PAN-EURASIAN EXPERIMENT (PEEX) PROGRAMME – ACTIVITIES IN 2019 AND FUTURE PROSPECTS

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1. INTRODUCTION

Pan-Eurasian Experiment (PEEX) Programme (*www.atm.helsinki.fi/peex*), initiated by the University of Helsinki INAR together with five main partners from Russia and China, is an international, multidisciplinary, multiscale bottom up initiative, established in autumn 2012. PEEX is an asset for INAR and its co-partners to have high international visibility, to attract further research collaboration and to upscale the scientific impact in various arenas. PEEX is built on four main pillars: Research Agenda (RA), Research Infrastructure (RI) development, capacity building activities and societal impact making. The PEEX geographical focus is on the northern high latitudes (Arctic, boreal) and on China and the new Silk Road Economic Belt regions. The PEEX research network is currently covering ca 4000 researchers coming from Europe, Russia and China and over 30 official collaboration agreements with universities and research organizations located mostly in Russia and in China (*www.atm.helsinki.fi/peex/index.php/mou*). PEEX framework is motivated by the all scales research approach, high quality RI and big data, education and training of the next generation of scientists and experts, participating processes aimed at the fast tract policy making and increasing awareness of the highly connected environmental challenges. All these aspects are needed for solving grand challenges, like climate change and air quality, and ensuring the ecosystem services now and for the future (Kulmala et al. 2015, Kulmala 2015).

2. ACTVITIES AND RESULTS IN 2019

2.1 Research Agenda

The PEEX scientific focus is on understanding of large-scale feedbacks and interactions between the land - atmosphere - ocean continuum under the changing climate of the Northern high latitudes (Kulmala et al. 2015, Lappalainen et al. 2014; 2015; 2016; 2018) and on the transport and transformation of air pollution in China. The backbone of the research work has been the Finnish Center of Excellence in "Atmospheric Science - From Molecular and Biological processes to the Global Climate". In addition, PEEX research results have been published the PEEX Special Issue in J. Atmospheric Chemistry and Physics (*www.atmos-chem-phys.net/special_issue395.html*), in the Journal "Geography, Environment, Sustainability"

(ges.rgo.ru/jour) and in the J. Big Data (journalofbigdata.springeropen.com). In order to coordinate and facilitate the research approach, PEEX has organized science conferences in Helsinki, St. Petersburg, Moscow and Beijing in years 2012-2018 (for conference proceedings see the Finnish Aerosol Research Report Series www.atm.helsinki.fi/FAAR/index.php?page=series).

In 2019 PEEX started comprehensive analysis on the first results over last five years based on the published peer review papers and results attained from the PEEX geographical domain. The aim of the analysis is to study the state-of-the-art research outcome versus the PEEX large-scale research questions addressed by the Science Plan (Lappalainen et al. 2015). To facilitate the direct input from the research community, we have asked researchers to answer to a form where they could list their main scientific results and activities considered relevant to PEEX region and also include ancillary information such as type of activity or geographical extend. The preliminary metadata database covers information from over 400 scientific papers and the analysis is in progress. The key gaps of current understanding and future research needs will be discussed from the system point of view, from the land ecosystems, atmosphere, ocean & river systems and society perspectives.

In addition PEEX coordinates research activities such as bi lateral research collaboration, subprograms and projects together with the partners from Russia and China and from the Europe and Nordic countries.

In Russia, the most important research activities are the Baikal Selenga Network (BaSeNet) (*www.atm.helsinki.fi/peex/index.php/baikal-selenga-network-basenet*) - PEEX subprogram and several bi-lateral research projects (www.atm.helsinki.fi/peex/index.php/projects). New openings, having high regional and global relevance, are related to permafrost dynamics in Siberia and the environmental health issues in the Russian Arctic under changing climate (Melnikov et al. 2018, Kasimov et al. 2018). The analysis of the borehole temperature datasets in Nadym and modelling of the permafrost evolution has been carried out in collaboration with the University of Tyumen. Observations confirm high sensitivity of permafrost dynamics in the discontinuous permafrost area near Nadym to snow thickness and warming, resulting in accelerated thaw during recent years with extreme summer temperatures and winter precipitation (Kukkonen et al. submitted). Dynamics of permafrost in Russia are also analyzed in the frame of the "Permafrost dynamics & Mechanisms, pathways and patchiness of the Arctic ecosystem responses and adaptation to changing climate" (CLIMECO) project funded by the Academy of Finland. The medical-geographical analysis of spatio-temporal distribution and changes in pattern of naturally-dependent and socially important diseases under the changing climate and economic development of the Russian Arctic with focus on Yamalo-Nenets Autonomous Okrug is performed in collaboration with Moscow State University. The studies of climatic factors leading to the recent anthrax outbreak emphasize the importance of precipitation dynamics in the region (Ezhova et al. paper in preparation). There are also ongoing joint research in hydrological observations (Vihma et al, 2019) and modelling of the water ecosystems of the Fennoscandia and NW Russia, Baltic and White Seas (collaboration with Northern Water Problems Institute, Karelia); on diagnosis and numerical simulation of the atmospheric boundary layer dynamics and the Arctic terrestrial ecosystems state under anthropogenic stress; physical models of extreme marine weather events caused by climate change in the Arctic zone in the first half of the 21st century (with Institute of Numerical Mathematics, Moscow); evaluation of accumulated ecological damage for forest ecosystems in Russia and Finland based on forest inventories, SMEAR stations fluxes, remote sensing data processing, monetary evaluation (with Scientific Research Center for Ecological Safety, St.Petersburg); measurements and modelling of spatio-temporal variability of atmospheric mercury in the Russian Arctic (with Kola Science Centre, Apatity); online integrated multi-scale modelling (for NW Russia, Kola, Scandinavia, and Arctic) of direct, indirect, combined effects of aerosols on meteorology and atmospheric composition (with Russian State Hydrometeorological University/ St.Petersburg State University, St. Petersburg).

In China, the joint PEEX research is coordinated as an integral part of the GlobalSMEAR approach (see the Lappalainen et al. GlobalSMEAR abstract of this proceedings) and is connected to the analysis of the new SMEAR standardized measurements done in China. The most active partners are the Nanjing University (NJU), the Beijing University of Chemical Technology (BUCT,) and the Institute of Remote

Sensing and Digital Earth, Chinese Academy of Sciences (RADI-CAS). The research together with NJU is carried under the "Joint international research laboratory of Atmospheric and Earth System Sciences" JirLATEST (jirlatest.nju.edu.cn/main.htm). JirLATEST also includes organization of joint workshops and student training. In addition INAR has also published several papers together with Nanjing University based on the data from the SMEAR benchmarked station called "Station for Observing Regional Processes of the Earth System" (SORPES-NJU). The new Beijing Haze station hosted by BUCT is the first urban mega city station based on the SMEAR concept and has been constructed in 2018-2019. The first datasets are currently analyzed and first report for Mayor of Beijing has been submitted. The RADI-INAR / PEEX collaboration is implemented in a frame of the Digital Belt and Road Program (DBAR), INAR named as International Center of Excellence (ICoE) in Helsinki of DBAR, abbreviate the "DBAR-ICoE- Helsinki". To promote the PEEX approach in China and in the frame Belt and Silk Road initiatives, PEEX has published a separate PEEX Belt and Silk Road agenda, which introduces the large research questions and research infrastructure relevant to Belt and Silk Road region (Lappalainen et al. 2018).

In the European and Nordic scale the most recent PEEX activity coordinated by INAR has been FutArcSoc (*Future Arctic: Feedbacks and System Understanding of, Scenarios and Innovation Insights for, Development of Arctic Societies*) proposal and a new cross disciplinary research concept outlined for the EU Horizon 2020 Cryospheric Call in 2018 and, a modified version, for the NordForsk "*Multidisiplinary Research Projects Call"*(submitted in Nov 2019). The FutArcSoc introduces a research concept for analyzing the feedbacks & system understanding of Arctic environment, scenarios & innovation insights for the future development of Arctic societies. The concept takes into account growing pressure and gaps in knowledge of local and global communities due to rapidly changing Arctic environment and the international geopolitical and geo-economic landscapes. FutArcSoc concept is addressing on the most relevant topical issues and the main opportunities for development, as well as how research infrastructure could be used more effectively across national borders and programs. The added value of the concept is the inter- and transdisciplinary research approach combined with the holistic system analysis and with the currently missing aspects such as societal security to the analysis (Heininen et al. in preparation).

2.2 Research Infrastructure development in the PEEX region

2.2.1 In situ observations

The basic principles of the PEEX *in situ* observation network based on the SMEAR (Stations Measuring the Earth Surface – Atmosphere Relations) concept has been introduced by Hari et al. (2016), Kulmala et al. (2016) and, for the marine environments by Vihma et al. (2019). The PEEX RI mission is to fill in the observational gap especially in the Northern Eurasian region, to expand the PEEX / GlobalSMEAR observation networks in Russia and China, and to promote the Arctic Ocean in situ observation concept in the Arctic RI forums such as Arctic Council SAON WG and Group on Earth Observations (GEO) Cold Regions Initiative (GEO CRI) framework, and PEEX was already involved in the co-lead board for this global effort for the new implementation for the next three years from 2020 to 2022. The PEEX RI mission finds synergy with and is contributing the international Arctic RI projects like EU Horizon-2020 iCUPE (*Integrative and Comprehensive Understanding on Polar Environments*; www.atm.helsinki.fi/icupe) coordinated by INAR (Petäjä et al., 2019 paper in preparation) and INTAROS (*Integrated Arctic Observation System*; *www.nersc.no/project/intaros*) coordinated by the Nansen Environmental and Remote Sensing Center (Norway).

In Russia, the PEEX RI collaboration is currently built on the existing in situ stations networks. PEEX has introduced, in collaboration with INTAROS, the Russian in situ station e-Catalogue (*www.atm.helsinki.fi/peex/index.php/peex-russia-in-situ-stations-e-catalogue*, a living document). The catalog is aimed at enhancing the research collaboration and data exchange between researchers. It also provide guidelines (co-locations etc. aspects) when stations selected for a station upgrading or new stations are initiated. PEEX continues expanding the contact network and news stations are invited to join the station network. At the moment, new data from Russia is mostly attained from the bi-lateral field campaigns, the most recent ones being "*Land – atmosphere feedback loops over Northern Eurasia /New Particle Formation*

in Siberia " (in collaboration with V.E. Zuev Institute of Atmospheric Optics) and the long-term measurements on the green-house gases fluxes at the Mukhrino Field Station West Siberia (in collaboration with the Yugra State University). Since 2019 the novel multicomponent study of air and water pollution in Moscow metropolis is implemented under PEEX umbrella. PEEX also provides topical framework for environmental, climate and meteorological education activities between the Moscow State University (MSU) PEEX Office and RosHydroMet. The example of such approach is Baikal Selenga Network (BaSeNet) which is a separate subprogram in PEEX aiming at investigating and quantifying the waterborne transport of matter under changing hydro-climatic conditions on large drainage basin scales (Karthe et al., 2019).

In China, the PEEX RI is an integral part of the GlobalSMEAR / Global Observatory approach (Kulmala 2015, 2018) and has the primary focus on the air quality in Chinese megacities and large metropolitan areas. Starting in 2012, we have made preliminary market analysis and established an extensive contact network in China. Our current China contact network covers ca. 30 universities and city administrations. The main interest in Chinese market is on urban air quality monitoring including indoor air quality. However, the Chinese Ecosystem Research Network (CERN) for ecosystem monitoring, as a part of global eLTER network, provides a standardized station network that could up upgraded to the SMEAR network. In case of CERN the ecosystem measurement could be complemented by the SMEAR atmospheric component. Our contacts in China are also actively involved with the Belt and Road Initiative, which has potential for establishing new SMEAR flagship stations along the Silk Road transport corridors and cities (SMEAR Upscaling Plan – ClimateKIC internal strategy document)**.**

2.2.2 PEEX Modelling Platform

PEEX-MP (www.atm.helsinki.fi/peex/index.php/modelling-platform) introduces an ensemble of the models from micro- to global scales. The future aim is to establish a seamless modelling framework from nano-scale modelling to Earth system models and to introduce community-based services for data mining and for demonstrating air pollution events at multi-scales in selected regions of Arctic-boreal-domain. Currently, PEEX-MP includes more than 30 different models with more than 100 members of the network. The models have varied coverage of different Earth system components, such as atmosphere-hydrosphere-pedosphere-biosphere and processes such as physical-chemical-biological. The models used for realization of the PEEX research agenda include: Earth System Models (EC-Earth, MPI-ESM, CESM, HadGEM2-ES); online integrated meteorology and atmospheric composition models (Enviro-HIRLAM, WRF-Chem); multi-scale atmospheric chemical transport models (SILAM, CAM-Chem, TOMCAT-GLOMAP, GEOS-Chem, EurCTM, ATMES, MMAD&IT, FLEXPART); ocean-sea-ice models (HYCOM-CICE, HBM, SWAN); models for atmosphere-vegetation-ecosystems processes and interactions (AVIM2, SOSAA, Agro-C, CH4MOD, CNMM-DNDC, SIM-BIM, EmpBVOC), large eddy simulation models (PALM, LESNIC, UCLALES-SALSA); inverse modelling tools (FLEXPART, CTDAS, IMDAF) and others. At INAR, in particular, the multi-scale and -processes modelling approach is realized through demonstration and application of the EC-Earth, Enviro-HIRLAM and MALTE-Box models, which are actively used in research tasks and science education (courses, trainings, schools) considering PEEX research agenda and knowledge transfer.

2.2.3 Satellite observations

Satellites provide information complementary to in situ observation and modelling. Where in situ observation can provide much detail from continuous observation representative for a specific location, satellites provide less detail but with large spatial coverage with up to daily repeat cycle, and several observations each day. In general, the satellite data are column-integrated quantities and sometimes this can be obtained also for several individual layers, whereas detail on the vertical structure is available from satellite-based lidars. Satellite data are often used to constrain models, to test models or, vice versa, models are used for better understanding of satellite observations or improve the retrieval results by providing a priori information. It is noted that satellite-based instrument provides limited information and the retrieval is under-constrained and often assumptions are needed to find a solution. The retrieval results are validated with reference data from ground-based instruments and observation networks are established for this purpose, such as the global sunphotometer network AERONET established by NASA (Holben et al., 1998),

with sites all over the PEEX study area, complemented with networks in China such as CARSNET, CARE-China and SONET. Satellites are used in China with RADI as primary partner and in Russia with (AEROCOSMOS) as primary partner. Strong cooperations on the use of satellite data and ground-based reference data exist in particular between Finnish Meteorological Institute (FMI) and several research institutes and universities in China, The current activities in Europe are a cooperation between FMI and the Royal Netherlands Meteorological Institute (KNMI) with a focus on atmospheric observations. Different types of satellites are used, providing information on aerosols, clouds, surface properties, trace gases and greenhouse gases. Such data has recently been used to study the spatial and temporal distribution of aerosols in China (de Leeuw et al., 2018), spanning a period of two decades showing the effect of national programs to reduce air pollution with a clear decrease since 2011 (Sogacheva et al., 2018a; 2018b). A satellite-based model has been developed to monitor PM2.5 concentrations (Zhang et al., 2019) and several studies are made together with Chinese colleagues on the occurrence of haze, contributions of natural and anthropogenic contributions to air pollution in China, chemical transformation of aerosols, aerosol-cloud interaction, etc. Furthermore satellites are used to study aerosols, trace gases and greenhouse gases over Eurasia, their relation to the occurrence of forest fires and transport of absorbing aerosol to the Arctic where they affect snow and ice properties, and vegetation/atmosphere interaction (de Leeuw et al, in preparation).

2.3 Capacity Building Activities, Outreach and Knowledge Transfer

The PEEX education is a cross-section activity, which covers the training of young scientists, organization of specific winter and summer schools, and the expert training targeted towards more technical aspects of measurement, modelling, and assessment techniques and running operations including data management aspects of field stations, running models, performing assessments. Most of these activities have been implemented as an integral part of UHEL-INAR's Masters and Doctoral programs. In addition, we have several short- and long-term visiting scientists, including young researchers, at INAR from the PEEX collaborating institutes, from Belarus, Russia, Ukraine, etc. The MODEST (*Doctoral Program Modernization of Doctoral Education in Science and Improvement Teaching Methodologies*; *www.atm.helsinki.fi/peex/index.php/projects/174-modest-project*) project for the 2018-2021 (Erasmus+ Capacity Building in the Field of Higher Education Program) is aimed at modernization of doctoral education in Science in European countries and Armenia, Belarus, and Russia and provides new contact network of students from Eastern Europe interested in atmospheric sciences for INAR and PEEX. The Finnish-Russian FIRST+ PEEX-AC (*Pan-Eurasian EXperiment – Academic Challenge*; *www.atm.helsinki.fi/peex/index.php/projects/183-pan-eurasian-experiment-academic-challenge-peex-ac-network*) networking project is aimed at strengthen international added value and prestige of the Finnish Universities educational system, to share knowledge, experience and promote state-of-the-art research and educational tools; and boost the PEEX international collaboration. Under the PEEX, annually the spring and autumn schools are organized at the Hyytiälä forestry station (*www.atm.helsinki.fi/peex/index.php/education*). In June 2019, the research training course (*www.atm.helsinki.fi/peex/images/Summary_ClimEco-ResTraining_Jun2019_vfinal.pdf*) on seamless integrated modelling took place in Tyumen (Russia) and workshop on the PhD programmes and University education in Helsinki (Finland) as part of ClimEco and MODEST projects, respectively. In addition, the research training intensive course (*www.rshu.ru/3170*) and young scientist summer school (*worldslargerivers.boku.ac.at/wlr/index.php/ysss.html*) on multi-scales and –processes modelling, observations, and assessments are planned in Russia for April and August 2020 in St.Petersburg and Moscow, respectively (as part of AoF ClimEco and FIRST+ PEEX-AC projects). Mini-crash-courses on aspects of the PhD education/programmes and building Nordic/Finnish Centers of Excellences and their linkage to PEEX will be organized in March 2020 (Moscow, Russia) and training educational workshop in May 2020 (Hyytiälä, Finland).

Starting 2016 PEEX has been active member of the Universities of Arctic (U-Arctic) community. PEEX has been named as one of the U-Arctic thematic networks called as "Arctic-Boreal Hub" (*www.uarctic.org/organization/thematic-networks/arctic-boreal-hub).* U-Arctic facilitates active Arctic network of researchers and students. A new education and outreach project "Climate change Effects on Nature and Society in the Arctic (CENSArctic) started under the thematic network in 2019. The goals of the

project are to provide unique educational opportunities for students at the circumpolar North, to enhance human capacity, and to expand a crucial interdisciplinary knowledge in the North by providing new e-learning tools and by running a summer school on climate change effects on nature and society in the Arctic. U-Arctic collaboration has also motivated PEEX to provide good information flows between communities. PEEX is currently releasing (3-4 times per year) the PEEX-Arctic-Boreal-e-Newsletter (*www.atm.helsinki.fi/peex/index.php/newsletters*), PEEX Blog (*peexhq.home.blog*), PEEX Twitter (twitter.com/PEEX_News) and continuous news line "News & Events" (*www.atm.helsinki.fi/peex*). These tools serve as a multi-functional platform for everyone to share their news on their latest research results, upcoming events, reports of the site visits etc. in the community.

2.4 Societal Impact Making

PEEX has been participated the Arctic Circle initiated by the former President of Iceland, Ó.R. Grímsson, and International Arctic Forum hosted by Russian President V. Putin. The participation at these high level international dialogue forums provides important up-to-date information on the political discussions, especially on the Arctic and processes on environmental matters and concerns. Participation to these forums supports PEEX keep up the momentum in the societal impact making. Furthermore, PEEX has co-organized the Sofia Earth Forums (Helsinki, Finland), which are gathering experts of various disciplines and backgrounds to discuss practical solutions to Grand Challenges of the PEEX Science Plan. The December 2019 forum is dedicated to the carbon neutrality, regulations and incentives and is organized for the Finnish decision makers and experts at a high level.

The back carbon has been the topic of high relevance and impact and has been addressed several times by the Finnish President S. Niinistö in the Arctic collaboration discussion. In September 2019 PEEX organized a special Finnish–Russian Workshop on "*Back Carbon and Arctic Dust*" (Moscow, RU) part of the "*Black carbon in the Arctic and significance compared to dust sources*" (IBA-FIN-BCDUST) project coordinated by the Finnish Meteorological Institute (FMI). In 2020, as a continuation of the impact processes INAR / PEEX will organize an event called "*Arena for the gap analysis of the existing Arctic Science Co-Operations (AASCO)*" with the support from the Prince Albert Foundation in Monaco. Moreover, the PEEX special session "*Pan-Eurasian EXperiment (PEEX) – Observation, Modelling and Assessment in the Arctic-Boreal Domain*" (meetingorganizer.copernicus.org/EGU2020/session/35931) is scheduled at the EGU-2020 (European Geosciences Union; www.egu2020.eu; 3-8 May 2020) General Assembly with a series of splinter meetings on the PEEX - Observations, Modelling, Impact on Society, Education/Knowledge Transfer - Platforms.

FUTURE PROSPECTS

Climate change together with the growing economic activities and traffic connected to the China Belt and Road Initiative are increasing pressures on the Arctic, Northern Eurasian environments and the Silk Road Economic Belt and Road region. There is an urgent need to improve the analysis of the atmospheric and environmental pollution in these regions, their sources and to quantify the role of local and transported pollution emissions at the region (Lappalainen et al. 2018, Petäjä et al. 2019 submitted). PEEX, together with GlobalSMEAR, provide all-round tools and research framework to find solutions the environmental problems at the regional and global scales.

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