SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

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*
Computer Project Account:	SPFIMAHU
Start Year - End Year :	January 2021 – December 2023
Principal Investigator(s)	Dr. Alexander Mahura
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Other Researchers (Name/Affiliation):	Risto Makkonen UHEL/FMI, Michael Boy UHEL, Ben Foreback UHEL, Putian Zhou UHEL, Eugeny Kadantsev UHEL/ FMI, Roman Nuterman UCPH, Eigil Kaas UCPH, Rossella Ferretti UoLA, Gabriele Curci UoLA, Paolo Tuccella UoLA, Sergey Smyshlayev RSHU, Maria Cherepova RSHU, Yuri Timofeev SPBU, Georgy Nerobelov SPBU, Margarita Sedeeva SPBU, Evgeny Panidi SPBU, Natalia Gnatiuk NIERSC, Svitlana Krakovska UHMI, Larysa Pysarenko UHMI, Mykhailo Savenets UHMI, Anastasia Chyhareva UHMI/ TShNUK, Olga Shevchenko TShNUK, Sergiy Snizhko TsNUK, Serge Ivanov OSENU, Alexey Penenko ICMMG, Huseyin Toros ITU, Sergey Chalov MSU, Pavel Konstantinov MSU, Mikhail Varentsov MUS, Pavel Amosov KSC, Victoria Maksimova KSC, Nikita Mikhailenko RSHU, Dmitrii Gabyshev UTMN, Alexander Zhuravlev UTMN & HIRLAM-C members *UHEL – University of Helsinki; UCPH – University of Copenhagen; FMI – Finnish Meteorological Institute; OSENU – Odessa State Environmental University; ITU – Istanbul Technical University; UoLA – University of L'Aquila; RSHU – Russian State Hydrometeorological University; UHMI – Ukrainian Hydrometeorological Institute; ICMMG – Institute Computational Mathematics and Mathematical Geophysics; NIERSC – Nansen International Environmental and Remote Sensing Centre; TShNUK – Taras Shevchenko National University of Kyiv; MSU – Moscow State University; SPBU – St. Petersburg State University; KSC – Kola Science Center; UTMN – University of Tyumen.*

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The main objectives of the Enviro-PEEX(Plus) on ECMWF Special Project are 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 main application areas to be considered include improving: (i) numerical weather prediction with short-term feedbacks of aerosols and chemistry on meteorological variables; (ii) atmospheric composition forecasting with two-way feedbacks between aerosols/chemistry and meteorology; (iii) coupling of aerosols and chemistry aiming towards better description of aerosols and relevant microphysical processes, and their effect on radiative fluxes and clouds; and (iv) understanding and ability in prediction of chemical and physical processes related to the formation and growth of atmospheric particles

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

(1) At beginning of the project, the procedures was followed for issuing and activating of new tokens with granted access to leaders of the teams: RSHU – Prof. Sergei Smyshlayev, SPBU – Dr. Evgeny Panidi, and KSC – Dr. Pavel Amosov), assigning to the fi-group/domain at ECMWF, getting access to the hirlam- and herald-groups as well as to hirlam.org for new members of the project. All was realised successfully and in time manner, and we would like to express our especial gratitude to Dr.-Ing. Carsten Maass (ECWMF) and Dr. Daniel Santos Muñoz (HIRLAM-C Project Leader for System) for assisting with all mentioned above procedures.

(2) Following e-mail (*Subject: 103rd ECMWF council outcome and actions*) from Dr. Daniel Varela Santoalla <Daniel.Varela@ecmwf.int> (dated by 24 March 2022), all colleagues/ researchers affiliated with Russian Universities/institutions and involved in this HPC project were informed and asked to stop immediately to use tokens for accessing ECMWF HPC accounts & confirmations were received that they will not use tokens and accounts. **Important note**: since spring 2022, all colleagues/ researchers affiliated with Russian Universities/institutions (whom were the main users) stopped using computing resources at ECMWF.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

We have had only a very positive experience working on the project, application procedure, reporting about status/ progress of the project, etc.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

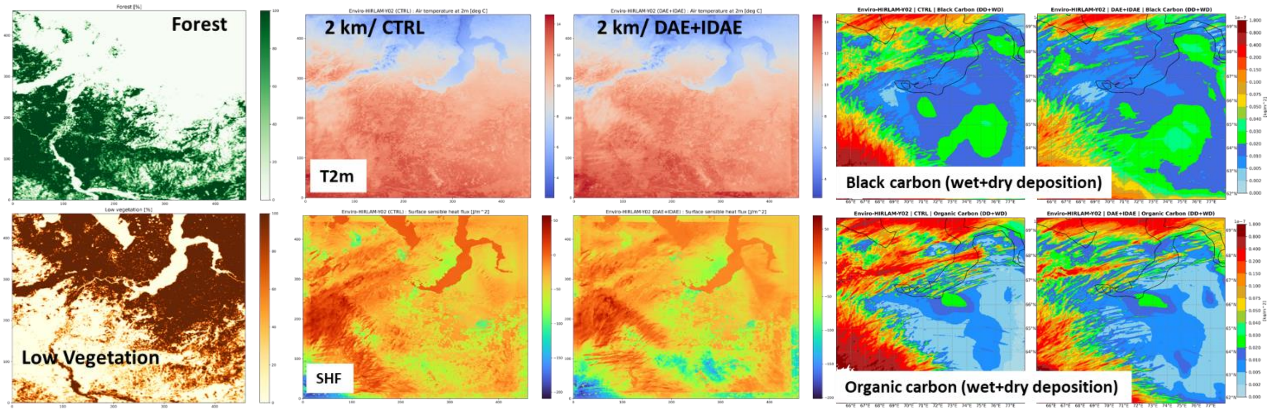
1. Implementation Concept: "The Pan-Eurasian Experiment Modelling Platform (PEEX-MP)"

The PEEX-MP is one of key blocks of the PEEX Research Infrastructure. It includes more than 30 different models. The approach has focus on a concept of seamless/online integrated environmental prediction, which allows to better understand physical-chemical-biological processes, Earth's system interactions and feedbacks, and to provide valuable information for assessment studies for population, environment and climate in the PEEX geographical domain. The PEEX-MP presents a strategy for best use of current generation modelling tools to improve process understanding and improve predictability on different scales in the PEEX domain. The seamless coupling includes different processes, components, scales and tools. The scales to be considered cover scales from micro- to local, urban, sub-regional, regional, hemispheric, global; and from box-model to large eddy simulations, meso- and climate scales. The horizontal resolutions for modelling are ranging from a few meters to more than a degree in the latitudinal-longitudinal domain. The processes, at the current moment studied at different degree of understanding and to be considered include meteorological and climatological, chemical and aerosols, biological, hydrological, and others as well as considering society interactions.

Available observations for atmosphere and ecosystems (in particular, from the SMEAR-type stations and PEEX meta database stations) are to be used for data assimilation and data processing as well as for the models' validation and verification studies. In particular, the Enviro-HIRAM modelling system continues further development and application (*Mahura et al., 2021acd, 2022ab, 2023abc, 2024*) for different research tasks according to the PEEX Science Plan (https://www.atm.helsinki.fi/peex/images/PEEX_Science_Plan.pdf).

2. Study: "Sensitivity of local meteorology vs. land-cover changes in the Arctic"

In the recent decade, the Arctic as a whole is subject to amplified warming and well documented changes in the Arctic ecosystems, and especially, these changes are becoming more and more pronounced over territories of the Russian Arctic. In this study (*Mahura et al., 2021b*), to investigate atmosphere-land-sea surfaces interactions, and in particular, heat-moisture exchange/ regime between these surfaces and for better understanding and forecasting of local meteorology in the Arctic, the seamless modelling approach (with Enviro-HIRLAM model) is tested and applied.



(a) *(b)* *(c)* *(d)* *(e)*

***Figure 2**: (a) Fraction of forest and low vegetation & example of the Enviro-HIRLAM model output at 2 km horizontal resolution for: (bc) air temperature, T2m and sensible heat flux, SHF – without (CTRL) / with (DAE+IDAE) aerosol effects; (de) black and organic carbon dry and wet deposition – with aerosol effects included.*

The model was adapted for a region of interest located in the Russian Arctic covering the inland, seashore and adjacent seas territories with the Yamal Peninsula in the centre of the domain. Two short-term periods during summer (in July) and winter (in January) of 2019 were chosen. The model runs include changes in vegetation and land-cover (Fig 2a) as well as with/ without direct and indirect aerosol effects considered (Fig 2bc; for summer), which is needed to estimate interactions and feedback between meteorology – atmospheric composition – land cover changes. The model run in downscaling chain with 5 and 2 km horizontal resolutions. The meteorological (ERA5) and aerosols/ gases (CAMS) initial and boundary conditions required were extracted from ECMWF. The model output includes both 3D meteorology and atmospheric composition (with focus on aerosols in this study; Fig 2de) in the surface, boundary layer and free troposphere. The analysis of variabilities on a diurnal cycle (for key selected meteorological parameters such as air temperature, relative humidity, wind characteristics, boundary layer height, latent and sensible heat fluxes; Fig 2bc) due to changes in vegetation and land-cover was performed for selected warm and cold periods is in focus.

3. Study: "Atmospheric boundary layer regimes over land and water surfaces"

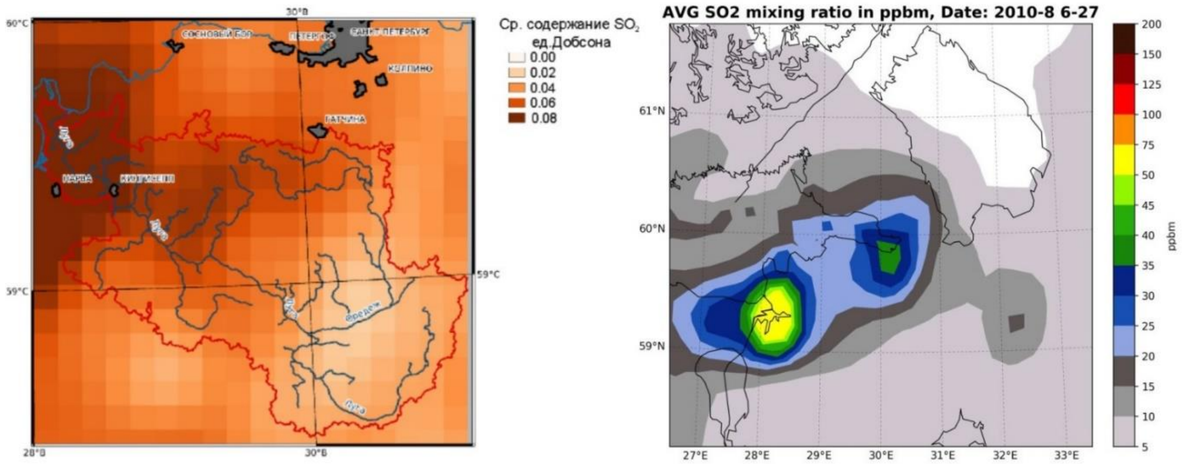
The atmospheric boundary layer (ABL) plays important role in human activities. Accurate prediction of the boundary layer's temperature-humidity-wind regimes is very important for both understanding of various processes occurred there as well as its influence on human activities for safe and efficient functioning of various industries, agriculture, transport, daily life and much more. And here, a seamless online integrated modelling approach was selected as promising direction to forecast weather conditions and studies of the Earth's atmosphere. In this study, the Enviro-HIRLAM model was employed (with direct and indirect aerosols effects included) with focus on unfavourable weather episodes with evaluated air pollution for warm and cold (August and January 2013) conditions over land and water surfaces (Fig. 3ac). The territory of the North-West Russia and Scandinavian countries was in focus (Fig. 3b). The spatiotemporal variabilities of the air temperature (at 1st model level, 500 - 1000 – 1500 m asl), total cloud cover and precipitation at ground level, specific humidity and wind speed and direction at model levels – were evaluated. It was found (*Mikhailenko, 2021*) that temperature-humidity-wind regimes, and in particular, the diurnal cycles showed in August a strong variability for temperature (up to 12°C), moderate – for wind (up to 4 m/s), and moderate – for humidity (up to 0.002 kg/kg); and showed low variability for all evaluated parameters in January. The vertical structure showed strong variability for all studied parameters. For January, the air temperature inversions were well modeled and confirmed by radio sounding measurements. For August, the elevated air pollution episodes in the cities of Nickel, Svetogorsk, and St. Petersburg of Russia may have led to increased air temperature. Further focus will be on in-depth analysis of boundary layer regimes and vertical structure over the regions of interests; analysis of influence of urban areas on formations and development of selected meteorological and atmospheric composition fields; and impact of aerosol effects on humidity parameters over land and water surfaces.

(a) (b) (c)

Figure 3: *Enviro-HIRLAM model output (examples): air temperature field on 19 Aug 2013, 12 UTC – for analysis of pollution episode; (b) model domain, N05; (c) accumulated convective precipitation field on 15 Aug 2013, 00-03 UTC – for analysis of cyclonic influence.*

4. Study: "Mapping long-term environmental changes and ecosystem response to anthropogenic and natural impacts: case study – Luga river"

This study (*Manvelova et al., 2021*) aims at evaluating long-term changes in remote-mapped characteristics as well as response of ecosystems to anthropogenic and natural impacts on example of the Luga river basin (covering Leningrad, Novgorod and Pskov regions of Russia). Existing ecosystems are under continuous technogenic influence from the mining and energy industries of Russia and Estonia. Based on long-term (17 years) remote sensing data (satellite images), the trends were mapped/constructed for temperature of the underlying surface (for the warmest month), vegetation index, ecological damage index, and average concentration of SO_2 in the atmosphere. To obtain the spatiotemporal SO_2 patterns, the online integrated Enviro-HIRLAM model was run at 15 km horizontal resolution for August 2010. Results (see Fig. 4) show that (1) aerotechnogenic impact of SO_2 on ecosystems is smaller from St.Petersburg (Russia) pollution sources compared with emissions and transboundary atmospheric transport from the heat-electro-stations from Narva (Estonia); (2) response of ecosystems on such impact is observed in increasing of the temperature of the underlying surface in the western area of the Luga river basin; (3) territories with a positive trend of the vegetation index in the city of Kingisepp (Russia) and its surroundings underline the effectiveness of rock dumps recultivation; (4) the trend of ecological damage index shows such consequences as wind-throw (occurred in 2010), mass reproduction of bark beetles, planned cuttings in forests.



(a) (b)

Figure 4*: (a) Long-term (2003-2021) averaged satellite measurements of SO_2 content by the AURA satellite; (b) Enviro-HIRLAM modelled the near surface SO_2 mixing ratio averaged for 6-27 August 2010.*

5. Study: "Temperature-Humidity-Wind Regimes in the Atmosphere over the Kola Peninsula"

This study (*Losev et al., 2022; Mahura et al. 2022b; Mahura et al. 2021c)* aims at identification of features in the temperature, humidity and wind regimes in the troposphere and stratosphere, and in concentrations and depositions of aerosol components over the Kola Peninsula for summer (July 2017). To achieve this goal, patterns of various meteorological parameters, concentrations and depositions of aerosol components were simulated using the Enviro-HIRLAM, Environment - High Resolution Limited Area Model. To perform numerical experiments, two model domains were selected. The ECMWF (European Center for Medium-range Weather Forecast) boundary conditions are used to run the model on the outer domain, and then, simulated meteorological fields are taken as boundary conditions for the inner domain.

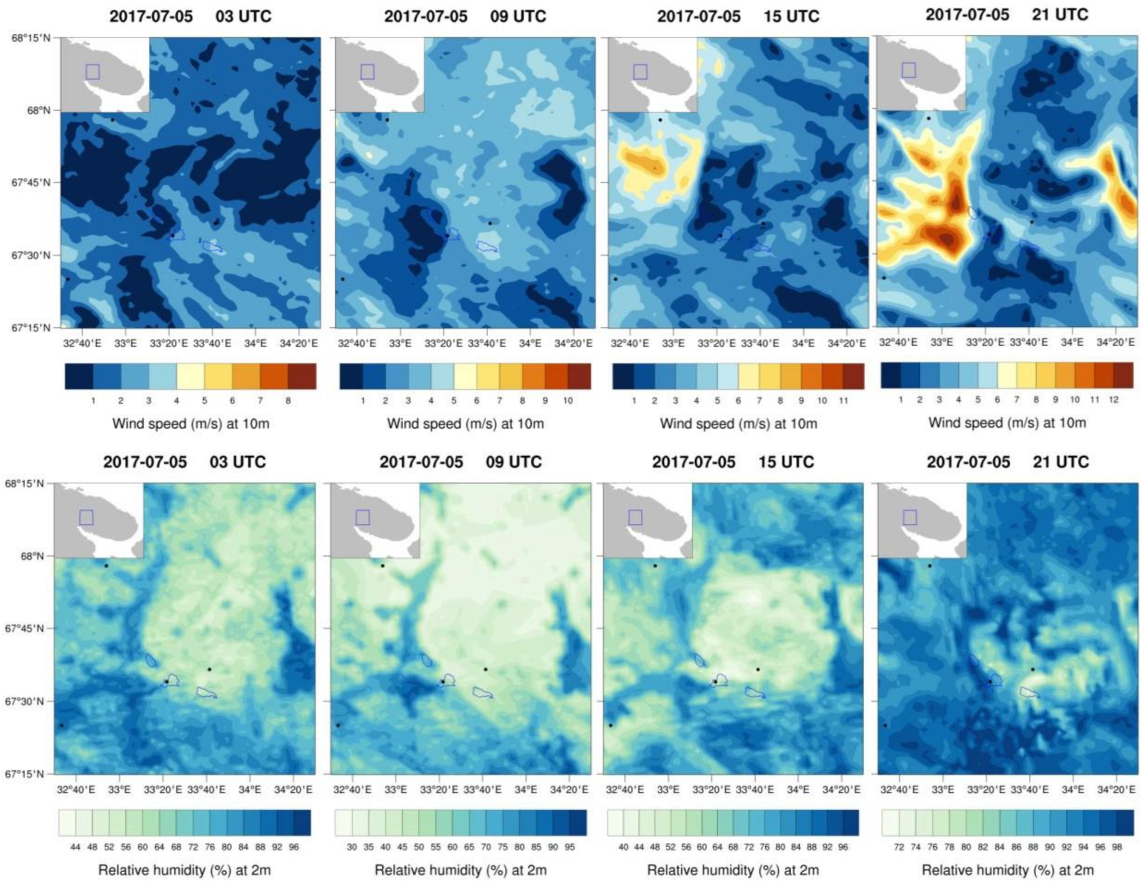


Figure 5: *Example of Enviro-HIRLAM model output for diurnal cycle (on 5 July 2017) for wind speed at 10 m and relative humidity at 2 m over the Khibiny mountains area (Kola Peninsula).*

Based on simulation results for July 2017, spatiotemporal patterns of temperature, relative and specific air humidity, wind speed and direction were constructed at the model levels and on standard isobaric surfaces (from 1000 to 10 hPa). Values of considered characteristics of temperature, humidity, and wind regimes in the main layers of the atmosphere are analyzed: (i) troposphere - surface layer (up to 100 m), boundary layer (up to 1.5 km), free troposphere (up to tropopause considering peculiarities of northern latitudes) and (ii) stratosphere. Specific features are identified in distribution of meteorological parameters in different atmospheric layers. Based on simulation results, daily variations of studied meteorological parameters (see Fig. 5) are constructed and analyzed. In addition, at the model levels and surfaces of land and water bodies of the Kola Peninsula, concentration and deposition of aerosol components (sulfates, organic and black carbon, etc.) on underlying surfaces are also analyzed.

6. Study: "Modeling processes of multi-dispersed dust transport on technogenic mining objects"

This study (*Amosov et al., 2022; Mahura et al. 2022b; Mahura et al. 2021c)* is focused on tailing-dumps of the "Apatit" Association (the largest technogenic area and most intense sources of aerotechnogenic impact on the environment in the Murmansk region and Arctic climate). According to "Murmansk UGMS" in Apatity during spring-autumn of 2016-2017-2018 with 14-10-13 cases of air pollution (dust) above the MPC level were recorded (see Fig. 6). Enviro-HIRLAM (Environment – High Resolution Limited Area Model) model is used to simulate atmospheric transport, dispersion and deposition of dust. To perform numerical experiments, two regions with resolutions of 5-1.5 km were built on the Kola Peninsula's territory.

To perform calculations a correct description of dusting intensity is required. The generalized calculation algorithm (module for integration into Enviro-HIRLAM has been prepared) of the dusting intensity and mass flow rate includes the following steps: (i) in each cell of computational grid with dusting object, the potential dusting area is estimated; (ii) based on analysis of data from stationary atmospheric monitoring stations, intervals of air temperature and humidity are determined, at which dusting process is observed, with MPC being exceeded; (iii) based on calculated values of wind speed at heights of 10 and 32 m (40th model level) above the surface in "dust"-cells, the dynamic speed is calculated; (iv) for each interval (7 bins with step of 10 µm) of dust size-distribution, calculated velocity is compared with threshold dusting velocity for the interval; (v) dust rate and mass flow in a particular "dust"-cell are calculated using Westphal et al. (1988) method and taking into account "weight" of the interval.

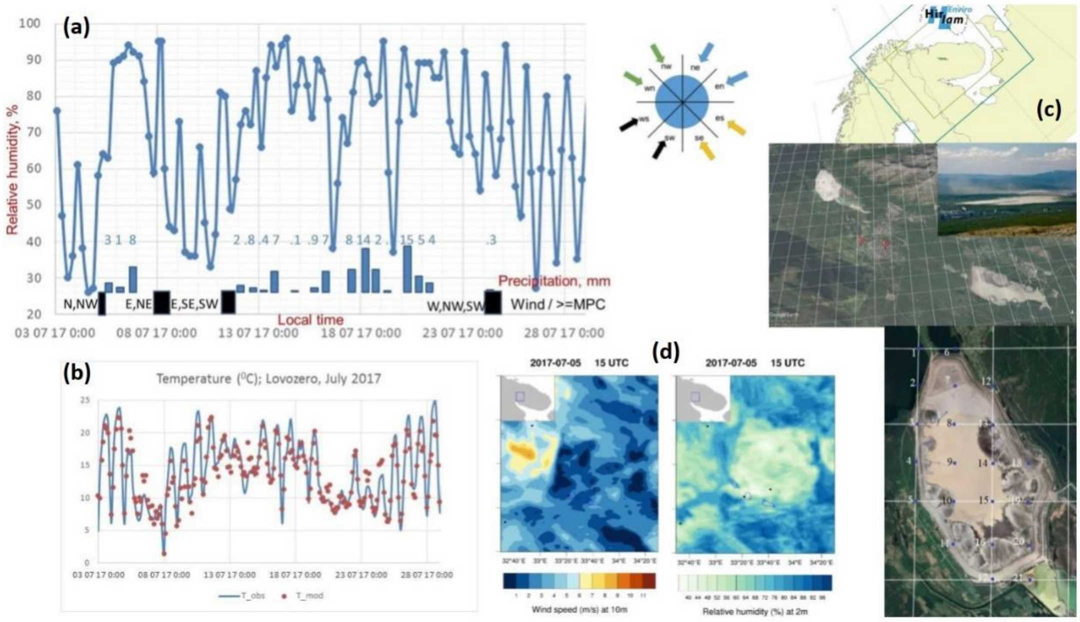


Figure 6: (a) Time-series of relative humidity, total precipitation and wind direction vs. concentration of dust during July 2017 (at the Apatity meteorological and air quality station); (b) observed vs. modelled air temperature (at the Lovozero meteorological station); (c) geographical domains - Enviro-HIRLAM model runs at 5 and 1.5 km horizontal resolution, Apatity's tailing dumps (ANOF-2 & 3 factories); (d) modelled wind speed and relative humidity at 15 UTC on 5 July 2017 in the Apatity-Kirovsk urban region and Khibiny mountains.

7. Study: "Integrated Modelling and Analysis of Influence of Land Cover Changes on Regional Weather Conditions/ Patterns"

This study (Pysarenko et al., 2023+, 2024+; Savenets et al., 2022b) aims to investigate influence of land-cover changes (current vs. scenarios) and its consequences on meteorology for cases of extreme meteorological situations (heatwave, heavy rains and snowfall) and air quality/ atmospheric composition. Methods applied include the following: (1) Seamless multi-scale (15-5-2-1.5 km res.) Enviro-HIRLAM modelling; (2) Study period: Jul-Aug 2010; Mar-Apr 2013; (3) Scenarios: deforestation total (TOT_DEF) & half (HALF_DEF); afforestation total (TOT_AFF) and half (HALF_AFF); (4) Model runs: REF + DAE, IDAE, DAI+IDAE aerosol effects included (see example on Fig. 7). Concluding remarks are the following: (i) Land cover changes significantly impact regional weather patterns through changes in radiation, moisture, temperature and wind regimes; (ii) Land cover changes can enhance the consequences of extreme meteorological conditions; (iii) Outcomes – showed consequences of deforestation and give solid ground for decision-makers in planning adaptation measures to climate change & developing possible recommendations for national forestry service.

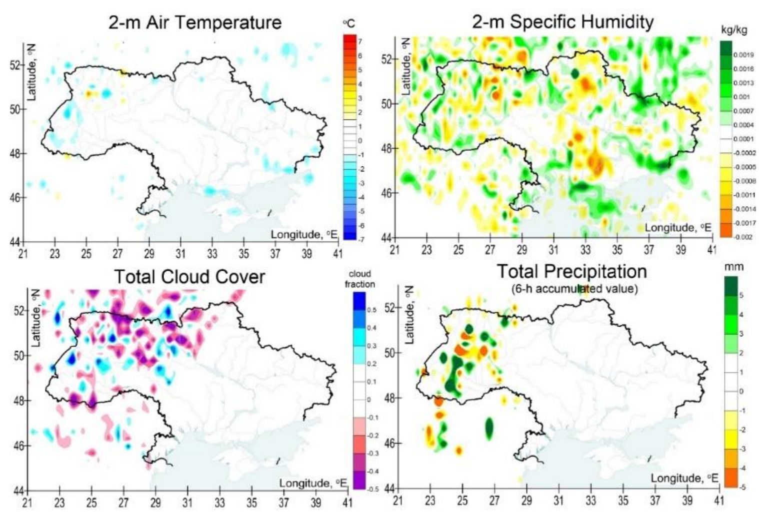


Figure 7: Impact of total deforestation on selected meteorological parameters – air temperature at 2 m, specific humidity at 2 m, total cloud cover, and total precipitation (6h accumulated) – on 1 August 2010 (12UTC) (for differences between Enviro-HIRLAM model runs: TOT_DEF – REF)).

8. Study: “Integrated Modelling for Assessment of Potential Pollution Regional Atmospheric Transport as Result of Accidental Wildfires”

This study (*Savenets et al., 2022ab, 2024ab*) aims to analyse regional influence of wildfires occurred in the Chernobyl exclusion zone & to identify affected territories in case of active wildfires near, within radioactive polluted hotspots, and in a close proximity to the nuclear power plant. Methods applied include the following: (1) Seamless multi-scale (15-5-2-1.5 km res.) Enviro-HIRLAM modelling; (2) Study period: 2-30 Apr 2020; (3) Model runs: REF + DAE, IDEA, DAI+IDAE aerosol effects included (see example on Fig. 8); (4) Sensitivity tests: time steps 300-240-180 sec (15 km), 150-120-90, 90-60-30 (2 & 1.5). Concluding remarks are the following: (i) Numerous feedbacks revealed in the atmosphere enhanced by aerosol compounds (emitted from wildfires); (ii) Aerosol effects show spatial non-homogeneity, dependence on meteorological conditions, and ratio of species; (iii) Outcomes – crucial for improving weather prediction considering aerosols’ influence & valuable for impact assessment on health and ecosystems in decision-making.

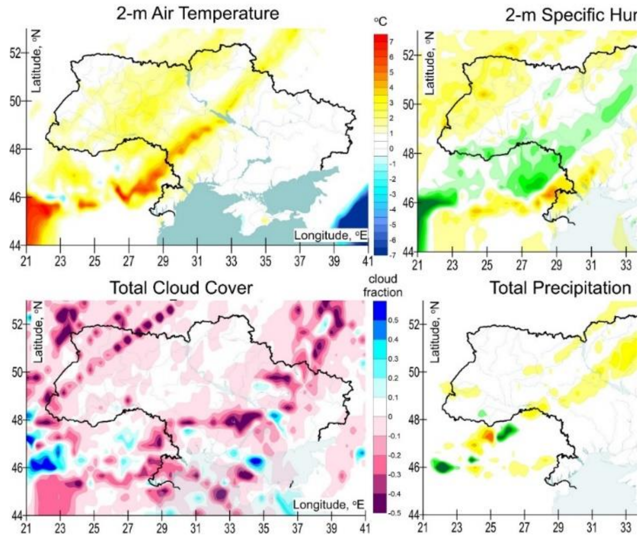
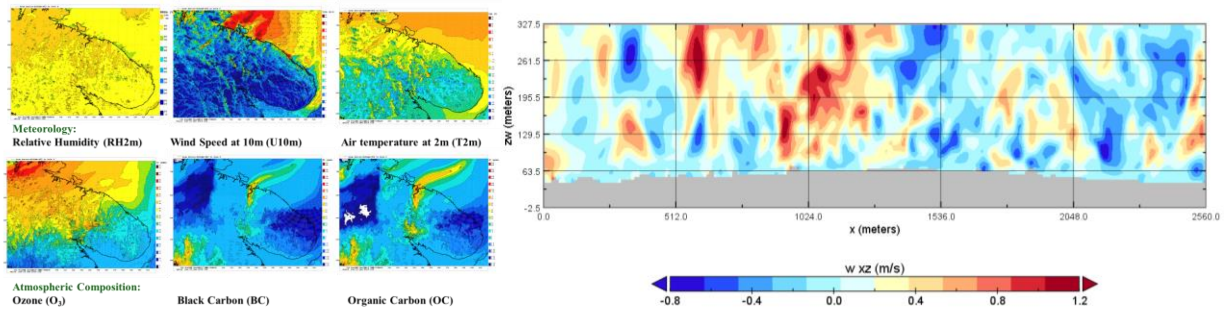


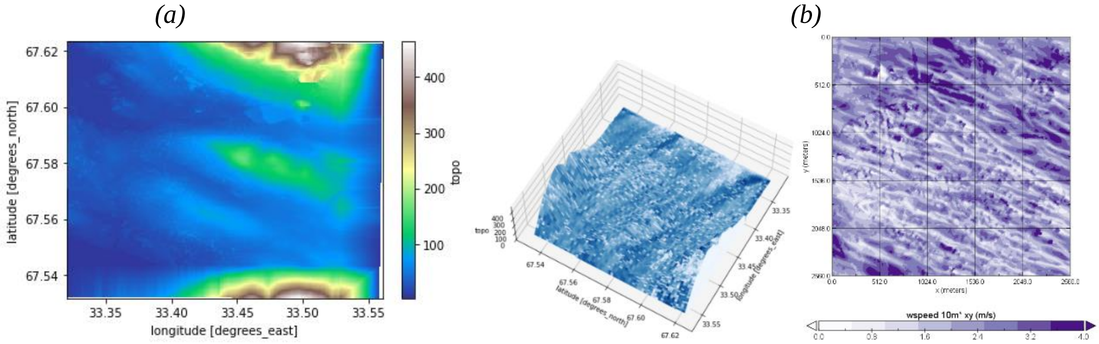
Figure 8*: Difference between Enviro-HIRLAM model runs (DAE+IDAE – REF) for selected meteorological parameters – air temperature at 2 m, specific humidity at 2 m, total cloud cover, and total precipitation (6h accumulated) – on 14 April 2020 (12UTC).*

9. Study: “High-Resolution Integrated Urban Environmental Modeling”

This study (*Esau et al., 2023+; Mahura et al. 2023a*) aims to integrate turbulence–resolving urban large-eddy simulation, LES (meter-scale; PALM) and meteorological (km-scale; Enviro-HIRLAM) simulations into a seamless modelling chain & to study urban climate and air quality with high-resolution (from km to m) numerical modelling and urban observational data fusion. Methods applied in this study include the following: (1) Seamless multi-scale (15-5-2 km res.) Enviro-HIRLAM modelling; (2) Study period: 1 Dec 2017 – 31 Jan 2018; (3) Model runs: REF + DAE, IDEA aerosol effects included (see example on Fig. 9a); (4) LES PALM modelling: modelling for Apatity urban area (see example on Fig. 9bcde).



(a) *(b)*

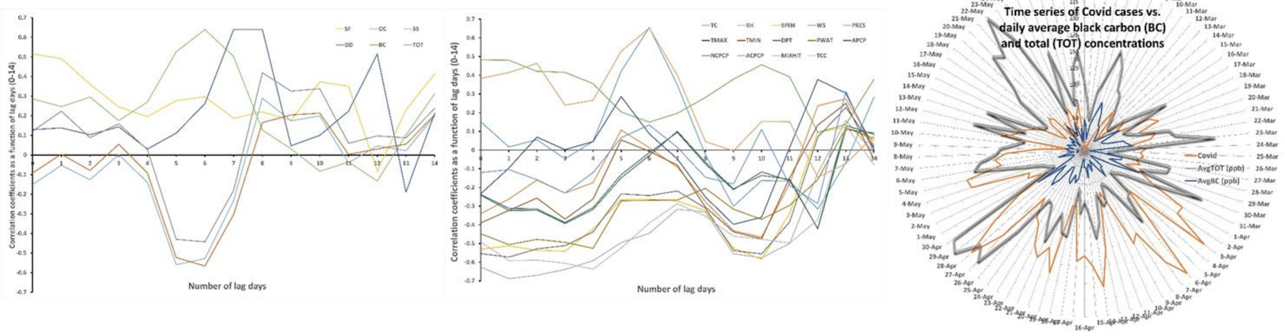


(c) *(d)* *(e)*

***Figure 9**: (a) Enviro-HIRLAM modelling results from downscaling to 2 km resolutions for selected meteorological and atmospheric composition parameters; (c) terrain over the Apatity urban area; and (b,d,e) PALM LES: (b) vertical wind velocity field, (d) friction velocity and (e) horizontal wind speed field at 10 m - over the Apatity urban area.*

10. Study: "Effects of Spring Air Pollution and Weather on Covid-19 Infection in Finland"

This study (*Heibati et al., 2023+; Mahura et al. 2023a*) aims to assess effects of meteorological (temperature, humidity and momentum regimes in the boundary layer) and air pollution (aerosol components) factors on covid19 cases in 20 hospital districts of Finland during spring 2020 (see Fig. 10 for examples). Methods applied in this study include the following: (1) Seamless subregional scale Enviro-HIRLAM modelling; (2) Study period: 1 March – 31 May 2020 with covid19 lockdowns; (3) Model runs: DAE+IDAE aerosol effects included; (4) Covid19 data: time-series of daily cases in 20 hospital districts of Finland in March-June 2020.

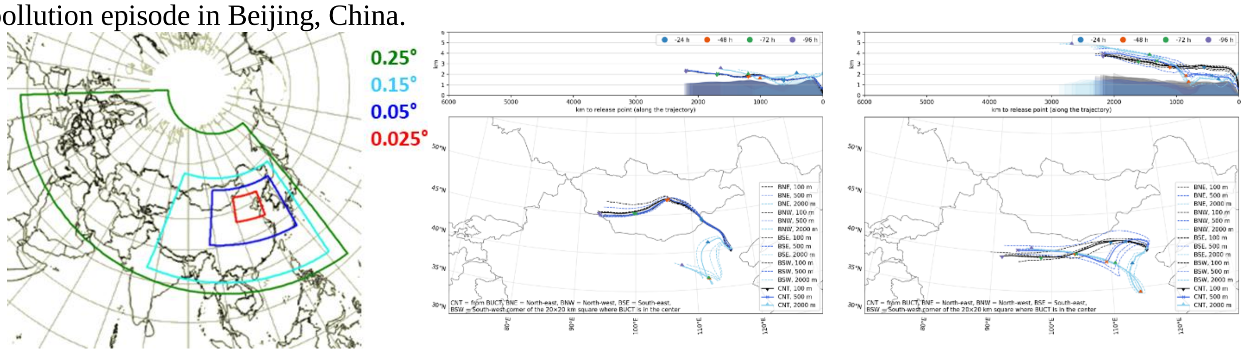


(a) (b) (c)

***Figure 10**: (a) Examples of correlation coefficients (for March 2020, with 0-14 lag days) for (a) aerosol components, and (b) meteorological parameters for the Helsinki Hospital District (Finland); (c) time-series of covid cases vs. daily average black carbon and aerosols' total concentrations.*

11. Study: "Enviro-HIRLAM meteorology for FLEXPART atmospheric trajectory calculations"

This study (*Foreback et al., 2024*) aims to integrate (develop method) the Enviro-HIRLAM modelled meteorology as input for FLEXPART's calculations of trajectories and dispersion of particles & to evaluate impact of aerosol effects on meteorology and trajectories. Methods applied in this study include the following: (1) Seamless downscaling (25-15-5-2+ km resol.) Enviro-HIRLAM modelling (see domains on Fig. 11a); (2) Study period: 1 Oct - 23 Nov 2018; (3) Model runs: REF, DAE, IDAE, DAE+IDAE aerosol effects included; (4) FLEXPART: atmospheric backward trajectory calculations (see examples on Fig. 11bc) for elevated pollution episode in Beijing, China.



(a) (b) (c)

***Figure 11**: (a) Enviro-HIRLAM downscaling modelling domains (25, 15, 5, 2.5 km horizontal resolutions; and (b,c) Atmospheric backward trajectories (96 hrs or 4 days) calculated by FLEX PART model based on (b) ERA-5 (0.25° resol.) and (c) Enviro-HIRLAM (reference run at 0.25° resol.) meteorological input arriving at heights of 100, 500 and 2000 m at 5 locations (i.e., BUCT, Beijing & the corners of a 20×20 km box with BUCT in the centre). Note, top panel shows altitude (ASL) and mean orography along the trajectories.*

12. Science Education with Enviro-HIRLAM model at Young Scientists School (YSS)

(1) The online YSS MEGAPOLIS-2021 on "Multi-Scales and -Processes Integrated Modelling, Observations and Assessment for Environmental Applications" in Memory of Prof. Sergej Zilitinkevich (1936-2021) took place during 15 Nov – 3 Dec 2021. The YSS introduced young generation of researchers to special topics in atmospheric and environmental sciences, Earth system modelling approaches and applications, especially considering transport and fate of small (micro) particles. During the school, participants learnt about the current progress and challenges in Earth system research; meteorological, hydrological and atmospheric composition modelling and observations (including ground-based and remote-sensing); and modern technologies for

environmental studies and assessments (including health impacts). The programme included a series of online theoretical lectures (24 in total) and remote work (19 Nov – 2 Dec 2021) on practical exercises as small-scale research projects (SSRPs, incl. Enviro-HIRLAM model) by students in groups/teams, with bi-weekly online consulting (by teachers). https://peexhq.home.blog/2021/12/15/megapolis-2021-school

(2) YSSchool (hybrid event, in Nov 2023) on "*Socio-Environmental Interactions in Sustainable Smart Cities*" – will include lecturing on seamless modelling, and Enviro-HIRLAM small-scale research projects (SSRPs) with focus on analysis of urban scale modelling results: i.e., impact of urban areas on meteorology and pollution patterns. https://peexhq.home.blog/2023/11/08/ursa-major-yss

(3) YSSchools on "*Multi-Scales and -Processes Integrated Modelling, Observations and Assessment for Environmental Applications*" have been included in a few proposals (with Nordic, COST, Europe Horizon, and national funding). In all these events, the lecturing on seamless modelling, and Enviro-HIRLAM SSRPs with focus on analysis of aerosol effects (direct, indirect, combined) on meteorology at regional-subregional-urbans scales – are included.

List of publications/reports from the project with complete references

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. (**2023+**): 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. (**2023+**): Covid-19 in urban Finland: Seamless modelling of meteorology and air pollution to estimate impacts. *Manuscript is in preparation*.

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Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The workplan outlined in the original proposal had been revised, because partners from Russia were excluded from the project.

Important note: some planned work (without Russian partners involvement) continued employing computing resources of the Center for Science Computing (CSC, Finland). The planned developments towards the PEEX-Modelling-Platform will provide additional scientific value for the numerical weather prediction, atmospheric composition forecasting, and climate modelling communities. In particular, simulations are expected for: (i) short-term case studies with physical and chemical weather downscaling forecasting to evaluate sensitivity of aerosol effects on meteorology, atmospheric composition and climate; (ii) episodes for weather, climate and air quality applications to evaluate possible effects; (iii) testing parameterisations, meteorological and chemical initial and boundary conditions, and chemical data assimilation.