SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	Reporting period from July 2022 to June 2023
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
Principal Investigator(s)	Dr. Alexander Mahura
Affiliation/ Address:	Institute for Atmospheric and Earth System Research (INAR) / Physics, Faculty of Science, University of Helsinki (UHEL), Finland Address: Physicum, Kumpula campus, Gustaf Hällströmin katu 2a, FI-00560 Helsinki Postal: P.O.Box 64, FI-00014, University of Helsinki, Helsinki, Finland
Name of ECMWF scientist(s) collaborating to the project (if applicable) & Other Researchers:	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.*
Start date of the project:	January 2021
Expected end date:	December 2023

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	4000 kSBU	901.182	4000 kSBU	0
Data storage capacity	(Gbytes)	9000	-	9000	-

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 (10 lines max)

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.

Summary of plans for the continuation of the project (10 lines max)

The workplan outlined in the original proposal has been revised, because partners from Russia were excluded from the project. **Important note**: some planned work will be 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.

List of publications/reports from the project with complete references

1st Reporting Period:

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*

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)*

2nd Reporting Period:

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 (**2021b**): 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., 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. (**2022**): 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.*

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.*

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). *Abstract submitted to Arctic Congress, Oct 2022, Moscow, Russia.*

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). *Abstract submitted to Arctic Congress, Oct 2022, Moscow, Russia.*

Savenets, M., Pysarenko, L., Krakovska, S., Mahura, A. (**2022**): 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, 2022.*

3rd Reporting Period:

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

Savenets, M., Pysarenko, L., Krakovska, S., Mahura, A., and Petäjä, T. (**2022**): 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, 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, 2023.*

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.*

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 feedbacks and interactions. Boundary-Layer Meteorology, 186, 475–503; https://doi.org/10.1007/s10546-022-00769-8.

Foreback B. et al. (**2023**): How crucial is the choice of input meteorology model when creating atmospheric trajectories with FLEXPART. *Manuscript is in preparation.*

Savenets M. et al. (**2023**): Seamless modelling of direct and indirect aerosol effects during April 2020 wildfire episode in Ukraine. *Manuscript is in preparation.*

Savenets M. et al. (**2024**): Urban effects on meteorology-aerosol feedbacks affected by elevated wildfire pollution. *Manuscript is in preparation*.
Heibati B. et al. (**2023**): Covid-19 in urban Finland: Seamless modelling of meteorology and air pollution to estimate impacts. *Manuscript is in preparation*.
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*.
Pysarenko L. et al. (**2023**): Seamless modelling of summer 2010 extreme weather events in Ukraine. *Manuscript is in preparation*.
Pysarenko L. et al. (**2024**): Meteorology-aerosol interactions during extreme March 2013 snowfall event in Ukraine. *Manuscript is in preparation*.
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*.
Mahura A., A. Baklanov, S.R. Arnold, R. Makkonen, M. Boy, T. Petäjä, V-M. Kerminen, H.K. Lappalainen, M. Jochum, R. Nuterman, A. Shvidenko, I. Esau, M. Sofiev, A. Stohl, T. Aalto, J. Bai, C. Chen, Y. Cheng, O. Drofa, M. Huang, L. Järvi, H. Kokkola, R. Kouznetsov, T. Li, K.S. Madsen, P. Malguzzi, S. Monks, S.B. Nielsen, S.M. Noe, Yu. Palamarchuk, T.S. Rasmussen, J. She, J.H. Sørensen, D. Spracklen, H. Su, J. Tonttila, S. Wang, J. Wang, T. Wolf-Grosse, Y. Yu, Q. Zhang, W. Zhang, W. Zhang, X. Zheng, P. Zhou, S. Zilitinkevich, M. Kulmala (**2023**): PEEX Modelling Platform for Seamless Environmental Applications. *Manuscript is in preparation*.

Summary of results (from June 2022 to June 2023)

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 taking into account society interactions. Available observations for atmosphere and ecosystems (in particular, from the SMEAR-type stations and PEEX metadatabase 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., 2022, 2023a*) for different research tasks according to the PEEX Science Plan (https://www.atm.helsinki.fi/peex/images/PEEX_Science_Plan.pdf).

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

This study (Pysarenko et al., 2023, 2024) 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. 2). 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.

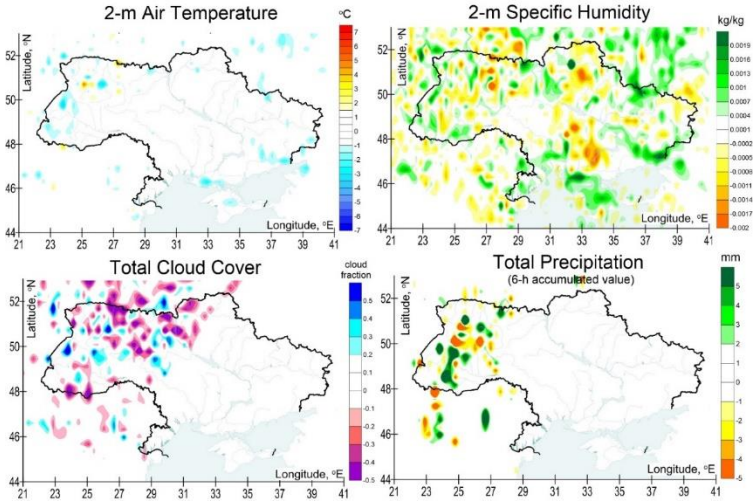


***Figure 2**: Impact of total deforestation on selected meteorological parameters – air temperature at 2 m, specific humidity at 2 m, total cloud cover, and total precipitation (6h accumulated) – on 1 August 2010 (12UTC) (for differences between Enviro-HIRLAM model runs: TOT_DEF – REF)).*

3. Study: "Integrated Modelling for Assessment of Potential Pollution Regional Atmospheric Transport as Result of Accidental Wildfires"

This study (*Savenets et al., 2023, 2024*) 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. 3); (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.

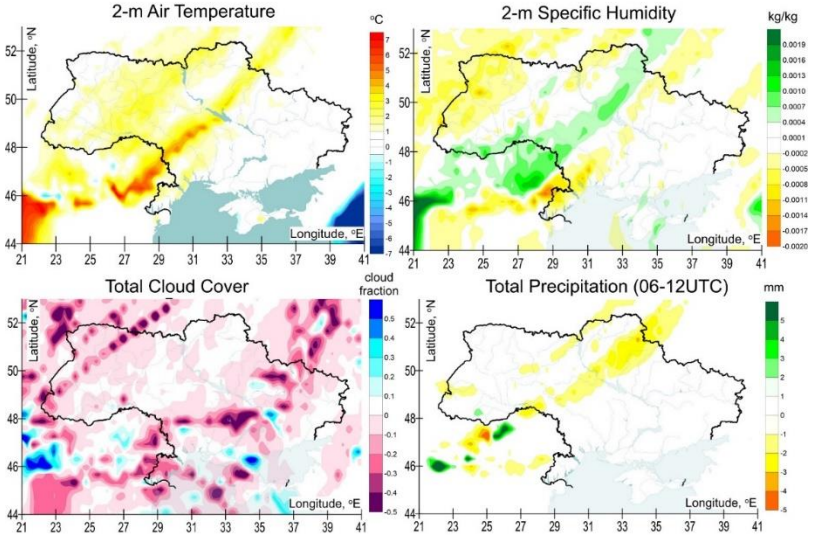


***Figure 3**: Difference between Enviro-HIRLAM model runs (DAE+IDAE – REF) for selected meteorological parameters – air temperature at 2 m, specific humidity at 2 m, total cloud cover, and total precipitation (6h accumulated) – on 14 April 2020 (12UTC).*

4. Study: "High-Resolution Integrated Urban Environmental Modeling"

This study (*Esau et al., 2023*) 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. 4a); (4) LES PALM modelling: modelling for Apatity urban area (see example on Fig. 4bcde).

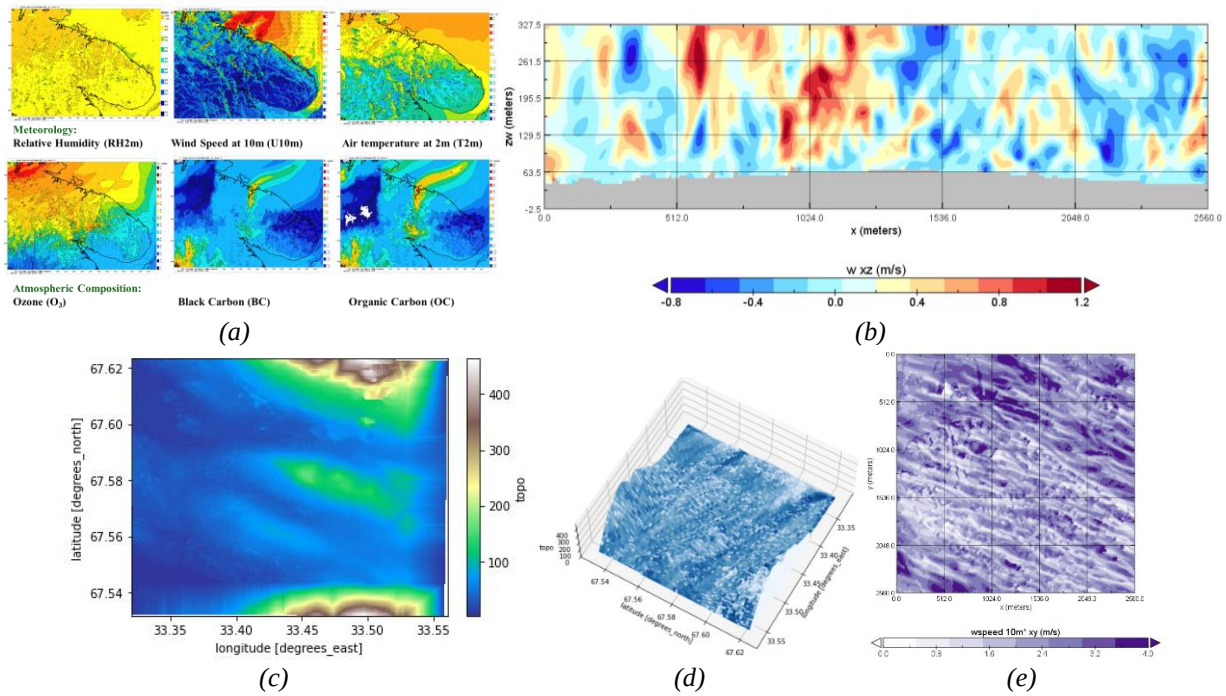


Figure 4*: (a) Enviro-HIRLAM modelling results from downscaling to 2 km resolutions for selected meteorological and atmospheric composition parameters; (c) terrain over the Apatity urban area; and (b,d,e) PALM LES: (b) vertical wind velocity field, (d) friction velocity and (e) horizontal wind speed field at 10 m - over the Apatity urban area.*

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

This study (*Heibati et al., 2023*) 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. 5 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.

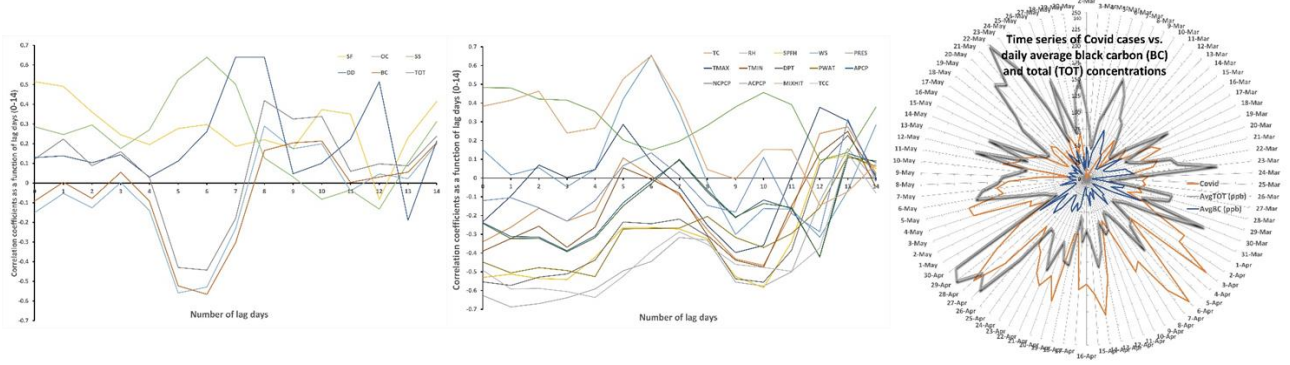
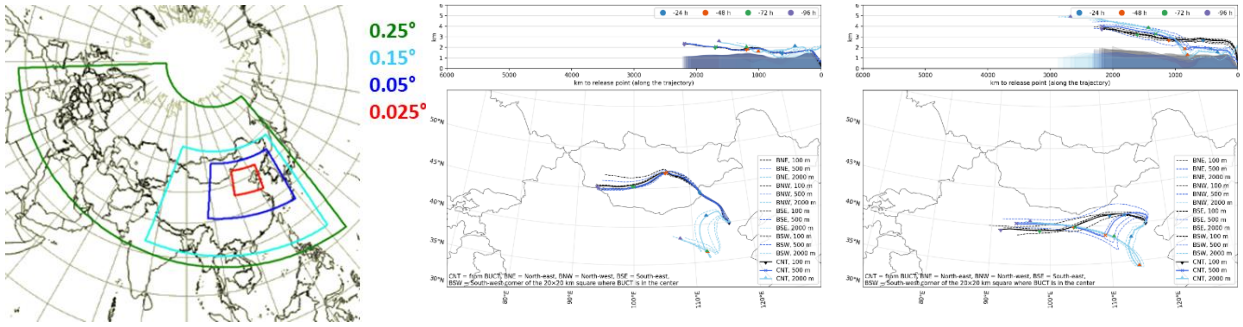


Figure 5*: (a) Examples of correlation coefficients (for March 2020, with 0-14 lag days) for (a) aerosol components, and (b) meteorological parameters for the Helsinki Hospital District (Finland); (c) time-series of covid cases vs. daily average black carbon and aerosols' total concentrations*.

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

This study (*Foreback et al., 2023*) 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. 6a); (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. 6bc) for elevated pollution episode in Beijing, China.



(a) *(b)* *(c)*

***Figure 6**: (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.*

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

There are two planned events where the Enviro-HIRLAM model will be used in educational process:
(1) Nov 2023 YSSchool (hybrid events) 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. The is event is a part of the
(2) Autumn 2024 YSSchool (onsite event) on "*Multi-Scales and -Processes Integrated Modelling, Observations and Assessment for Environmental Applications*" – will include 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.