REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: ……………………FINLAND……………………….…………………..….

This form needs to be submitted via the relevant National Meteorological Service.

Principal Investigator[1]: …………Alexander Mahura…………………………………….……..

Affiliation: University of Helsinki (UHEL), Faculty of Science/Physics, Institute for Atmospheric and Earth System Research ……………..

Address: *Postal address*: P.O.Box 64, FI-00014, University of Helsinki, Helsinki, Finland ……………………………………………………. *Physical address*: Physicum building, Kumpula campus, Gustaf Hällströmin katu 2a, FI-00560 Helsinki ……………………………. E-mail: …….. alexander.mahura@helsinki.fi ..…………………….…….

Other researchers:

Risto Makkonen UHEL [risto.makkonen@helsinki.fi]
Jukka-Pekka Keskinen UHEL [jukka-pekka.keskinen@helsinki.fi]
Michael Boy UHEL [michael.boy@helsinki.fi]
Putian Zhou UHEL [putian.zhou@helsinki.fi]
Roman Nuterman UCPH [nuterman@nbi.ku.dk]
Eigil Kaas UCPH [kaas@nbi.ku.dk]
Serguei Ivanov OSENU [svvivo@te.net.ua]
Igor Ruban OSENU [iggru@i.ua]
Larisa Poletaeva OSENU [l.poletayeva555@gmail.com]
Ruslana Zazimko OSENU [rusificator1228@gmail.com]
Olga Derik OSENU [olga.deryk@gmail.com]
Ashour Sassi OSENU [ashoursassi@gmail.com]
Eugeny Kadantsev UHEL/ FMI [evgeny.kadantsev@helsinki.fi]
Sergej Zilitinkevich FMI/ UHEL [sergej.zilitinkevich@fmi.fi]
Rossella Ferretti UoLA [rossella.ferretti@aquila.infn.it]
Gabriele Curci UoLA [gabriele.curci@aquila.infn.it]
Paolo Tuccella UoLA [paolo.tuccella@aquila.infn.it]
Sergey Smyshlayev RSHU [smyshl@rshu.ru]
Maria Cherepova RSHU [mariacherepova@yandex.ru]
Yuri Timofeev SPBU [y.timofeev@spbu.ru]
Georgy Nerobelov SPBU [akulishe95@mail.ru]
Margarita Sedeeva SPBU [sedgret@gmail.com]
Evgeny Panidi SPBU [e.panidi@spbu.ru]
Natalia Gnatiuk NIERSC/ UHMI [gnatiuk@niersc.spb.ru]
Svitlana Krakovska UHMI [KraSvit@ua.fm]
Larysa Pysarenko UHMI [lolinal@ukr.net]
Mykhailo Savenets UHMI [savenetsm@gmail.com]
Anastasia Chyhareva UHMI/ TShNUK [chinastuha@gmail.com]
Olga Shevchenko TShNUK [o_g_shevchenko@ukr.net]
Sergiy Snizhko TsNUK [snizhkosi@gmail.com]
Alexey Penenko ICMMG [a.penenko@gmail.com]
Huseyin Toros ITU [huseyintoros@yahoo.com]
Sergey Chalov MSU [hydroserg@mail.ru]
Pavel Konstantinov MSU [kostadini@mail.ru]
Pavel Amosov KSC [vosoma_55@mail.ru]
Victoria Maksimova KSC [fourthmax@mail.ru]

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

Project Title: **Enviro-PEEX(Plus) on ECMWF:** *Research and development for integrated meteorology – atmospheric composition multi-scales and – processes modelling for the Pan-Eurasian EXperiment (PEEX) domain for weather, air quality and climate applications*

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** __________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☐

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	4000 kSBU	4000 kSBU	4000 kSBU
Accumulated data storage (total archive volume)[2]	(GB)	9000	9000	9000

***An electronic copy of this form must be sent via e-mail to**:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date):

…………30 June 2020……..……

Continue overleaf

Principal Investigator: …………Alexander Mahura………………………………………

Project Title: **Enviro-PEEX(Plus) on ECMWF:** *Research and development for integrated meteorology – atmospheric composition multi-scales and – processes modelling for the Pan-Eurasian EXperiment (PEEX) domain for weather, air quality and climate applications*

Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.
All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.
Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.
Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

Introduction

As the societal impacts of hazardous/ unfavorable weather and other environmental pressures grow, the need for integrated predictions which can represent the numerous feedbacks and linkages between sub-systems of our environment is greater than ever. This has led to development of a new generation of high resolution coupled prediction tools to represent the two-way interactions between different components of the environment. For example a new generation of online integrated Atmospheric Chemical Transport (ACT) and Meteorology (Numerical Weather Prediction, NWP and Climate) models represent the interactions between different atmospheric processes including chemistry (both gases and aerosols), clouds, radiation, boundary layer, emissions, meteorology and climate. In parallel, coupled environmental prediction at km-scale which includes feedbacks between the atmosphere, land surface, coastal areas and oceans aim to better represent the interactions in the water cycle, to provide tools for improved natural hazard response or water management, for example. Global Earth system models simulate the atmosphere, cryosphere, biosphere, and oceans, allowing investigation of interactions and feedbacks within and between these different spheres, including how these affect climate and biogeochemistry on timescales of hours to millennia.

The simulation of the coupled evolution of atmospheric transport and chemical composition remain one of the most challenging tasks in environmental modelling. Many of the current environmental challenges in weather, climate, and air quality modelling involve strongly coupled systems (*Zhang, 2008; Baklanov et al., 2008a, 2010; Alapaty et al., 2011*). It is well accepted that weather is element of key importance for air quality for daily life as well as accidental/emergency situations. It is also recognized that chemical species and aerosols can influence weather by changing the atmospheric radiation budget as well as through cloud and precipitation formation. However, until recently (because complexity and lack of computer power) air pollution and weather forecasts have developed as separate disciplines, leading to development of separate modelling systems which are only loosely coupled (off-line). In Numerical Weather Prediction (NWP), a substantial increase in computer power and capabilities enables to run NWP models at higher horizontal (down to 1+ km) as well as vertical (more model levels within the atmospheric boundary layer) resolutions to explicitly resolve small-scale circulation features, fronts, clouds, or to increase the complexity of the numerical models. Additionally, even though it is widely accepted that atmospheric processes have an impact on hydrological systems, these are not yet well integrated with NWP; and hence, modules for water runoff generation and water quality in hydrological pathways need to be coupled.

In recent years, it became possible to directly couple air quality forecast models with numerical weather prediction models to produce a unified modelling system – online – that allows two-way interactions. While climate modelling centres have directed towards an Earth System Modelling (ESM) approach that includes also atmospheric chemistry and ocean-sea-ice interactions, the NWP and Air Quality (AQ) forecasting centers/ organizations have started discussions whether an on-line approach is important enough to justify the extra-cost (*IFS, 2006; Grell, 2008; Baklanov et al, 2008a; Grell & Baklanov, 2011*). The later forecasting centres need to additionally invest in computing power (including infrastructure, high performance computing, data storage) as well as additional man-power. The national meteorological institutes are in favour of integrating weather and chemistry together, for improvement of weather prediction skills as well as for air quality and chemical composition forecasting. For NWP centres, an additional attractiveness of the on-line approach is its possible usefulness for meteorological data assimilation (*Hollingsworth et al., 2008*), where the retrieval of satellite data and direct assimilation of radiances can improve – assuming that the modelling system can beat climatology when forecasting concentrations of aerosols and radiatively active gases.

The focus on integrated systems is timely, since recent research has shown that meteorology/climate and chemistry feedbacks are important in the context of many research areas and applications, including weather, climate, and air quality forecasting, and Earth system modelling. Potential impacts of aerosol feedbacks include (*Jacobson et al., 2007; Zhang, 2008; Baklanov et al., 2008a; Baklanov, 2010; Grell & Baklanov, 2011; Zhang et al., 2010ab*): reduction of downward solar radiation (direct effect); changes in surface temperature, wind speed, relative humidity, and atmospheric stability (semi-direct effect); decrease in cloud drop size and an increase in drop number by serving as cloud condensation nuclei (first indirect effect); increase in liquid water content, cloud cover, and lifetime of low level clouds, and suppression or enhancement of precipitation (second indirect effect). Aerosols' feedbacks and interaction mechanisms are important on a wide range of temporal and spatial scales, from days to decades and from global to local. Field experiments and satellite measurements have shown that chemistry-meteorology feedbacks exist among the Earth systems including the atmosphere (*e.g., Kaufman & Fraser, 1997; Rosenfeld, 1999; Rosenfeld & Woodley, 1999; Givati & Rosenfeld, 2004; Grell et al., 2005; Lau & Kim, 2006; Rosenfeld et al., 2007, 2008*).

Research, Development and Application for PEEX-Modelling-Platform Models

The PEEX-MP (https://www.atm.helsinki.fi/peex/index.php/modelling-platform) presents a strategy for best use of current generation modeling tools to improve process understanding and improve predictability on different timescales within the PEEX domain, and also presents potential future developments. A number of application areas of new integrated modelling developments are expected to be considered, including: (i) improved numerical weather prediction (NWP) and chemical weather forecasting (CWF) with short-term feedbacks of aerosols and chemistry on meteorological variables; (ii) two-way interactions between atmospheric pollution/ composition and climate variability/ change; (iii) better prediction of atmosphere and/or ocean state through closer coupling between the component models to represent the two-way feedbacks and exchange of the atmospheric and ocean boundary layer properties.

The PEEX-MP focuses on new generation of integrated models and is based on the seamless Earth System Modelling (ESM) approach to evolve from separate model components to seamless meteorology-composition-environment models to address challenges in weather, climate and atmospheric composition fields whose interests, applications and challenges are now overlapping. Several models, being a part of the PEEX-MP, are to be further developed and tested in this HPC project.

The **Enviro-HIRLAM** (***Environment – HIgh Resolution Limited Area Model***) was developing as an on-line coupled Numerical Weather Prediction (NWP) and Atmospheric Chemical Transport (ACT) integrated modelling system for research purposes and for joint forecasting of meteorological, chemical, and biological (including pollen) weather. The integrated modeling system was started since 2000s to be developed by DMI (*Chenevez et al., 2004; Baklanov et al., 2004, 2008ab; Korsholm, 2009; Korsholm et al., 2008, 2009, 2010; Mahura et al., 2017abcd*) and further in a close collaboration with the Universities, and it was used by the HIRLAM consortium as a baseline system for the HIRLAM Chemical Branch (http://www.hirlam.org/chemical). The Enviro-HIRLAM model was the first meso-scale on-line coupled model in Europe, which considered two-way feedbacks between meteorology and chemistry/ aerosols (see overview paper by *Baklanov et al., 2017*).

The Enviro-HIRLAM is a fully online-coupled NWP-ACT modeling downscaling system for hemispheric-, regional-, subregional- and urban scale different environmental applications. The NWP part was originally developed by the HIRLAM consortium (*Unden et al, 2002*) and it is used for operational weather forecasting. Since beginning of 2000, the Enviro-components were mainly developed, tested and implemented in the model by Danish Meteorological Institute (DMI) with partners from European Universities. Since May 2017, the further research and development of the modelling system is realized by the University of Helsinki (UHEL), Institute for Atmospheric and Earth System Research (INAR) in collaboration with the University of Copenhagen (UCPH) and involvement of DMI. These further developments are summarized in the "*Resulted presentations/ publications from previous project - Enviro-PEEX on ECMWF*" section of this proposal.

It consists of gas-phase chemistry CBMZ (*Zaveri & Peters, 1999*) and aerosol microphysics M7 (*Vignati et al., 2004*), which includes sulfate, mineral dust, sea-salt, black and organic carbon (*Nuterman et al. 2013*). There are modules of urbanization for land surface scheme, natural and anthropogenic emissions, nucleation, coagulation, condensation, dry and wet deposition, and sedimentation of aerosols. The Savijarvi radiation scheme (*Savijaervi, 1990; Wyser, 1999*) has been improved to account explicitly for aerosol radiation interactions for 10 aerosol subtypes. The aerosol activation scheme (*Abdul-Razzak & Ghan, 2000*) was also implemented in STRACO condensation-convection scheme. The nucleation is dependent on aerosol properties and the ice-phase processes are reformulated in terms of classical nucleation theory. Emission inventories include: anthropogenic - TNO-MEGAPOLI, MACC, ECLIPSE, and others; biomass burning - IS4FIRES; natural - interactive sea-salt (*Zakey et al., 2008*) and mineral dust (*Zakey et al., 2006)* emission modules. The latest description of the Enviro-HIRLAM modeling system is given by Baklanov et al. (2017; https://www.geosci-model-dev.net/10/2971/2017).

Following the main development strategy of the HIRLAM community, the Enviro-HIRLAM further developments are moving step-by-step towards the new NWP **HARMONIE** (***HIRLAM-ALADIN Research for Meso-scale Operational NWP In Europe***) model platform by incorporating (of the Enviro-part of the Enviro-HIRLAM modelling system - chemistry and aerosol-radiation-cloud interactions modules), testing and further development of the **Enviro-HARMONIE** integrated modelling system. It is also possible to consider enhancement of the HARMONIE framework by coupling NWP and ACT models in order to provide on-line weather information needed for modelling atmospheric composition and air quality. Note that the NWP HARMONIE system combines elements from the global IFS/Arpege model (*Déqué et al., 1994*) with the ALADIN non-hydrostatic dynamics (*Bénard et al., 2010*). At high horizontal resolutions (<2.5 km), the forecast model and analysis system are basically linked with AROME model from Météo-France (*Seity et al., 2011; Brousseau et al., 2011*). Physical parametrizations from ALARO, HIRLAM (*Undén et al., 2002*) and ECMWF are applicable in this framework.

SOSAA is a 1D column model which was first developed by *Boy et al. (2011)* and applied in several subsequent studies (e.g., *Kurtén et al., 2011; Mogensen et al., 2011; Bäck et al., 2012; Boy et al., 2013; Smolander et al., 2014; Zhou et al., 2015; Mogensen et al., 2015; Zhou et al., 2017*). SOSAA is written in Fortran90 and able to run in parallel in superclusters. The current version has coupled 5 modules. The meteorology module is derived from SCADIS (SCAlar DIStribution; *Sogachev et al., 2002*) which is originally a 3D boundary layer meteorology model. The BVOC emissions from the forest ecosystem are computed by MEGAN (Model of Emissions of Gases and Aerosols from Nature; *Guenther et al., 2006*). The chemistry module codes are created by the Kinetic PreProcessor (*Damian et al., 2002*) based on the chemical mechanisms generated by the Master Chemical Mechanism v3.2 (http: //mcm.leeds.ac.uk/MCM) (*Jenkin et al., 1997; Saunders et al., 2003; Jenkin et al., 2012*). The aerosol module is based on the UHEL Multicomponent Aerosol model (*Korhonen et al., 2004*), which describes the nucleation, condensation, coagulation and deposition of aerosol particles; with later included gaseous dry deposition module (*Zhou et al., 2017ab)*; and implemented peroxy radical autoxidation mechanism (PRAM) for production of highly oxygenated organic molecules (HOM) from ozonolysis of monoterpenes with endocyclic double bonds.

The **EC-Earth** is developed jointly by 28 European research institutes (*Hazeleger et al., 2010*). EC-Earth comprises of atmosphere model IFS, ocean model NEMO and vegetation model LPJ-GUESS, coupled with OASIS coupler. Aerosols and chemistry are included through the global chemistry-transport model TM5 *(van Noije et al., 2014*). EC-Earth is participating in ongoing Coupled Model Intercomparison project phase 6 (CMIP6). EC-Earth has been implemented to ECMWF supercomputing infrastructure, and is being used there by e.g. KNMI.

The **EurCTM** (Chemistry transport model of the gas composition for Eurasia) is off-line numerical model for Eurasia's tropospheric and stratospheric chemical gases (*Galin et al., 2007; Smyshlyaev et al., 2010ab*). The model predicts air quality and stratospheric composition change as well as links between regional and mesoscale processes. Two categories of atmospheric species are in the model: long-lived greenhouse gases (CO_2, CH_4, etc.) and short-lived reactive species (O_3, NO_x, CO, SO_2, VOC, etc.). The model chemical scheme includes 74 components interacting in 174 chemical (both gaseous and heterogeneous) reactions and 51 photo-dissociation processes. Model horizontal resolution is 0.5°x0.5°, 22 vertical levels (up to 10 hPa). Chemical species' atmospheric transport is driven by wind, temperature, humidity and surface pressure fields given at 6 h intervals.

Scientific developments

The overall objectives of the special project will be to analyse the importance of the meteorology-chemistry-aerosols interactions and feedbacks and to provide a way for development of efficient techniques for on-line coupling of numerical weather prediction and atmospheric chemical transport via process-oriented parameterizations and feedback algorithms, which will improve the numerical weather prediction, climate and atmospheric composition forecasting.

The developing on-line integrated meteorology-chemistry-aerosols modelling system Enviro-HIRLAM/ HARMONIE is expected to be able to handle the following major processes and interactions (*Jacobson et al.,* *2007; Zhang, 2008*): (i) direct effect - radiative effect of chemical species such as ozone and aerosols in the atmosphere via absorption and scattering; (ii) semi-direct effect - effect of aerosols and clouds on photolysis rates via modifying actinic fluxes and temperature; (iii) semi-direct effect - effect of aerosols on boundary layer meteorology via changing meteorological variables and atmospheric stability; (iv) 1st and 2nd indirect effects - effect of aerosols on cloud formation and reflectance via aerosol activation, droplet and ice core nucleation, autoconversion, and collection; (v) indirect effects - effect of aerosols on precipitation by affecting clouds and water vapour. These processes and interactions are essential in studies for weather, climate and air quality. Aerosol particles, as an integral part of the atmosphere, play important role in the environment and have impact on human health. Depending on aerosols' origin, chemical composition, lifetime, size, shape and optical properties aerosols can cause multiple complex effects in the atmosphere at various spatio-temporal scales (*Kulmala et al., 2009; Sesartic et al., 2013; Lohmann & Feichter, 2005; Calvoa et al., 2012*). These processes can be also coupled with integrated meteorology-chemistry-hydrology conceptual framework.

The COST Action EuMetChem (European framework for online integrated air quality and meteorology modelling; http://eumetchem.info), showed that among main important couplings for numerical weather prediction there are the following when changes in aerosols affect: precipitation (initiation and intensity of precipitation); radiation (short-wave scattering/ absorption and long-wave absorption); cloud droplet or crystal number density (cloud optical depth); haze (hydroscopic growth of aerosols interrelated with relative humidity); cloud morphology (reflectance); and others. Among main important couplings for chemical weather forecasting there are the following when changes: in wind speed affect dust and sea-salt emissions; in precipitation affect atmospheric composition; in temperature and radiation affect chemical reaction rates and photolysis; in liquid water affect wet scavenging and atmospheric composition; and others.

In the previous **Enviro-PEEX on ECMWF HPC** project (2018-2020) the following studies were realised and on-going: conceptual developments for the Pan-Eurasian Experiment Modelling Platform (PEEX-MP); implementation of mesoscale resolution and weather radar assimilation experiments for weather prediction system; aerosols impact on atmospheric processes on regional and urban scales with focus on metropolitan areas; aerosols impact vs. atmospheric pollution on regional scale; elevated pollution episodes due to forest fires emissions from remote sources; energy flux balance for stable boundary layer; wind dynamics in the planetary boundary layer; elevated black carbon episodes; fires in ecosystems and influence on the atmosphere; aerosols feedbacks and interactions in Arctic-boreal domain; science education activities on modelling.

Overview of projects that benefits from the special project

The three previous Special Projects "***EnviroChemistry on ECMWF***: *Enviro-HIRLAM/HARMONIE development and test of an NWP model system accounting for aerosol-meteorology interactions*" (2012-2014); "***EnviroAerosols on ECMWF***: *Enviro-HIRLAM/ HARMONIE model research and development for online integrated meteorology-chemistry/aerosols feedbacks and interactions in weather and atmospheric composition forecasting*" (2015-2017) and "***Enviro-PEEX on ECMWF***: *Pan-Eurasian EXperiment (PEEX) Modelling Platform research and development for online coupled integrated meteorology-chemistry-aerosols feedbacks and interactions in weather, climate and atmospheric composition multi-scale modelling*" substantially contributed to the following EU and national research projects:

- HIRLAM-B(&-C) (http://hirlam.org);
- COST Action EuMetChem ES1004 "*European framework for online integrated air quality and meteorology modelling*" (http://eumetchem.info);
- FP7 EU MEGAPOLI "*Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation*" (http://megapoli.info);
- FP7 EU MACC "*Monitoring of Atmospheric Composition and Climate*" (https://www.gmes-atmosphere.eu);
- FP7 EU PEGASOS "*Pan-European Gas-AeroSOls-climate interaction Study*" (http://pegasos.iceht.forth.gr);
- FP7 EU TRANSPHORM "*Transport related Air Pollution and Health impacts - Integrated Methodologies for Assessing Particulate Matter*" (http://www.transphorm.eu);
- CEEH "*Danish strategic research Center for Energy, Environment and Health*" (http://ceeh.dk);
- AQMEII "*Air Quality Model International Initiative*" Phase 2 (http://aqmeii.jrc.ec.europa.eu);
- NordForsk CarboNord "*Impact of black carbon on air quality and climate in Northern Europe and Arctic*";
- NordForsk CRAICC-PEEX "*Cryosphere-atmosphere interactions in a changing Arctic climate - Pan-Eurasian Experiment";*

- NordForsk PEEX-CRUCIAL "*Pan-Eurasian Experiment - Critical steps in understanding land surface – atmosphere interactions: from improved knowledge to socio-economic solutions*";
- FP7 EU MarcoPolo "*Monitoring and Assessment of Regional air quality in China using space Observations, Project Of Long-term sino-european co-Operation*" (http://www.marcopolo-panda.eu);
- AoF ClimEco "*Mechanisms, pathways and patchiness of the Arctic ecosystem responses and adaptation to changing climate*" (https://www.atm.helsinki.fi/peex/index.php/climeco);
- NordForsk TRAKT-2018 "*TRAnsferable Knowledge and Technologies for high-resolution environmental impact assessment and management*" (https://www.atm.helsinki.fi/peex/index.php/trakt-2018);
- FCoE-ATM "*The Centre of Excellence in Atmospheric Science - From Molecular and Biological processes to The Global Climate*" (https://www.atm.helsinki.fi/FCoE);
- and others.

The suggested new Special Project "***Enviro-PEEX(Plus) on ECMWF****: Research and development for integrated meteorology – atmospheric composition multi-scales and – processes modelling for the Pan-Eurasian EXperiment (PEEX) domain for weather, air quality and climate applications* (2021-2023)" is to be realised in a close relation with several European and national research projects as well as in a close collaboration with Universities and research institutions:

UHEL – University of Helsinki, Finland;
UCPH – University of Copenhagen, Denmark;
FMI – Finnish Meteorological Institute, Finland;
OSENU – Odessa State Environmental University, Ukraine;
ITU – Istanbul Technical University, Turkey;
UoLA – University of L'Aquila, Italy;
RSHU – Russian State Hydrometeorological University, Russia;
UHMI – Ukrainian Hydrometeorological Institute, Ukraine;
ICMMG – Institute Computational Mathematics and Mathematical Geophysics, Russia;
NIERSC – Nansen International Environmental and Remote Sensing Centre, Russia;
TShNUK – Taras Shevchenko National University of Kyiv, Ukraine;
MSU – Moscow State University, Russia;
SPBU – Saint-Petersburg State University, Russia;
KSC – Kola Science Center, Russia

involved into Enviro-HIRLAM/HARMONIE and PEEX-Modelling-Platform research and development tasks/ activities, including the following:

HIRLAM: ALADIN/HIRLAM/LACE Rolling Work Plans (annual updates) include realisations of specific tasks on coupling with atmospheric chemistry and cloud microphysics, radiation and aerosols within the HIRLAM community for development of on-line integrated NWP and ACT modelling system (e.g. from Enviro-HIRLAM to further Enviro-HARMONIE) to be realised by members of the HIRLAM-ALADIN consortium in collaboration with mentioned Universities.

PEEX: (Pan-Eurasian Experiment) Programme (https://www.atm.helsinki.fi/peex) is a multidisciplinary, multi-scale programme focused on solving grand challenges in Northern Eurasia and China focusing on the Arctic and boreal regions. Among main building blocks are the PEEX Research Agenda; Infrastructure (including Modelling and Observational Platforms); Impact on Society; and Knowledge Transfer. Following PEEX Science Plan (http://www.atm.helsinki.fi/peex/images/PEEX_Science_Plan.pdf), programme will also help to develop service, adaptation and mitigation plans for societies to cope with global change. It is a bottom-up initiative by several European, Russian and Chinese research organizations and institutes with co-operation of US and Canadian organizations and Institutes. The PEEX approach emphasizes that solving challenges related to climate change, air quality and cryospheric change requires large-scale coordinated co-operation of the international research communities.

PBL-ECS: "*Planetary Boundary Layer in the Earth's Climate System*" project is aimed to develop and to explore climatology of physical, dynamical and long-term effects of stochastic forcing in varying planetary boundary layers; to study boundary layer effects on urban climates and for improvements of NWP and climate scale models; to model, analyze, and demonstrate these on examples of case studies.

iTRAKT: "*integrated TRAnsferable Knowledge and Technologies for regional environmental assessment*" is aimed to combine socio-economic and physical environmental data within an integrated downscaling modeling chain, and in particular, the modelled environmental quality indices and population exposure for reduced environmental quality in the northern urban area. The project will combine in-situ meteorological data with satellite remote sensing products and modeling chains; and includes an educational and network building components.

DEPOT: "*Digital depot suppling mass-media with science-proved environmental indicators*" project is aimed to provide environmental quality indicators in collaboration with mass media. Such indicators to be based on existing networks observations and modelling output. For selected urban areas as testbeds, to utilize seamless/online integrated approach in high resolution modelling with downscaling and interpolation/ zooming to urban/ local areas as well as data fusion of extensive and heterogeneous observations. Obtained results to be delivered through modern digital solutions.

iARCDEV: "*integrated Arctic change observations and services for sustainable Arctic development*" project is aimed to utilize pan-Arctic in-situ and satellite observations, community and citizen science-based monitoring and establish pilot services with modelling components, that will enable the transition to a greener, resource efficient and climate-resilient economy, and support the UN's Sustainable Development Goals, the COP21 Paris Agreement and UNDRR Sendai Framework.

INTAROS: "*Integrated Arctic Observation System*" project is aimed to extend and integrate Arctic observing and data systems related to environment and climate as basis for services towards end-users from local to regional and pan-Arctic scales. For PEEX domain of interest, the PEEX-View tool will be upgraded by combining in-situ observations from Nordic and Russian stations in Arctic and sub-Arctic regions, remote sensing data and multi-resolution modelling results based on PEEX-MP modelling tools.

CRiceS: "*Climate relevant interactions and feedbacks: key role of sea ice and snow in the polar and global climate system*" project is aimed to understanding of how rapid sea ice decline is interlinked with physical and chemical changes in the polar oceans and atmosphere, and in particular, the ocean-ice/snow-atmosphere system interactions through analysis of existing and new observations in polar regions and applications of multi-scales and –processes modelling tools with new and refined parameterizations.

FutArcSoc: "*Feedbacks and system understanding of scenarios and innovation insights for future development of Arctic societies*" project is aimed to study impacts and feedbacks of Arctic futures. It is aimed at enhancing the implementation of societal security and sustainability/resilience in differently developed Arctic societies. Project has multi-dimensional, inter- and transdisciplinary research approach and deals with several Arctic fields and themes, including pollution, Arctic/Earth systems, feedbacks, and others. One of key objectives is to study the land – atmosphere – ocean – sea ice – society feedback loops.

PEEX Academic Challenge: FIRST+ networking project is aimed to strength collaboration between Finnish and Russian Universities involved into the PEEX research and educational agenda & to share knowledge, experience and promote the state-of-the-art research and educational tools such as the SMEAR observational platform and the seamless/online integrated and Earth system modelling and GIS technology by research-educational training (through short- and long-term visits and intensive courses). The outcomes of the Enviro-PEEX will be used for lecturing and developing small-scale research projects for research training intensive course on multi-scales and –processes modelling (with PEEX-MP's EC-Earth/Enviro-HIRLAM/ HARMONIE/MALTE-Box models).

Workplan

The main **application areas** of the on-line integrated modelling are expected to be considered:

(i) improved numerical weather prediction with short-term feedbacks of aerosols and chemistry on formation and development of meteorological variables;
(ii) improved atmospheric composition forecasting with on-line integrated meteorological forecast and two-way feedbacks between aerosols/chemistry and meteorology;
(iii) coupling of aerosols and chemistry with aiming towards more realistic description of aerosols and relevant microphysical processes, and their effect on radiative fluxes and clouds;
(iv) improved understanding and ability in prediction of chemical and physical processes related to the formation and growth of atmospheric particles.

Following the previous projects, the **emphasis** in this Special Project at ECMWF is primarily on the evaluation and testing of selected models of the PEEX-Modelling-Platform and sensitivity analyses the feedback mechanisms for weather, climate and atmospheric composition modelling.

The **simulations** are expected for:

(i) short-term case studies with physical and chemical weather forecasting (downscaling from hemispheric-regional-subregional to urban/ city scales) in order to evaluate sensitivity of aerosol feedback effects on meteorology, atmospheric composition and climate;
(ii) episodes simulations for weather, climate and air quality applications to evaluate possible effects;
(iii) testing of parameterisations, meteorological and chemical initial and boundary conditions, and chemical data assimilation.

The Special Project computational resources will be used mainly to experiment with newly developed components of the modelling systems and evaluate their performance and sensitivity to feedbacks. In-depth validation and intensive testing of all of these developments will be carried out at UHEL, mentioned Universities and research institutions as well as ECMWF environments.

The **evaluation methodology** will follow the recommendations/guidelines for the evaluation methodology and protocol for online integrated meteorology-chemistry-aerosols modelling systems, developed by the COST Action EuMetChem ES1004 (*EuMetChem, 2010*; *Galmarini et al., 2011;* http://eumetchem.info).
The **duration** of the requested Special Project is expected to be from 1 January 2021 until 31 December 2023. The computational costs of these simulations and validation activities might likely extend beyond the requested project resources (see the specification below).

New developments towards PEEX-Modelling-Platform

Based on recent scientific developments and working plan the following topics, which are important for operational numerical weather prediction, atmospheric composition forecasting, and climate modelling will be investigated during the Special Project (through collaboration of UHEL with the listed above in the "Overview …" partners):

- Develop and implement method to import near-real-time high-resolution 3D CAMS mass mixing ratio (MMR) data for operational forecasting *(OSENU, FMI);*
- Develop approach for use near-real-time aerosol concentration data in cloud-precipitation microphysics parametrizations, and evaluate cloud particle effective size *(OSENU, ITU, UHEL);*
- Implement mass mixing ratio 3D optical properties of aerosol mixture to radiation schemes for improvements of short- and long-wave radiation transfer parametrizations *(OSENU, ITU, FMI);*
- Aerosols direct and indirect effects for dust transport events, aerosols impact on changes in atmospheric circulation, aerosols influence of high resolution forecasting *(UoLA, UHMI, UHEL);*
- Case studies on wind dynamics of boundary layer in breeze-dominated conditions; moisture, heat and momentum exchanges over complex terrain *(UoLA);*
- Sensitivity tests and case studies for weather and pollution events development in urban areas under conditions of climate change; downscaling technology for high-resolution meteorological fields for better understanding of fine-scale processes on regional-to-local scales in a changing climate (*UoLA, MSU, UHEL*);
- Integrated modelling and assessment of potential pollution regional atmospheric transport due to wildfires and of land cover changes' influence on regional weather patterns *(UHMI, UHEL);*
- Numerical modelling of the climate change impact on the variability of the gas composition of the lower and middle atmosphere of Eurasia *(RSHU);*
- Modelling and evaluation of meteorological patterns and stratification on vertical transport of dust from technogenic sources and levels of pollution of the atmospheric boundary layer and urban settlements *(KSC, UHEL);*
- Case studies on influence of selected metropolitan areas on formation and development of the urban heat island, microclimate features, and meteorology-chemistry-aerosols fields due to effects from urban structure/ surfaces and existing/ developing urban land-cover/ use in a changing climate (*UHEL, SPBU, TSchNSU, UoLA, MSU, UHEL*);
- Sensitivity tests with nucleation and growth of atmospheric aerosols, secondary organic aerosol formation, and with peroxy radical autoxidation mechanism (PRAM) for different environments (*UHEL*).
- Chemical data assimilation for Nordic, European and Siberian domains at regional-subregional-urban scales (*ICMMG, UCPH, UHEL*);
- Development and testing approaches for integration of multi-scale modelling results for risk assessment on environment and population (*ICMMG, UCPH, SPBU, UHEL*);
- Sensitivity tests and assessment for different meteorological situations and episodes for short-term and continuous emissions on regional, subregional and urban scales (*UCPH, SPBU, UHMI, UHEL*);
- Sensitivity tests and cases studies for seasonal meteorological patterns in northern latitudes (*NIERSC*).

Workplan tasks for the first year (2021)

Within the Special Project the following specific activities will be performed:

T01-2021: Adaptation of selected PEEX-MP models on ECMWF HPC
T02-2021: Implementation and tests of modules for both aerosols and clouds interactions
T03-2021: Testing and evaluation of models for case studies/ episodes simulations
T04-2021: Sensitivity tests/ runs and case studies for aerosol feedback mechanisms on meteorology and air pollution, for selected geographical domains, for selected metropolitan areas, for urban heat island intensity and microclimate features, for extreme events, for accidental wildfires, for land cover changes, etc.

List of deliverables for the first year (2021)

D1: 31-05-2021: Modelling systems setup on the ECMWF HPC
D2: 31-08-2021: Test runs for selected case studies/ episodes completed
D3: 31-10-2021: Analyses and preliminary results of evaluation for selected case studies/ episodes according to new developments
D4: 31-12-2018: Summary reporting on 1st year results of performed sensitivity tests and case studies

Estimated resource requirements

The initial phase of the proposed Special Project will focus on performing various technical evaluations, sensitivity experiments and configuration studies, based on the Enviro-HIRLAM /HARMONIE/ EC-Earth/ SOSAA modelling systems implemented at the ECMWF platform.
For example, for a typical Enviro-HIRLAM (note, that Enviro-HARMONIE – more expensive due to non-hydrostatic approach and more expensive dynamical core) simulation with a gas-phase (simple) chemistry, the runtime costs is at the order of 10000 SBU per experiment day. For example, for a typical EC-Earth, a typical simulation time is about 2 simulated years per wall-clock day (when all model components (IFS, NEMO, TM5) coupled with OASIS and a CPU configuration of about 400 cores are considered); note that parallellization of EC-Earth is somewhat limited by 3D communication between IFS and TM5).
Note that significant variations depend on horizontal/vertical resolutions and overall size of models' domains, sophistication of chemistry and aerosol schemes, etc. A rough estimate of a half-year worth of simulation experiments would arrive at 4 million (for Enviro-HIRLAM/HARMONIE/EC-Earth/ SOSAA and other modules simulations) SBU.

Allocation of 1 token per research team of the – OSENU, UHMI, RSHU, NIERSC, ICMMG, TSchNSU, KSC - might be sufficient for realisation of the research and development tasks towards the PEEX-Modelling-Platform by the mentioned teams.

ECMWF tokens are required for the following researches involved:

- has already - Alexander Mahura UHEL [alexander.mahura@helsinki.fi]
- has already - Risto Makkonen UHEL/FMI [risto.makkonen@helsinki.fi]
- has already - Jukka-Pekka Keskinen UHEL/FMI [jukka-pekka.keskinen@helsinki.fi]
- has already - Huseyin Toros ITU [huseyintoros@yahoo.com]
- has already - Eigil Kaas UCPH [kaas@nbi.ku.dk]
- has already - Michael Boy UHEL [michael.boy@helsinki.fi]
- has already - Eugeny Kadantsev FMI/ UHEL [evgeny.kadantsev@helsinki.fi]
- has already - Sergej Zilitinkevich FMI/ UHEL [sergej.zilitinkevich@fmi.fi]
- has already - Serguei Ivanov OSENU [svvivo@te.net.ua]
- has already - Roman Nuterman UCPH [nuterman@nbi.ku.dk]
- has already - Svitlana Krakovska UHMI [KraSvit@ua.fm]
- has already - Rossella Ferretti UoLA [rossella.ferretti@aquila.infn.it]
- has already - Georgy Nerobelov SPBU/RSHU [akulishe95@mail.ru]
- has already - Natalia Gnatiuk NIERSC [gnatiuk@niersc.spb.ru]
- has already - Olga Shevchenko TShNUK [o_g_shevchenko@ukr.net]
- has already - Alexey Penenko ICMMG [a.penenko@gmail.com]
- has already - Sergey Chalov MSU [hydroserg@mail.ru]
- has already - Pavel Konstantinov MSU [kostadini@mail.ru]
- new (new person) – Pavel Amosov KSC [vosoma_55@mail.ru]

- new (new person) – Sergey Smyshlyaev RSHU [smyshl@rshu.ru]
- new (new person) – Evgeny Panidi SPBU [e.panidi@spbu.ru]

References

Abdul-Razzak, H., and S. J. Ghan (2000), A parameterization of aerosol activation: 2. Multiple aerosol types, J. Geophys. Res., 105(D5), 6837–6844, doi:10.1029/1999JD901161.

Alapaty, K., R. Mathur, J. Pleim, Ch. Hogrefe, S. T. Rao, V. Ramaswamy, S. Galmarini, M. Schaap, R. Vautard, P. Makar, A. Baklanov, G. Kallos, B. Vogel, R. Sokhi (2011) "New Directions: Understanding Interactions of Air Quality and Climate Change at Regional Scales". *Atmospheric Environment*. doi:10.1016/j.atmosenv.2011.12.016

Baklanov, A., 2010: Chemical weather forecasting: A new concept of integrated modelling. *Advances in Science and Research*, 4: 23-27. www.adv-sci-res.net/4/23/2010/

Baklanov, A., A. Gross and J.H. Sørensen, 2004: Modeling and Forecasting of Regional and Urban Air Quality and Microclimate, *J. Computational Technologies*. 9(2), 82-97.

Baklanov, A., A. Mahura, R. Sokhi (eds), 2010: *Integrated systems of meso-meteorological and chemical transport models*, 186 pp. Springer, ISBN: 978-3-642-13979-6

Baklanov, A., Korsholm, U., Mahura, A., Petersen, C., and Gross, A., 2008a: ENVIRO-HIRLAM: on-line coupled modelling of urban meteorology and air pollution, *Advances in Science and Research*, 2, 41-46.

Baklanov, A., P. Mestayer, A. Clappier, S. Zilitinkevich, S. Joffre, A. Mahura, N.W. Nielsen, 2008b: Towards improving the simulation of meteorological fields in urban areas through updated/advanced surface fluxes description. *Atmospheric Chemistry and Physics*, 8, 523-543.

Baklanov, A., Smith Korsholm, U., Nuterman, R., Mahura, A., Nielsen, K. P., Sass, B. H., Rasmussen, A., Zakey, A., Kaas, E., Kurganskiy, A., Sørensen, B., and González-Aparicio, I.: Enviro-HIRLAM online integrated meteorology–chemistry modelling system: strategy, methodology, developments and applications (v7.2), Geosci. Model Dev., 10, 2971-2999, https://doi.org/10.5194/gmd-10-2971-2017, 2017.

Bénard, P., Vivoda, J., Mašek, J., Smolíková, P., Yessad, K., Smith, Ch., Brožková, R. and Geleyn, J.-F. (2010), Dynamical kernel of the Aladin–NH spectral limited-area model: Revised formulation and sensitivity experiments. Q.J.R. Meteorol. Soc., 136: 155–169. doi: 10.1002/qj.522

Brousseau, P., Berre, L., Bouttier, F. and Desroziers, G. (2011), Background-error covariances for a convective-scale data-assimilation system: AROME–France 3D-Var. Q.J.R. Meteorol. Soc., 137: 409–422. doi: 10.1002/qj.750

Calvoa, A.I., Alvesa, C., Castrob, A., Pontc, V., Vicentea, A.M., Fraileb, R., 2012. Research on aerosol sources and chemical composition: Past, current and emerging issue. Atmos. Res. 120–121, pp. 1–28, doi:10.1016/j.atmosres.2012.09.021.

Chenevez, J., A. Baklanov and J. H. Sørensen, 2004: Pollutant Transport Schemes Integrated in a Numerical Weather Prediction Model: Model Description and Verification Results. *Meteorological Applications.* 11, 265-275.

Déqué M., Dreveton C., Braun A., Cariolle D. (1994): The ARPEGE-IFS atmosphere model: a contribution to the French community climate modelling. Climate Dynamics 10:249-266

EuMetChem, 2010: Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action ES1004: *European framework for online integrated air quality and meteorology modelling*, Brussels, Dec. 2010, http://eumetchem.info/images/es1004-e.pdf

Galmarini, S., Rao, S.T., 2011: The AQMEII Two-Continent Regional Air Quality Model Evaluation Study: Fueling Ideas with Unprecedented Data. *Atm. Environ.* 45(14), 2464.

Givati, A., Rosenfeld, D., 2004: Quantifying Precipitation Suppression Due to Air Pollution. *Journal of Applied Meteorology* 43, 1038–1056.

Grell, G. A., S. E. Peckham, R. Schmitz, and S. A. McKeen, G. Frost, W. C. Skamarock, and B. Eder, 2005: Fully coupled "online" chemistry within the WRF model, *Atmos. Environ*., 39, 6957-6975.

Grell, G. and A. Baklanov, 2011: Integrated Modeling for Forecasting Weather and Air Quality: A Call for Fully Coupled Approaches. *Atmospheric Environment*, doi:10.1016/j.atmosenv.2011.01.017.

Grell, G.A., 2008: Coupled Weather Chemistry Modeling. Large-Scale Disasters: Prediction, Control, Mitigation, Mohamed Gad-el-Hak, Cambridge University Press. Book Chapter.

Hazeleger W., X. Wang, C. Severijns, S.S Tefanescu, R. Bintanja, A. Sterl, K. Wyser, T. Semmler, S. Yang, B. van den Hurk, T. van Noije, E. van der Linden, K. van der Wiel, 2012: EC-Earth V2: description and validation of a new seamless Earth system prediction model, *Climate Dynamics*, 39 (11), 2611-2629.

Hollingsworth, A., R.J. Engelen, C. Textor, A. Benedetti, O. Boucher, F. Chevallier, A. Dethof, H. Elbern, H. Eskes, J. Flemming, C. Granier, J.W. Kaiser, J. J. Morcrette, P. Rayner, V-.H Peuch, L. Rouil, M. Schultz, A. Simmons and the GEMS consortium, 2008: Toward a monitoring and forecasting system for atmospheric composition. The GEMS Project. *Bull. of the American Meteor. Soc*., 89, 1147-1164.

IFS, 2006: *Integrated Forecasting System, Documentation*. Cy31r1, Physical Processes. ECMWF, http://www.ecmwf.int/research/ifsdocs/.

Jacobson, M.Z., Kaufmann, Y.J., Rudich, Y., 2007: Examining feedbacks of aerosols to urban climate with a model that treats 3-D clouds with aerosol inclusions. *Journal of Geophysical Research* 112, D24205, doi:10.1029/2007JD008922.

Kaufman, Y.J., R.S. Fraser, 1997: The effect of smoke particles on clouds and climate forcing. *Science*, Washington, DC, 277(5332), 1636-1638.

Korsholm U.S., Baklanov A., Gross A., Mahura A., Sass B.H., Kaas E., 2008: Online coupled chemical weather forecasting based on HIRLAM – overview & prospective of Enviro-HIRLAM. *HIRLAM Newsletter*, 54: 1-17.

Korsholm, U., 2009: *Integrated modeling of aerosol indirect effects – development and application of a chemical weather model*, PhD thesis. University of Copenhagen, Niels Bohr Institute and Danish Meteorological Institute, http://www.dmi.dk/dmi/sr09-01.pdf.

Korsholm, U., A. Baklanov, A. Gross, J.H. Sørensen, 2009: Influence of offline coupling interval on meso-scale representations. *Atmospheric Environment*, 43 (31), 4805-4810.

Korsholm, U., Mahura, A., Baklanov, A., 2010: Monthly averaged changes in surface temperature due to aerosol indirect effects of primary aerosol emissions in Western Europe. *Atmos. Environ*. (in review), available from: http://megapoli.dmi.dk/publ/MEGAPOLI_sr10-10.pdf

Kulmala, M., Asmi, A., Lappalainen, H. K., Carslaw, K. S., Pöschl, U., Baltensperger, U., Hov, Ø., Brenquier, J.-L., Pandis, S. N., Facchini, M. C., Hansson, H.-C., Wiedensohler, A., O'Dowd, C. D., 2009. Introduction: European Integrated Project on Aerosol Cloud Climate and Air Quality interactions (EUCAARI) – integrating aerosol research from nano to global scales, Atmos. Chem. Phys. 9, 2825-2841, dx.doi.org/10.5194/acp-9-2825-2009.

Lau, K.-M., Kim, K.-M., 2006: Observational relationships between aerosol and Asian monsoon rainfall, and circulation. *Geophysical Research Letter* 33, L21810, doi:10.1029/2006GL027546.

Lohmann, U. and Feichter, J., 2005. Global indirect aerosol effects: a review. Atmos Chem and Physics. 5, 715-737

Mahura A., R. Nuterman, A. Baklanov (2017a): High Resolution Modelling of Aerosols-Meteorology Interactions over Northern Europe and Arctic regions. Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2017, Vienna, Austria; Geophysical Research Abstracts, Vol.19, EGU2017-9607.

Mahura A., Nuterman R., Amstrup B., Baklanov A., Makkonen R., Kulmala M., Zilitinkevich S. (2017b): Research vs. operational applications of Enviro-HIRLAM: regional and sub-regional scale modelling for PEEX. pp. 292-296. In Proceedings of the 3rd Pan-Eurasian Experiment (PEEX) Science Conference and 7th PEEX Meeting (19-22 Sep 2017, Moscow, Russia), Eds. H.K. Lappalainen, P. Haapanala, A. Borisova, S. Chalov, N. Kasimov, S. Zilitinkevich, M. Kulmala. Report Series in Aerosol Science, n201, 548p.

Mahura A., Amstrup B., Nuterman R., Yang X., Baklanov A. (2017c): Multi-Scale Enviro-HIRLAM Forecasting of Weather and Atmospheric Composition over China and its Megacities. Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2017, Vienna, Austria; Geoph Research Abstracts, Vol.19, EGU2017-9564.

Mahura A., Nuterman R., Amstrup B., Gonzalez-Aparicio I., Baklanov A. (2017d): Enviro-HIRLAM downscaling to metropolitan areas for forecasting weather and atmospheric composition. pp. 297-301. In Proceedings of the 3rd Pan-Eurasian Experiment (PEEX) Science Conference and 7th PEEX Meeting (19-22 Sep 2017, Moscow, Russia), Eds. H.K. Lappalainen, P. Haapanala, A. Borisova, S. Chalov, N. Kasimov, S. Zilitinkevich, M. Kulmala. Report Series in Aerosol Science, n201, 548p.

Nuterman, R., Korsholm, U., Zakey, A., Nielsen, K. P., Sørensen, B., Mahura, A., Rasmussen, A., Mažeikis, A., Gonzalez-Aparicio, I., Morozova, E., Sass, B. H., Kaas, E., and Baklanov, A.: New developments in Enviro-HIRLAM online integrated modeling system. Geophysical Research Abstracts, Vol. 15, EGU2013-12520-1, 2013.

Rosenfeld, D., 1999. TRMM Observed First Direct Evidence of Smoke from Forest Fires Inhibiting Rainfall. *Geophysical Research Letter* 26 (20), 3105-3108.

Rosenfeld, D., Dai, J., Yu, X., Yao, Z., Xu, X., Yang, X., Du, C., 2007. Inverse relations between amounts of air pollution and orographic precipitation. *Science* 315.

Rosenfeld, D., Woodley, W. L., Axisa, D., Freud, E., Hudson, J. G., Givati, A., 2008. Aircraft measurements of the impacts of pollution aerosols on clouds and precipitation over the Sierra Nevada. *Journal of Geophysical Research* 113, D15203, doi:10.1029/2007JD009544.

Rosenfeld, D., Woodley, W.L., 1999. Satellite-inferred impact of aerosols on the microstructure of Thai convective clouds. Proceedings, Seven WMO Scientific Conference on Weather Modification, Chiang Mai, Thailand, 17-22 February 1999, 17-20.

Savijärvi, Hannu, 1990: Fast Radiation Parameterization Schemes for Mesoscale and Short-Range Forecast Models. J. Appl. Meteor., 29, 437–447.

Seity Y., P. Brousseau, S.Malardel, G. Hello, P. Benard, F. Bouttier, C. Lac, and V. Masson, 2011, The AROME-France Convective-Scale Operational Model, MWR, 139, 976-991, doi: http://dx.doi.org/10.1175/2010MWR3425.1

Sesartic, A., Lohmann, U., Storelvmo, T., 2013. Modelling the impact of fungal spore ice nuclei on clouds and precipitation. Environ. Res. Lett. 8, 0140029. http://dx.doi.org/10.1088/1748-9326/8/1/014029

Undén, P., et al., 2002. Hirlam-5 scientific documentation. Tech. rep., SMHI.

van Noije T.P.C., Le Sager P., Segers A.J., van Velthoven P.F.J., Krol M.C., Hazeleger W., Williams A.G., Chambers S.D., 2014: Simulation of tropospheric chemistry and aerosols with the climate model EC-Earth, *Geosci. Model Dev*., 7, 2435-2475, https://doi.org/10.5194/gmd-7-2435-2014

Vignati, E., Wilson, J. and Stier, P. (2004). M7: An efficient size-resolved aerosol microphysics module for large-scale aerosol transport models. Journal of Geophysical Research 109(D22): doi: 10.1029/2003JD004485.

Zakey, A. S., F. Giorgi, and X. Bi, 2008: Modeling of sea salt in a regional climate model: Fluxes and radiative forcing, J. Geophys. Res., 113, D14221, doi:10.1029/2007JD009209.

Zakey, A. S., Solmon, F., and Giorgi, F., 2006: Implementation and testing of a desert dust module in a regional climate model, Atmos. Chem. Phys., 6, 4687-4704, doi:10.5194/acp-6-4687-2006.

Zaveri R.A. and L.K. Peters, 1999: A new lumped structure photochemical mechanism for large-scale applications. J. Geophys. Res., Vol. 104, D23, 30,387-30, 415.

Zhang, Y., 2008: Online-coupled meteorology and chemistry models: history, current status, and outlook, *Atmos. Chem. Phys*., 8, 2895-2932.

Zhang, Y., X.-Y. Wen, Y. Pan, and C. J. Jang, 2010a, Simulating Climate-Chemistry-Aerosol-Cloud-Radiation Feedbacks in Continental U.S. using Online-Coupled WRF/Chem, *Atmos. Environ*., 44(29), 3568-3582.

Zhang, Y., Y. Pan., K. Wang, J. D., Fast, and G. A. Grell, 2010b: Incorporation of MADRID into WRF/Chem and Initial Application to the TexAQS-2000 Episode, *J. Geophys. Res*., 115, D18202, doi:10.1029/2009JD013443.

Bäck, J., Aalto, J., Henriksson, M., Hakola, H., He, Q., and Boy, M., 2012: Chemodiversity of a Scots pine stand and implications for terpene air concentrations, Biogeosciences, 9, 689–702

Boy, M., Sogachev, A., Lauros, J., Zhou, L., Guenther, A., and Smolander, S., 2011: SOSA–a new model to simulate the concentrations of organic vapours and sulphuric acid inside the ABL – Part 1: Model description and initial evaluation, Atmos. Chem. Phys., 11, 43–5.

Boy, M., Mogensen, D., Smolander, S., Zhou, L., Nieminen, T., Paasonen, P., Plass-Dülmer, C., Sipilä, M., Petäjä, T., Mauldin, L., Berresheim, H., and Kulmala, M., 2013: Oxidation of SO2 by stabilized Criegee intermediate (sCI) radicals as a crucial source for atmospheric sulfuric acid concentrations, Atmospheric Chemistry and Physics, 13, 3865–3879, doi:10.5194/acp-13-3865-2013, http: //www.atmos-chem-phys.net/13/3865/2013/

Guenther, A. B., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P. I., Geron, C., 2006: Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature), Atmos. Chem. Phys., 6, 3181–3210

Jenkin, M. E., Wyche, K. P., Evans, C. J., Carr, T., Monks, P. S., Alfarra, M. R., Barley, M. H., McFiggans, G. B., Young, J. C., and Rickard, A. R., 2012: Development and chamber evaluation of the MCM v3.2 degradation scheme for β-caryophyllene, Atmospheric Chemistry and Physics, 12, 5275–5308, doi:10.5194/acp-12-5275-2012, http://www.atmos-chem-phys.net/12/5275/2012/

Korhonen, H., Lehtinen, K. E. J., and Kulmala, M., 2004: Multicomponent aerosol dynamics model UHMA: model development and validation, Atmospheric Chemistry and Physics, 4, 757–771, doi:10.5194/acp-4-757-2004, http://www.atmos-chem-phys.net/4/757/2004/

Kurtén, T., Zhou, L., Makkonen, R., Merikanto, J., Räisänen, P., Boy, M., Richards, N., Rap, A., Smolander, S., Sogachev, A., Guenther, A., Mann, G. W., Carslaw, K., and Kulmala, M., 2011: Large methane releases lead to strong aerosol forcing and reduced cloudiness, Atmospheric Chemistry and Physics, 11, 6961–6969, doi:10.5194/acp-11-6961-2011, http://www.atmos-chem phys.net/11/6961/2011/

Mogensen, D., Smolander, S., Sogachev, A., Zhou, L., Sinha, V., Guenther, A., Williams, J., Nieminen, T., Kajos, M. K., Rinne, J., Kulmala, M., and Boy, M., 2011: Modelling atmospheric OH-reactivity in a boreal forest ecosystem, Atmos. Chem. Phys., 11, 9709–9719

Saunders, S. M., Jenkin, M. E., Derwent, R. G., and Pilling, M. J., 2003: Protocol for the development of the Master Chemical Mechanism, MCM v3 (Part A): tropospheric degradation of non-aromatic volatile organic compounds, Atmos Chem and Physics, 3, 161–180, doi:10.5194/acp-3-161-2003, http://www.atmos-chem-phys.net/3/161/2003/

Smolander, S., He, Q., Mogensen, D., Zhou, L., Bäck, J., Ruuskanen, T., Noe, S., Guenther, A., Aaltonen, H., Kulmala, M., and Boy, M., 2014: Comparing three vegetation monoterpene emission models to measured gas concentrations with a model of meteorology, air chemistry and chemical transport, Biogeosciences, 11, 5425–5443

Sogachev, A., Menzhulin, G., Heimannn, M., and Lloyd, J., 2002: A simple three dimensional canopy – planetary boundary layer simulation model for scalar concentrations and fluxes, Tellus, 54B, 784–819

Galin V.Ya., Smyshlyaev S.P., Volodin E.M. (2007): Combined chemistry-climate model of the atmosphere, - Izvestiya, Atmospheric and Oceanic Physics, 2007, Vol. 43, No. 4, pp. 399–412. © Pleiades Publishing, Ltd., 2007.

Smyshlyaev S.P., Galin V.Ya., Shaariibuu G., Motsakov M.A. (2010): Modeling the Variability of Gas and Aerosol Components in the Stratosphere of Polar Regions, - Izvestiya, Atmospheric and Oceanic Physics, 2010, Vol. 46, No. 3, pp. 265–280. © Pleiades Publishing, Ltd., 2010.

Smyshlyaev S.P., Mareev E.A., Galin V.Ya. (2010): Simulation of the impact of thunderstorm activity on atmospheric gas composition, - Izvestiya, Atmospheric and Oceanic Physics, 2010, Vol. 46, No. 4, pp. 451–467. © Pleiades Publishing, Ltd., 2010.

Zhou, L., Gierens, R., Sogachev, A., Mogensen, D., Ortega, J., Smith, J. N., Harley, P. C., Prenni, A. J., Levin, E. J. T., Turnipseed, A., Rusanen, A., Smolander, S., Guenther, A. B., Kulmala, M., Karl, T., and Boy, M., 2015: Contribution from biogenic organic compounds to particle growth during the 2010 BEACHON-ROCS campaign in a Colorado temperate needleleaf forest, Atmospheric Chemistry and Physics, 15, 8643–8656, doi:10.5194/acp-15-8643-2015, http://www.atmos-chem-phys.net/15/8643/2015/

Zhou, P., Ganzeveld, L., Rannik, Ü., Zhou, L., Gierens, R., Taipale, D., Mammarella, I., and Boy, M., 2017a: Simulating ozone dry deposition at a boreal forest with a multi-layer canopy deposition model, Atmospheric Chemistry and Physics, 17, 1361–1379, doi:10.5194/acp-17-1361- 2017

Zhou, P., Ganzeveld, L., Taipale, D., Rannik, Ü., Rantala, P., Rissanen, M. P., Chen, D., and Boy, M., 2017b: Boreal forest BVOC exchange: emissions versus in-canopy sinks, Atmospheric Chemistry and Physics, in print.

Resulted presentations/ publications from previous project - Enviro-PEEX on ECMWF (2018-2020)

Ivanov S., Michaelides S., Ruban I., (**2018a**): Precipitation simulation with radar reflectivity pre-processing in the HARMONIE model. *EGU General Assembly 2018, Geophysical Research Abstracts, Vol. 20, EGU2018-3315.*

Ivanov S., Michaelides S., Ruban I. (**2018b**): Mesoscale resolution radar data assimilation experiments with the HARMONIE model. *Remote Sensing Journal, 10(9):1453; Sep 2018; DOI: 10.3390/rs10091453*

Ivanov S., S. Michaelides, I. Ruban, D. Charalambous, F. Tymvios (**2019**): Implementation of Weather Radar Assimilation into a Numerical Weather Prediction System: A Case Study for Cyprus. *Geophysical Research Abstracts, Vol. 21, EGU-2019-5276*

Ivanov S., S. Michaelides, I. Ruban, D. Charalambous, F. Tymvios (**2020**): Implementation of Weather Radar Assimilation into a Numerical Weather Prediction System: A Case Study for Cyprus. *Remote Sensing Journal. In review.*

Mahura A., Makkonen R., Boy M., Petäjä T., Kulmala M., Zilitinkevich S., and "Enviro-PEEX on ECMWF" modelling team (**2018a**): Seamless multi-scale and -processes modelling activities at INAR. *In Proceedings of the NOSA-FAAR Symposium 2018, p. 88; (Eds) P. Clusius, J. Enroth, A. Lauri. Report Series in Aerosol Science, N208 (2018), 142 p., ISBN 978-952-7091-98-2, http://www.atm.helsinki.fi/FAAR/reportseries/rs-208.pdf*

Mahura A., R. Nuterman, A. Baklanov, B. Amstrup, G. Nerobelov, M. Sedeeva, R. Makkonen, M. Kulmala, S. Zilitinkevich, S. Smyshlyaev (**2018b**): Enviro-HIRLAM: research and operational applications for PEEX studies. *EGU General Assembly 2018, Geophysical Research Abstracts, Vol. 20, EGU2018-19408.*

Mahura A., Baklanov A., Arnold S.R., Makkonen R., Boy M., Petäjä T., V-M. Kerminen, H.K. Lappalainen, M. Jochum, Nuterman R., Shvidenko A., Esau I., Gordov E., Penenko V., Penenko A., Sofiev M., Stohl A., Zilitinkevich S., Kulmala M., and PEEX-Modelling-Platform team (**2018c**): PEEX Modelling Platform: concept, models, components, infrastructure and virtual research platforms – applicability for seamless environmental prediction. *Abstract submitted for the International Conference IBFRA18 "Critical role of boreal and mountain ecosystems for people, bioeconomy, and climate" (17-20 Sep 2018, Laxenburg, Austria), ID-173.*

Mahura A., R. Nuterman, G. Nerobelov, M. Sedeeva, S. Smyshlayev, M. Savenets, L. Pysarenko, S. Krakovska, S. Ivanov, S. Michaelides, I. Ruban, A.S. Sassi, R. Makkonen, A. Baklanov, T. Petaja, S. Zilitinkevich, M. Kulmala (**2019**): Integrated Multi-Scale Modelling for Meteorology-Chemistry-Aerosols Interactions. *In Proceedings of the*

CoE-ATM 2019, pp. 425-429; (Eds) T. Laurila, A. Lintunen, M. Kulmala. Report Series in Aerosol Science, N226 (2019), 817 p., ISBN 978-952-7276-34-1

Mahura A., A. Baklanov, T. Petäjä, R. Nuterman, S. Ivanov, S. Michaelides, I. Ruban, R. Makkonen, H.K. Lappalainen, S. Zilitinkevich, M. Kulmala (**2020a**): PEEX Integrated Multi-scales and -Process Modelling for Environmental Applications. *European Geosciences Union General Assembly, 4-8 May 2020, Vienna, Austria; Geophysical Research Abstracts, EGU2020-11582; https://doi.org/10.5194/egusphere-egu2020-11582*

Mahura et al. (**2020b**): Aerosol feedbacks and interactions at regional scale in Arctic-boreal domain. *Manuscript in preparation*

Mahura A. et al. Enviro-PEEX team (**2020c**): Enviro-PEEX: integrated multi-scale and multi-processes modelling of meteorology-chemistry-aerosols feedbacks and interactions in weather, climate and atmospheric composition. *Manuscript in preparation*

Mahura A., A. Baklanov, S.R. Arnold, R. Makkonen, M. Boy, T. Petäjä, V-M. Kerminen, H.K. Lappalainen, M. Jochum, R. Nuterman, A. Schvidenko, I. Esau, E. Gordov, A. Titov, I. Okladnikov, V. Penenko, A. Penenko, M. Sofiev, A. Stohl, T. Aalto, J. Bai, C. Chen, Y. Cheng, M. Cherepova, O. Drofa, M. Huang, L. Järvi, H. Kokkola, R. Kouznetsov, T. Li, K.S. Madsen, P. Malguzzi, K. Moiseenko, S. Monks, S. Myslenkov, G. Nerobelov, S.B. Nielsen, S.M. Noe, Y. Palamarchuk, E. Pyanova, T.S. Rasmussen, J. She, A. Skorohod, S. Smyshlyaev, J.H. Sørensen, D. Spracklen, H. Su, J. Tonttila, E. Tsvetova, S. Wang, J. Wang, T. Wolf-Grosse, Y. Yu, Q. Zhang, W. Zhang, W. Zhang, X. Zheng, P. Zhou, S. Zilitinkevich, M. Kulmala (**2020d**): PEEX Modelling Platform for Seamless Environmental Prediction. *Atm Chem & Phys Discuss, acp-2018-541, 49 p., Manuscript in Re-revision.*

Nerobelov G., Sedeeva M., Mahura A., Nuterman R., Mostamandi S., Smyshlyaev S. (**2018**): Online integrated modeling on regional scale in North-West Russia: Evaluation of aerosols influence on meteorological parameters. *Geography, Environment, Sustainability journal. 11(2): 73-83. https://doi.org/10.24057/2071-9388-2018-11-2-73-83*

Nerobelov G. (**2019**): Modelling of aerosols impact on atmospheric processes on regional and urban scales with focus on metropolitan areas. *MSc thesis, Russian State Hydrometeorological University (RSHU), June 2019, (in Russian)*

Nerobelov G., A. Mahura, R. Nuterman, S. Mostamandy, S. Smyshlyaev (**2019**): Regional online integrated modeling of aerosols impact on meteorological parameters. *RSHU Scientific Reports (in Russian), Accepted.*

Nerobelov G., Sedeeva M., A. Mahura, R. Nuterman, S. Smyshlyaev (**2020a**): Enviro-HIRLAM modeling of atmospheric aerosols and pollution transport and feedbacks: North-West Russia and Northern Europe. *European Geosciences Union General Assembly, 4-8 May 2020, Vienna, Austria; Geophysical Research Abstracts, EGU2020-201; https://doi.org/10.5194/egusphere-egu2020-201*

Nerobelov G., A. Mahura, R. Nuterman, S. Smyshlyaev (**2020b**): Online-integrated modeling of aerosols feedbacks for the St. Petersburg, Moscow and Helsinki metropolitan areas. *Manusript in preparation.*

Popov M., S. Stankevich, A. Kozlova, I. Piestova, M. Lubskiy, O. Titarenko, M. Svideniuk, A. Andreiev, S. Ivanov, S. Michaelides (**2020**): Assessing long-term land cover changes in watersheds via classified images spatio-temporal fusion based on probability propagation. *Remote Sensing Journal. In review.*

Pysarenko L., Savenets M. (**2020**): Fires in ecosystems and influence on the atmosphere. Manuscript accepted for publication. “Visnyk of V.N. Karazin Kharkiv National University, series «Geology. Geography. Ecology»”. Vol. 53

Savenets M., Pysarenko L., Krakovska S., Mahura A. (**2020**): Estimation of elevated black carbon episodes over Ukraine using Enviro-HIRLAM. Manuscript in finalization for ACP.

Sedeeva (**2019**): Modelling and evaluation of aerosols impact vs. atmospheric pollution on regional scale. *MSc thesis, Russian State Hydrometeorological University (RSHU), June 2019, (in Russian)*

Sedeeva M., Mahura A., Nuterman R., Smyshlyaev S. (**2019**): Enviro-HIRLAM modeling and GIS evaluation of pollution in Northern Fennoscandia and North-West Russia. *Manuscript in preparation.*