LATE REQUEST FOR A SPECIAL PROJECT 2025–2027

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

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

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Project Title: **Enviro-PEEX(Next) on ECMWF:** *Research and development for seamless modelling of meteorology – atmospheric composition on multi-scales 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** _______ SPFIMAHU-2021 _________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2025	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2025-2027: (To make changes to an existing project please submit an amended version of the original form.)		**2025**	**2026**	**2027**
High Performance Computing Facility	(SBU)	4000 kSBU	4000 kSBU	4000 kSBU
Accumulated data storage (total archive volume)[2]	(GB)	9000	9000	9000

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports 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.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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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 unfavorable/ hazardous weather and other environmental pressures grow, the need for seamless 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 seamless/ 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. Simultaneously, coupled environmental prediction at kilometer-scale, which incorporates feedback between the atmosphere, land surface, coastal areas and oceans, aims to better represent the interactions in the water cycle and provide tools for improved natural hazard response or water management. Global Earth system models simulate the atmosphere, cryosphere, pedosphere, biosphere, and oceans, allowing to study the interactions and feedbacks within and between these different spheres, especially how these affect climate and biogeochemistry on timescales of hours to millennia.

Yet, the simulation of the coupled evolution of atmospheric transport and chemical composition remains 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; Gross et al., 2018; Ma et al., 2021*). 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 changes. However, until recently weather and air pollution forecasts have developed as separate disciplines, leading to development of separate modelling systems, which are only loosely coupled (offline). The NWP models benefit from recent advances in computer power and capabilities, which have enabled running those NWP models at higher horizontal (less than 1 km) as well as vertical (with more levels within the atmospheric boundary layer) resolutions to explicitly resolve small-scale circulations, fronts, clouds, and precipitation patterns, while also increasing the complexity of the numerical models.

Recently, it became possible to directly seamlessly coupled air quality forecast models with numerical weather prediction models to produce a unified modelling system – seamless/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 centres/ organizations have started discussions whether a seamless approach is important enough to justify the extra-cost (*IFS, 2006; Grell, 2008; Baklanov et al, 2008a; Grell & Baklanov, 2011; Laloyaux et al., 2015; de Rosnay et al., 2022*). The modern forecasting centres additionally always invest in computing power (including infrastructure, high performance computing, data storage) as well as manpower. 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.

Additional attractiveness of the seamless approach is its possible usefulness for meteorological data assimilation, 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: 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) (*e.g., Jacobson et al., 2007; Zhang, 2008; Baklanov et al., 2008a; Baklanov, 2010; Grell & Baklanov, 2011; Zhang et al., 2010a,b; Sato et al., 2018; Gao et al., 2022; Pendharkar et al., 2023*). 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; Liu et al., 2018; Wang et al., 2021; Im et al., 2022*).

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

The PEEX-MP (*Mahura et al., 2024*) 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 seamless 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/aerosols 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 a 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 air quality 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 developed 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 the 2000s to be developed by the Danish Meteorological Institute, DMI (*Chenevez et al., 2004; Baklanov et al., 2004, 2008a,b; Korsholm, 2009; Korsholm et al., 2008, 2009, 2010; Mahura et al., 2017a,b,c,d*) 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 mesoscale on-line coupled model in Europe, which considered two-way feedbacks between meteorology and chemistry/ aerosols (see overview paper by *Baklanov et al., 2017; Mahura et al., 2024*).

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 the beginning of 2000, the Enviro-components were mainly developed, tested, and implemented in the model by 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) (*Mahura et al., 2019; Mahura et al., 2021; Mahura et al., 2022a,b; Mahura et al., 2023a,b)* in collaboration with the University of Copenhagen (UCPH) and other universities/ research organizations. These further developments are summarized in the "*Resulted presentations/ publications from previous project - Enviro-PEEX(Plus) 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 et al., 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 (*Sahyoun et al., 2016; 2017*). Emission inventories include: anthropogenic - MEGAPOLI, MACC, TRANSPHORM, 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)* and *Mahura et al. (2024).*

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 Mesoscale 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 aspects for integrated modelling system. It is also possible to consider enhancement of the HARMONIE framework by coupling NWP and ACT models in order to provide online 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.

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 **ARCA-Box** is the Atmospherically Relevant Chemistry and Aerosol Box Model (*Clusius et al. 2022; Hulkkonen et al., 2022; Saarikoski et al., 2023; Shang et al., 2023*). It is designed to simulate atmospheric chemistry, molecular cluster formation, and aerosol particle evolution. It describes atmospheric trace gas concentrations, supports smog chamber experiment design, and estimates indoor air quality. The model's chemical library is based on the Master Chemical Mechanism (MCM) and extended with the Peroxy Radical Autoxidation Mechanism (PRAM), allowing for further customization. Molecular clustering is handled by the Atmospheric Cluster Dynamics Code (ACDC), and particle size distribution is modeled using configurable methods. Condensation of organic vapors and Brownian coagulation are simulated with established theories, with an optional precision optimizer ensuring accurate and efficient calculations.

The **PALM** (Parallelized Large-Eddy Simulation Model) model has been developed at the University of Hannover, Germany (*Maronga et al., 2015; Raasch & Schröter, 2001).* The model is based on the non-hydrostatic, filtered, incompressible Navier–Stokes equations in their Boussinesq approximated form. The pressure gradient term of the momentum equation is replaced by an expression for the geostrophic wind via the geostrophic balance. Discretization is done with the finite difference method on a horizontally equidistant Arakawa staggered C-grid. Topography is represented by bottom-surface mounted obstacles occupying full grid cells. The turbulence closure in the model is a 1.5-order sub grid scale closure (*Deardorff, 1980; Moeng & Wyngaard, 1988; Saiki et al., 2000*). PALM is used by a large user community and has been applied repeatedly for the simulation of urban flows (*Esau et al., 2024*).

Scientific developments

The overall objectives of this special project will be focused on (1) analysing the importance of the meteorology-chemistry/aerosols interactions and feedback, and on (2) providing a way for development of efficient techniques for seamless coupling of NWP and ACT models via process-oriented parameterizations and feedback algorithms. Such coupling will improve the numerical weather prediction, climate and atmospheric composition forecasting.

The developing seamless meteorology – atmospheric composition modelling system Enviro-HIRLAM/ HARMONIE is expected to be able to handle the following major processes and interactions (*Jacobson et al., 2007; Zhang, 2008*): (1) **direct effect -** radiative effect of chemical species such as ozone and aerosols in the atmosphere via absorption and scattering; (2) **semi-direct effect -** effect of aerosols and clouds on photolysis rates via modifying actinic fluxes and temperature; (3) **semi-direct effect -** effect of aerosols on boundary layer meteorology via changing meteorological variables and atmospheric stability; (4) **indirect effects -** effect of aerosols on precipitation by affecting clouds and water vapour; (5) **first and second indirect effects** - effect of aerosols on cloud formation and reflectance via aerosol activation, droplet and ice core nucleation, auto-conversion, and collection; 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*).

The COST Action EuMetChem (*European framework for online integrated air quality and meteorology modelling*) (*Baklanov et al., 2014*) showed that among main important couplings for NWP, 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 CWF 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(Plus) on ECMWF HPC** project (2021-2023) the following studies were realised and ongoing: conceptual developments for the Pan-Eurasian Experiment Modelling Platform (PEEX-MP); Sensitivity of local meteorology vs. land-cover changes in the Arctic; Atmospheric boundary layer regimes over land and water surfaces; Mapping long-term environmental changes and ecosystem response to anthropogenic and natural impacts; Temperature-humidity-wind regimes in the atmosphere over the Kola Peninsula mountains; Modelling processes of multi-dispersed dust transport on technogenic mining objects; Integrated modelling and analysis of influence of land cover changes on regional weather conditions/ patterns; Integrated modelling for assessment of potential pollution regional atmospheric transport as result of accidental wildfires; High-resolution integrated urban environmental modelling; Effects of spring air pollution and weather on Covid-19 infection; seamlessly modelled meteorology for atmospheric trajectory calculations; and also contributed to science education for Enviro-HIRLAM model at young scientist schools (YSS) in 2021 (YSS on "*Multi-Scales and -Processes Integrated Modelling, Observations and Assessment for Environmental Applications*"; https://peexhq.home.blog/2021/12/15/megapolis-2021-school) and in 2023 (YSS on "*Socio-Environmental Interactions in Sustainable Smart Cities*"; https://peexhq.home.blog/2023/11/08/ursa-major-yss).

Overview of projects that benefits from the special projects

The four previous Special Projects --- "***EnviroChemistry on ECMWF****: (1) Enviro-HIRLAM/HARMONIE development and test of an NWP model system accounting for aerosol-meteorology interactions*" (2012-2014); (2) "***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); (3) "***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*" (2018-2020); and (4) "***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) --- 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);
- PEEX-MP-Europa3 "*PEEX Modelling Platform research and development through HPC-Europa3 Transnational Access Programme*" (https://www.atm.helsinki.fi/peex/index.php/peex-mp-europa3);
- TURBAN "*Turbulent-resolving urban modelling of air quality and thermal comfort*" (https://www.project-turban.eu)
- URSA-MAJOR "*URban Sustainability in Action: Multi-disciplinary Approach through Jointly Organized Research schools*" (https://arcg.is/0LSuzr0)
- Horizon-2020 RI-URBANS "*Research Infrastructures Services Reinforcing Air Quality Monitoring Capacities in European Urban & Industrial AreaS*" (https://riurbans.eu);
- Horizon-2020 CRiceS: "*Climate relevant interactions and feedbacks: key role of sea ice and snow in the polar and global climate system*" (https://www.crices-h2020.eu);
- AoF ACCC Flagship "*The Atmosphere and Climate Competence Center*" (https://www.acccflagship.fi);
- Horizon Europe FOCI "*Non-CO2 Forcers And Their Climate, Weather, Air Quality And Health Impacts*" (https://www.project-foci.eu);
- Horizon Europe CERTAINTY "*Cloud-aERosol inTeractions & their impActs IN The earth sYstem*" (https://certainty-aci.eu);
- and others.

The suggested new Special Project ***Enviro-PEEX(Next) on ECMWF*** (2025-2027) is to be realised in a close relation with several European and national research projects as well as in a close collaboration with the Universities and research institutions:

UHEL – University of Helsinki, Finland;
UCPH – University of Copenhagen, Denmark;
FMI – Finnish Meteorological Institute, Finland;
UHMI – Ukrainian Hydrometeorological Institute, Ukraine;
UiT – The Arctic University of Tromso, Norway;
MPI-BioGeoChem – Max-Planck Institute for Biogeochemistry, Germany;
KazNU – All-Farabi Kazakh National University, Kazakhstan

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

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.

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.

CERTAINTY: "*Cloud-aERosol inTeractions & their impActs IN The earth sYstem*" project is aimed to capitalise available data together with advanced algorithms, machine learning and data assimilation methods, high resolution models, and Earth system models to bring the fundamental knowledge of interactions between clouds, aerosols, and radiation to a new level & to bring the observation based knowledge to be used in modeling frameworks to improve predictive models and knowledge of processes controlling aerosols, clouds, and their interactions from hours to decades.

RI-URBANS: "*Research Infrastructures Services Reinforcing Air Quality Monitoring Capacities in European Urban & Industrial AreaS*" project is aimed to develop an air quality monitoring system that complements those that are currently available. Identifying and measuring the changes in air pollutants will allow European health administrations and agencies to effectively mitigate the impact of poor air quality on human health. Especial concerns are nanoparticles and particulate matter fractions in the air, increasingly contributed to poor air quality in recent years. To improve air quality modelling tools and urban-scale emission inventories of higher resolution by assimilating measurements and source contributions.

FOCI: "*Non-CO2 Forcers And Their Climate, Weather, Air Quality And Health Impacts*" project is aimed to better understand the impacts of key non-CO_2 radiative forcers (known as short-lived climate pollutants), to assess where and how they arise, and their impact on the climate system. The project will find and test an effective implementation of them into global Earth System Models and Regional Climate Models (RCMs) and subsequently to use these tools to investigate mitigation and adaptation policies incorporated in selected scenarios of future development, targeted at Europe and other regions of the world. Provide policy recommendations by bridging knowledge gaps on the impact of non-CO_2 climate forcing pollutants.

ACCC: "*The Atmosphere and Climate Competence Center*" is the Academy of Finland Flagship, which is aimed to bring together the top-level science of the ACCC research partners (3 Finnish Universities and Finnish national meteorological service) and needs and expertise of key stakeholders to co-create knowledge-based solutions. The mission is to contribute toward achieving carbon neutrality in Finland, EU, and global societies; contribute to mitigate air pollution to sustain a healthy atmosphere; finding ways to mitigate CO_2 emission sources and reliably verify them; and assess the climate neutrality of mitigation measures and air quality management actions.

COST Action PEEX-EU-NEN-ReN: *"Pan-Eurasian EXperiment – Europe – Near Europe Neighbourhood countries Earth System Research Network"* aims: (1) to open opportunities for research collaboration in atmospheric and environmental sciences and carry out mobilities of PhD students; (2) to assess the current environmental observations and define actions towards harmonization; (3) to improve integrated multi-scales and -processes simulations and modelled data analyses; and (4) to educate new generation of young researchers. This project will contribute to a framework: (1) upscale the prestige of the PEEX research (WG-Research), (2) facilitate the development towards integrated in-situ observations (WG-Observations and Data), (3) enhance seamless/ online integrated multi- scales and -processes modelling (WG-Integrated Modelling), and (4) carry out education between this Partners and stakeholders coming from EU and NEN countries (WG-Knowledge Transfer). It will contribute to scientific, observational, and modelling gaps in Earth system research. It will focus on understanding the interlinked land–atmosphere–ocean–society system in the EU-NEN region context. It will promote collaboration on 3 levels between: (1) Research fields (ecology–physics–technology–chemistry–meteorology–geography–social sciences); (2) Research methodologies (theory–modelling–experiments–observations); and (3) Universities, research institutes, companies and different policy- and decision-making organizations.

Workplan

The main **application areas** of the seamless modelling approach 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 seamless 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 testing and evaluation 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 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; Baklanov et al., 2014*).
The **duration** of the requested Special Project is expected to be from 1 January 2025 until 31 December 2027. 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):

- Integrated Urban Environmental Modelling: from Development to Implementation (*combined examination of urban climate and atmospheric pollution through an integrated methodology employing high-resolution numerical modelling and data fusion techniques*) – **UiT, UHEL**.
- Effects of Aerosol-Cloud-Meteorology Interactions on Extreme Weather Events under Anthropogenic Impact (*considering uncertainties in modelling aerosol-cloud-meteorology interactions, seamlessly model and analyse various aerosol impacts on extreme weather events, with focus on cases with convective clouds under anthropogenic impact with enhancing consequences)* – **UHMI, UHEL**.
- Influence of Aerosol-Cloud-Meteorology Interactions on Extreme Weather Events under Land Use/ Land Cover Changes (*considering uncertainties in modelling aerosol-cloud-meteorology interactions, seamlessly model and analyse different aerosol impacts on extreme weather events, with focus on cases with convective clouds and how land use/ land cover redistribution can enhance the consequences*) – **UHMI, UHEL**.
- Integrated Systems and Analysis of Urban Mobility for Climate-Neutral and Sustainable Cities in Europe (*enhancing understanding of the interactions among urban multimodal mobility, traffic emissions, air quality, and thus, climate change in cities, to utilize seamless model for multi-scenarios simulations, and for proposing multi-mode transport schemes conducive to sustainable development, with emissions reduction and mitigation of health and climate risks*) – **UCPH, UHEL**.
- Assessment of Atmospheric Air State on Regional Scale in the Sustainable Development Context (*analysing meteorological and air quality monitoring data, seamlessly modelling meteorology and atmospheric composition (with focus on aerosols) on regional scale, developing recommendations for improving air quality management on a basis of scenario assessments and advance diagnostics of air environment parameters*) – **KazNU, UHEL**.
- Seamless Modelling of Atmospheric State and Composition under Influence Urban Areas (*studying effects of Helsinki and other cities in the Baltic Sea region on meteorology and atmospheric composition (with focus on aerosols) in the atmospheric boundary layer with seamless approach and accounting for effects of buildings and anthropogenic fluxes for elevated pollution episodes*) – **MPI-BioGeoChem, UCPH, UiT, UHEL**.
- Development and testing approaches for integration of multi-scale modelling results for risk assessment on environment and population – **All Partners**.

- Sensitivity tests and assessment for different meteorological situations and episodes for short-term and continuous emissions on regional, subregional and urban scales – **All Partners**.

Workplan tasks for the first year (2025)

Within the Special Project the following specific activities will be performed:
T01-2025: Adaptation of selected PEEX-MP models on ECMWF HPC
T02-2025: Implementation and tests of modules for both aerosols and clouds interactions
T03-2025: Testing and evaluation of models for case studies/ episodes simulations
T04-2025: Sensitivity tests/ runs and case studies for aerosol feedback mechanisms on meteorology and air pollution, for selected geographical domains, for selected metropolitan areas, for extreme weather and pollution events, for accidental wildfires, for land cover changes, etc.

List of deliverables for the first year (2025)

D1: 31-05-2025: Modelling systems setup on the ECMWF HPC
D2: 31-08-2025: Test runs for selected case studies/ episodes completed
D3: 31-10-2025: Analyses and preliminary results of evaluation for selected case studies/ episodes according to new developments
D4: 31-12-2025: 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/ ARCA-Box modelling systems implemented at the ECMWF platform.
For example, for a typical Enviro-HIRLAM (note that Enviro-HARMONIE is more expensive due to non-hydrostatic approach and more expensive dynamical core) simulation with simple gas-phase 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 parallelisation 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/ ARCA-Box and other modules simulations) SBU.

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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. *Atmos. Chem. &Physics*, 8, 523-543.

Baklanov, A., Schlünzen, K., Suppan, P., Baldasano, J., Brunner, D., Aksoyoglu, S., Carmichael, G., Douros, J., Flemming, J., Forkel, R., Galmarini, S., Gauss, M., Grell, G., Hirtl, M., Joffre, S., Jorba, O., Kaas, E., Kaasik, M., Kallos, G., Kong, X., Korsholm, U., Kurganskiy, A., Kushta, J., Lohmann, U., Mahura, A., Manders-Groot, A., Maurizi, A., Moussiopoulos, N., Rao, S. T., Savage, N., Seigneur, C., Sokhi, R. S., Solazzo, E., Solomos, S., Sørensen, B., Tsegas, G., Vignati, E., Vogel, B., and Zhang, Y.: Online coupled regional meteorology chemistry models in Europe: current status and prospects, Atmos. Chem. Phys., 14, 317–398, doi.org/10.5194/acp-14-317-2014, 2014.

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.

Clusius, P., Xavier, C., Pichelstorfer, L., Zhou, P., Olenius, T., Roldin, P., and Boy, M. (2022): Atmospherically Relevant Chemistry and Aerosol box model – ARCA box (version 1.2), Geosci. Model Dev., 15, 7257–7286, doi.org/10.5194/gmd-15-7257-2022

Deardorff, J. W.: Stratocumulus-capped mixed layers derived from a three Layer Meteorol., 18(4), 495–527, doi:10.1007/BF00119502, 1980.

de Rosnay P., Browne P., de Boisséson E., Fairbairn D., Hirahara Y., Ochi K., Schepers D., Weston P., Zuo H. et al. (2022). Coupled data assimilation at ECMWF: current status, challenges and future developments. Q. J. R. Meteorol. Soc. 148(747): 2672-2702 https://doi.org/10.1002/qj.4330

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

Esau, I., Belda, M., Miles, V., Geleti, J., Resler, J., Kr, P., Bauerov, P., Bure, M., Eben, K., Fuka, V., Jare, R., Karel, J., Keder, J., Patio, W., Pettersson, L.H., Radovi, J., eznek, H., indelov, A., Vlek, O., 2024. A city-scale turbulence-resolving model as an essential element of integrated urban services. Urban Clim. 56, 102059. doi.org/10.1016/j.uclim.2024.102059

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

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.

Gao, C., Xiu, A., Zhang, X., Tong, Q., Zhao, H., Zhang, S., Yang, G., & Zhang, M. (2022) Two-way coupled meteorology and air quality models in Asia: a systematic review and meta-analysis of impacts of aerosol feedbacks on meteorology and air quality, Atmos. Chem. Phys., 22, 5265–5329, https://doi.org/10.5194/acp-22-5265-2022

Givati, A., Rosenfeld, D., 2004: Quantifying Precipitation Suppression Due to Air Pollution. *J. 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.

Gross, M., Wan, H., Rasch, P. J., Caldwell, P. M., Williamson, D. L., Klocke, D., Jablonowski, C., Thatcher, D. R., Wood, N., Cullen, M., Beare, B., Willett, M., Lemarié, F., Blayo, E., Malardel, S., Termonia, P., Gassmann, A., Lauritzen, P. H., Johansen, H., Zarzycki, C. M., Sakaguchi, K., & Leung, R. (2018). Physics–Dynamics Coupling in Weather, Climate, and Earth System Models: Challenges and Recent Progress. Monthly Weather Review, 146(11), 3505-3544. https://doi.org/10.1175/MWR-D-17-0345.1

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.

Hulkkonen, M., R. O. Kaaronen, Kokkola, H., Mielonen, T., Clusius, P., Xavier, C., Hellen, H., Niemi, J. V., Malila, J. (2023): Modeling non-linear changes in an urban setting: From pro- environmental affordances to responses in behavior, emissions and air quality. Ambio, doi.org/10.1007/s13280-022-01827-8

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

Im U., Geels C., Hanninen R., Kukkonen J., Rao S., Ruuhela R., Sofiev M., Schaller N., Hodnebrog Ø., Sillmann J., Schwingshackl C., Christensen J.H., Bojariu R. & Aunan K. (2022) Reviewing the links and feedbacks between climate change and air pollution in Europe. Front. Environ. Sci. 10:954045. https://doi.org/10.3389/fenvs.2022.954045

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*, 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.

Laloyaux P., Balmaseda M., Dee D., Mogensen K., & Janssen P. (2015). A coupled data assimilation system for climate reanalysis. Q. J. R. Meteorol. Soc. 142 (694): 65-78. https://doi.org/10.1002/qj.2629

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.

Liu, Q., Jia, X., Quan, J., Li J., Wu Y., Chen D., Wang Z. & Liu Y. (2018). New positive feedback mechanism between boundary layer meteorology and secondary aerosol formation during severe haze events. Sci Rep 8, 6095. doi.org/10.1038/s41598-018-24366-3

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

Ma, Y., Li, J., Zhang, S. & Zhao H. (2021) A multi-model study of atmosphere predictability in coupled ocean–atmosphere systems. Clim Dyn 56, 3489–3509. https://doi.org/10.1007/s00382-021-05651-w

Mahura A. Nuterman R., Nerobelov G., Sedeeva M., Smyshlyaev S., Savenets M., Pysarenko L., Krakovska S., Ivanov S., Michaelides S., Ruban I., Sassi A.S., Makkonen R., Baklanov A., Petaja T., Zilitinkevich S., Kulmala M. (2019) Integrated Multi-Scale Modelling for Meteorology-Chemistry-Aerosol Interactions. Report Series in Aerosol Science (Proceedings of The Center of Excellence in Atmospheric Science (CoE ATM)). No. 226: 425–429.

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., Baklanov A., Makkonen R., Boy M., Petäjä T., Lappalainen H.K., Nuterman R., Kerminen V-M., Arnold S.R., Jochum M., Shvidenko A., Esau I., Sofiev M., Stohl A., Aalto T., Bai J., Chen Ch., Cheng Ya., Drofa O., Huang M., Järvi L., Kokkola H., Kouznetsov R., Li T., Malguzzi P., Monks S., Poulsen M.B., Noe S.M., Palamarchuk Yu., Foreback B., Clusius P., Rasmussen T.A.S., She J., Sørensen J.H., Spracklen D., Su H., Tonttila J., Wang S., Wang J., Wolf-Grosse T., Yu Y., Zhang Q., Zhang W., Zhang We., Zheng S., Li S., Li Y., Zhou P., & Kulmala M. (2024): Towards seamless environmental prediction – development of Pan-Eurasian EXperiment (PEEX) modelling platform, Big Earth Data, https://doi.org/10.1080/20964471.2024.2325019

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 Proc. of 3rd Pan-Eurasian Experiment (PEEX) Science Conference & 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. Rep. Series in Aerosol Sci., n201, 548p.

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.

Mahura A., Nuterman R., Baklanov A., Savenets M., Pysarenko L., Krakovska S., Ezau I., Heibati B., Foreback B., Boy M., Makkonen R., Lappalainen H., Petäjä T., Kulmala M. (2023a) Enviro-HIRLAM Seamless Modelling: Research, Development, Application. EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-17305. https://doi.org/10.5194/egusphere-egu23-17305

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., Baklanov, A., Nerobelov, G., Savenets, M., Pysarenko, L., Losev, A., Maksimova, V., Esau, I., Amosov, P., Krakovska, S., Smyshlyaev, S., Foreback, B., Boy, M., Makkonen, R., Petaja, T., Kulmala, M. (2021). Online integrated downscaling modelling for environmental applications. Report Series in Aerosol Science (Proceedings of Atmosphere and Climate Competence Center (ACCC) Research Flagship and Finnish Atmospheric Science Network Conference 2021). No. 245: 156–157.

Mahura, A., Nuterman, R., Baklanov, A., Nerobelov, G., Savenets, M., Pysarenko, L., Sedeeva, M., Amosov, P., Losev, A., Maksimova, V., Pankratov, F., Krakowska, S., Smyshlayaev, S., Petaja, T., Kulmala, M. (2022a) Seamless Modelling for Environmental Studies: Enviro-HIRLAM Recent Research and Development. EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022. EGU22-10551. https://doi.org/10.5194/egusphere-egu22-10551

Mahura, A., Nuterman, R., Baklanov, A., Savenets, M., Pysarenko, L., Esau, I., Foreback, B., Krakovska, S., Boy, M., Makkonen, R., Petaja, T., Kulmala, M. (2022b) Seamless modelling in environmental studies: Enviro-HIRLAM applications. Report Series in Aerosol Science. Abstract Book of the ACCC & Finnish Atmospheric Science Network Conference (21-22 November 2022, Tampere, Finland). 257: 162–163. https://www.faar.fi/wp-content/uploads/2022/11/RS257_ACCC_FASN_abstract_book.pdf

Mahura, A., Nuterman, R., Baklanov, A., Savenets, M., Pysarenko, L., Esau, I., Foreback, B., Clusius, P., Heibati, B., Krakovska, S., Boy, M., Makkonen, R., Petaja, T., Lappalainen, H.K., Kulmala, M. (2023b) Enviro-HIRLAM in environmental studies: research, development, application, and science education. Proc. of ACCC-FASN Conference (21-22 Nov 2023, Kuopio, FI), 117-118.

Maronga, B., Gryschka, M., Heinze, R., Hoffmann, F., Kanani-Sühring, F., Keck, M., Ketelsen, K., Letzel, M. O., Sühring, M. and Raasch, S.: The Parallelized Large-Eddy Simulation Model (PALM) version 4.0 for atmospheric and oceanic flows: model formulation, recent developments, and future perspectives, Geosci. Model Dev., 8(8), 2515–2551, doi:10.5194/gmd-8-2515-2015, 2015

Moeng, C.-H., Wyngaard, J. C.: Spectral analysis of large-eddy simulations of the convective boundary layer, J. Atmos. Sci., 45(23), 3573–3587, doi:10.1175/1520-0469(1988)045<3573:SAOLES>2.0.CO;2, 1988.

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.

Pendharkar, J. Figueroa, S.N., Vara-Vela, A., Krishna, R.P.M., Schuch, D., Kubota, P.Y., Alvim, D.S., Vendrasco, E.P., Gomes, H.B., Nobre, P., et al. (2023) Towards Unified Online-Coupled Aerosol Parameterization for the Brazilian Global Atmospheric Model (BAM): Aerosol–Cloud Microphysical–Radiation Interactions. Remote Sens., 15, 278. doi.org/10.3390/rs15010278

Raasch, S. and Schröter, M.: PALM – A large-eddy simulation model performing on massively parallel computers, Meteorol. Zeitschrift, 10(5), 363–372, doi:10.1127/0941-2948/2001/0010-0363, 2001

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.

Saarikoski, S., Hellén, H., Praplan, A. P., Schallhart, S., Clusius, P., Niemi, J. V., Kousa, A., Tykkä, T., Kouznetsov, R., Aurela, M., Salo, L., Rönkkö, T., Barreira, L. M. F., Pirjola, L., and Timonen, H. (2023): Characterization of volatile organic compounds and submicron organic aerosol in a traffic environment, Atmos. Chem. Phys., 23, 2963–2982, doi.org/10.5194/acp-23-2963-2023

Saiki, E. M., Moeng, C. and Sullivan, P. P.: Large Eddy Simulation of the stably stratified planetary layer, Boundary-Layer Meteorol., 95(1), 1–30, doi:10.1023/A:1002428223156, 2000

Sato, Y., Goto, D., Michibata, T., Suzuki K., Takemura T., Tomita H. & Nakajima T. (2018). Aerosol effects on cloud water amounts were successfully simulated by a global cloud-system resolving model. Nat Comm 9, 985. doi.org/10.1038/s41467-018-03379-6

Savijärvi, H., 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

Shang, D., Hu, M., Wang, X., Tang, L., Clusius, P. S., Qiu, Y., Yu, X., Chen, Z., Zhang, Z., Dao, X., Zeng, L., Guo, S., Wu, Z., and Boy, M. (2023): Spatial Inhomogeneity of New Particle Formation in Urban and Mountainous Atmospheres of the North China Plain during the 2022 Winter Olympics, Atmosphere, 14(9), 1395, doi.org/10.3390/atmos14091395

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, 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.

Wang, K., Zhang, Y., Yu, S., Wong, D. C., Pleim, J., Mathur, R., Kelly, J. T., & Bell, M. (2021). A comparative study of two-way and offline coupled WRF v3.4 and CMAQ v5.0.2 over the contiguous US: performance evaluation and impacts of chemistry–meteorology feedbacks on air quality, Geosci. Model Dev., 14, 7189–7221, doi.org/10.5194/gmd-14-7189-2021

Wyser, K., Rontu, L., and Savijärvi, H.: Introducing the effective radius into a fast radiation scheme of a mesoscale model, Contr. Atmos. Phys., 72, 205–218, 1999

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, outlook, *Atm. 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.

Resulted presentations/ publications from previous project - Enviro-PEEX(Plus) on ECMWF (2021-2023)

Amosov P., Baklanov A., Mahura A., Losev A., Maksimova V., Nuterman R. (**2022**): Algorithm for calculating the intensity of dusting on technogenic mining objects (modeling of the processes of transfer of multi-dispersed dust in the Enviro-HIRLAM model). *Book of Abstracts of the Arctic Congress, Oct 2022, Moscow, Russia.*

Esau I. et al. (**2024+**): Seamless multi-scale modelling and integration of meteorology (at km scale) with turbulence–resolving large-eddy simulation (at meter scale) for urban area. *Manuscript is in preparation*.

Foreback, B., Mahura, A., Clusius, P., Xavier, C., Baykara, M., Zhou, P., Nieminen, T., Sinclair. V., Kerminen, V.M., Kokkonen, T. V., Hakala, S., Aliaga, D., Makkonen, R., Baklanov, A., Nuterman, R., Xia, M., Hua, C., Liu, Y., Kulmala, M., Paasonen, P. & Boy, M. (**2024**): A new implementation of FLEXPART with Enviro-HIRLAM meteorological input, and a case study during a heavy air pollution event, Big Earth Data, https://doi.org/10.1080/20964471.2024.2316320, 2024.

Heibati B. et al. (**2024+**): Covid-19 in urban Finland: Seamless modelling of meteorology and air pollution to estimate impacts. *Manuscript is in preparation*.

Kulmala M., Kokkonen, Ezhova, Baklanov, Mahura, Marmarella, Back, Lappalainen, Tyuryakov, Kerminen, Zilitinkevich, Petaja (**2023**): Aerosols, clusters, greenhouse gases, trace gases and boundary-layer dynamics: on feedback and interactions. Boundary-Layer Meteorology, 186, 475–503; https://doi.org/10.1007/s10546-022-00769-8

Lappalainen H.K., A. Mahura, R. Makkonen, L. Sogacheva, A-M. Sundström, M. Boy, P. Clusius, H. Junninen, H. Lipp, S.M. Noe, A. Kangur, M. Kulmala, T. Petäjä (**2023+**): Insights into atmospheric and environmental observations in the Arctic - boreal region and a service concept for their data in a frame of Pan-Eurasian Experiment programme. *Manuscript is in preparation*.

Losev A., Maksimova V., Mahura A., Amosov P., Demin V. (**2022**): Temperature-humidity-wind regimes in the troposphere and stratosphere, concentration and deposition of aerosol pollution on the Kola Peninsula (July 2017). *Book of Abstracts of the Arctic Congress, Oct 2022, Moscow, Russia.*

Mahura et al. (**2021a**): Enviro-HIRLAM seamless modelling approach for environmental studies: recent research and development. *International Conference «Marchuk Scientific Readings 2021» (MSR-2021), 4-8 Oct 2021, Novosibirsk, Russia*

Mahura A., Nuterman R., Baklanov A., Zilitinkevich S., Kulmala M. (**2021b**): Numerical experiments on sensitivity of local meteorology vs. land-cover changes in the Arctic through seamless Enviro-HIRLAM modelling. *EGU21-13613, European Geoscience Union General Assembly, Apr 2021*

Mahura A., Amosov P., Baklanov A., Nuterman R., Losev A., Maksimova V., Petaja T., Kulmala M. (**2021c**): Apatity City Studies: Seamless Multi-Scale Approaches. *Online 4th PACES Open Science Meeting, 26-28 May 2021*

Mahura A., R. Nuterman, A. Bakanov, Nerobelov, M. Savenets, L. Pysarenko, A. Losev, V. Maksimova, I. Esau, P. Amosov, S. Krakovska, S. Smyshlyaev, B. Foreback, M. Boy, R. Makkonen, T. Petäjä, M. Kulmala (**2021d**): Online Integrated Downscaling Modelling for Environmental Applications. *Proceedings of the Atmosphere and Climate Competence Center (ACCC) Research Flagship and Finnish Atmospheric Science Network Conference 2021. pp. 156-157.*

Mahura A., R. Nuterman, A. Bakanov, M. Savenets, L. Pysarenko, I. Esau, B. Foreback, S. Krakovska, M. Boy, R. Makkonen, T. Petäjä, M. Kulmala (**2022a**): Seamless Modelling in Environmental Studies: Enviro-HIRLAM Applications. *In Report Series in Aerosol Science, N257 (2022), pp. 162-163, of Abstract Book of the ACCC & Finnish Atmospheric Science Network Conference (Nov 20222, Tampere, Finland), Eds. Aino Ovaska and Elisa Mannist, 336p.*

Mahura, A., Nuterman, R., Baklanov, A., Nerobelov, G., Savenets, M., Pysarenko, L., Sedeeva, M., Amosov, P., Losev, A., Maksimova, V., Pankratov, F., Krakowska, S., Smyshlayaev, S., Petaja, T., and Kulmala, M. (**2022b**): Seamless Modelling for Environmental Studies: Enviro-HIRLAM Recent Research and Development , *EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-10551, https://doi.org/10.5194/egusphere-egu22-10551, 2022.*

Mahura, A., Nuterman, R., Baklanov, A., Savenets, M., Pysarenko, L., Krakowska, S., Ezau, I., Heibati, B., Foreback, B., Boy, M., Makkonen, R., Lappalainen, H. K., Petäjä, T., and Kulmala, M. (**2023a**): Enviro-HIRLAM Seamless Modelling: Research, Development, Application, *EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-17305, https://doi.org/10.5194/egusphere-egu23-17305*

Mahura A., Nuterman R., Baklanov A. (**2023b**): Seamless/ Online Integrated Modelling: Enviro-HIRLAM Research, Development, Application, and Science Education. *Oral talk/pres. at research seminar Univ Jordan - Univ Helsinki, 28 May & 22 Jun 2023*.

Mahura A., R. Nuterman, A. Baklanov, I. Ezau, B. Heibati, B. Foreback, P. Clusius, M. Boy, R. Makkonen, H.K. Lappalainen, T. Petäjä, M. Kulmala (**2023c**): Enviro-HIRLAM Seamless Modelling: Applications for Northern Areas. *Oral talk/pres. at PACES Workshop, 6-8 June 2023, Helsinki, Finland*.

Mahura, A., Nuterman, R., Baklanov, A., Savenets, M., Pysarenko, L., Esau, I., Foreback, B., Clusius, P., Heibati, B., Krakovska, S., Boy, M., Makkonen, R., Petaja, T., Lappalainen, H.K., and Kulmala, M. (**2023d**): Enviro-HIRLAM in environmental studies: research, development, application, and science education. *Proceedings of the ACCC-FASN Conference (21-22 Nov 2023, Kuopio, Finland). P.117-118.*

Mahura A., Baklanov A., Makkonen R., Boy M., Petäjä T., Lappalainen H.K., Nuterman R., Kerminen V-M., Arnold S.R., Jochum M., Shvidenko A., Esau I., Sofiev M., Stohl A., Aalto T., Bai J., Chen Ch., Cheng Ya., Drofa O., Huang M., Järvi L., Kokkola H., Kouznetsov R., Li T., Malguzzi P., Monks S., Poulsen M.B., Noe S.M., Palamarchuk Yu., Foreback B., Clusius P., Rasmussen T.A.S., She J., Sørensen J.H., Spracklen D., Su H., Tonttila J., Wang S., Wang J., Wolf-Grosse T., Yu Y., Zhang Q., Zhang W., Zhang We., Zheng S., Li S., Li Y., Zhou P., & Kulmala M. (**2024**): Towards seamless environmental prediction – development of Pan-Eurasian EXperiment (PEEX) modelling platform, *Big Earth Data, https://doi.org/10.1080/20964471.2024.2325019*

Manvelova A., Nerobelov G., Sedeeva M., Kiselev A., Mahura A., Gornyy V. (**2021**): Long-term changes in remote-mapped characteristics of the Luga river basin as a response of ecosystems to anthropogenic and natural impacts. *Proceedings of the 19th International Conference "Modern Problems of Remote Sensing of the Earth from Space (Physical basics, methods and technologies for monitoring of the environment, potentially dangerous phenomena and objects)", 15-19 Nov 2021, St. Petersburg, Russia (in Russian), pp. 362.*

Mikhailenko N. (**2021**): Study of the atmospheric boundary layer regimes over land and water surfaces with online integrated meteorology-aerosols interactions Enviro-HIRLAM model. *BSc thesis, Russian State Hydrometeorological University (RSHU), June 2021, (in Russian)*

Pysarenko, L., Mahura, A., Nuterman, R., and Krakovska, S. (**2024a**): A case study of aerosol effects impact on key meteorological characteristics in Ukraine during heat wave event in July-August 2010. *EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-17895, https://doi.org/10.5194/egusphere-egu24-17895.*

Pysarenko L. et al. (**2024b+**): Seamless modelling of summer 2010 extreme weather events in Ukraine. *Manuscript is in preparation*.

Pysarenko L. et al. (**2025+**): Meteorology-aerosol interactions during extreme March 2013 snowfall event in Ukraine. *Manuscript is in preparation*.

Sahyoun M., Wex H., Gosewinkel U., Šantl-Temkiv T., Nielsen N. W., Finster K., Sørensen J. H., Stratmann F., and Korsholm U. S. (**2016**): On the usage of classical nucleation theory in quantification of the impact of bacterial INP on weather and climate, Atmospheric Environment. 139, 230-240. https://doi.org/10.1016/j.atmosenv.2016.05.034.

Sahyoun M., Korsholm U. S., Sørensen J. H., Šantl-Temkiv T., Finster K., Gosewinkel U., and Nielsen N. W. (**2017**): Impact of bacterial ice nucleating particles on weather predicted by a numerical weather prediction model, Atmospheric Environment. 170, 33-44. https://doi.org/10.1016/j.atmosenv.2017.09.029.

Savenets, M., Pysarenko, L., Krakovska, S., Mahura, A. (**2022a**): Integrated modelling for assessment the influence of aerosol feedbacks on a regional scale as a result of accidental wildfires and land cover changes in Ukraine, *EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-4792,* *https://doi.org/10.5194/egusphere-egu22-4792*

Savenets, M., Pysarenko, L., Krakovska, S., Mahura, A., and Petäjä, T. (**2022b**): Enviro-HIRLAM model estimates of elevated black carbon pollution over Ukraine resulted from forest fires, *Atmos. Chem. Phys., 22, 15777–15791,* *https://doi.org/10.5194/acp-22-15777-2022*

Savenets, M., Pysarenko, L., Krakovska, S., Mahura, A. (**2023**): Quantifying aerosol effects on meteorology in various weather conditions using the enviro-HIRLAM modelling system: case studies of Ukraine. *Proceedings of the ACCC-FASN Conference (21-22 Nov 2023, Kuopio, Finland). P. 163-164*

Savenets, M., Mahura, A., Nuterman, R., and Petäjä, T. (**2024a**): Near-surface meteorology changes driven by aerosol effects during the April 2020 wildfires in the Chornobyl Exclusion Zone, Ukraine. *EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-303,* *https://doi.org/10.5194/egusphere-egu24-303*

Savenets M, Rybchynska V, Mahura A, Nuterman R, Baklanov A, Kulmala M, Petäjä T. (**2024b**): Seamless Modeling of Direct and Indirect Aerosol Effects during April 2020 Wildfire Episode in Ukraine. *Atmosphere. 2024; 15(5):550.* *https://doi.org/10.3390/atmos15050550*

Savenets M. et al. (**2024c+**): Diverse aerosol effects under changeable synoptic conditions revealed during the April 2020 wildfire and dust storm events in Ukraine. *Manuscript is in preparation*.