving. The participants of the events come from different disciplines and are specialized in very different topics. Thus, traditional "vertical" training courses have been out of question. Instead, horizontal learning has taken place, taking a broader approach, addressing a cross-section of knowledge from different fields and blending the information to reach new levels of understanding. The students working in small groups take the responsibility to find the best ways to reach these goals in a short time. Often the solution has been horizontal: students from different fields of study give small lectures to each other in the groups. This horizontal learning principle has been shown to be a good example of participatory action research.

CONCLUSIONS

The PEEX initiative emphasizes fast actions for establishing coherent, coordinated, interdisciplinary (i) research programme, (ii) research infrastructures and (iii) education activities the focused in the Northern Eurasian and China. It is important to have fast-track assessments for climate policy making and provide mitigation and adaptation strategies and services to the Northern Eurasian and China. The PEEX initiative can take a position in the international research landscape to be a major initiative 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.

PEEX is a solution orientated research programme that will provide gap-filling and integrated scientific knowledge related to many relevant questions in terms of society connected to the impacts of climate change on the Arctic and boreal regions and the need to adapt to them as well as early warning systems against natural hazards. After comprehensive and integrative science plan, one of the first tasks of the PEEX implementationis to fill the atmospheric in-situ observational gap in the Siberian and Far East regions and start the process towards standardized or comparable data procedures.

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