SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	Reporting period from July 2018 to June 2019
Project Title:	**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)*
Computer Project Account:	SPFIMAHU
Principal Investigator(s)	Dr. Alexander Mahura
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Name of ECMWF scientist(s) collaborating to the project (if applicable) & Other Researchers:	Risto Makkonen, Jukka-Pekka Keskinen, Michael Boy, Roman Nuterman, Eigil Kaas, Serguei Ivanov, Igor Ruban, Larisa Poletaeva, Julia Palamarchuk, Eugeny Kadantsev, Sergej Zilitinkevich, Kairat Bostanbekov, Daniyar Nurseitov, Rossella Ferretti, Gabriele Curci, Sergey Smyshlayev, Georgy Nerobelov, Margarita Sedeeva, Natalia Gnatiuk, Svitlana Krakovska, Larysa Pysarenko, Mykhailo Savenets, Anastasia Chyhareva, Olga Shevchenko, Sergiy Snizhko, Alexey Penenko, Huseyin Toros, Sergey Chalov, Pavel Konstantinov, Putian Zhou, HIRLAM-C members
Start date of the project:	January 2018
Expected end date:	December 2020

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	353.185	4000 kSBU	495.931
Data storage capacity	(Gbytes)	9000	-	9000	-

Summary of project objectives
(10 lines max)

The main objectives of the Enviro-PEEX 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: (i) improved numerical weather prediction with short-term feedbacks of aerosols and chemistry on formation and development of meteorological variables; (ii) improved atmospheric composition forecasting with on-line integrated meteorological forecast and two-way feedbacks between aerosols/chemistry and meteorology; (iii) coupling of aerosols and chemistry in Earth System modelling, 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.

Summary of problems encountered (if any)
(20 lines max)

None of problems were encountered.
The current “Enviro-PEEX” project required to establish a linkage with the National Meteorological Service of Finland (Finnish Meteorological Institute, FMI), and to follow the procedures for issuing and activating of new ECWMF tokens, 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.

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

The workplan outlined in the proposal will be continued according to the planned tasks and deliverables. These 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 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; and (iii) testing of parameterisations, meteorological and chemical initial and boundary conditions, and chemical data assimilation.

List of publications/reports from the project with complete references

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

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

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

Mahura A., A. Baklanov, S.R. Arnold, R. Makkonen, M. Boy, T. Petäjä, V-M. Kerminen, H.K. Lappalainen, M. Jochum, R. Nuterman, A. Schvidenko, I. Esau, E. Gordov, A. Titov, I. Okladnikov, V. Penenko, A. Penenko, M. Sofiev, A. Stohl, T. Aalto, J. Bai, C. Chen, Y. Cheng, M. Cherepova, O. Drofa, M. Huang, L. Järvi, H. Kokkola, R. Kouznetsov,

T. Li, K.S. Madsen, P. Malguzzi, K. Moiseenko, S. Monks, S. Myslenkov, G. Nerobelov, S.B. Nielsen, S.M. Noe, Y. Palamarchuk, E. Pyanova, T.S. Rasmussen, J. She, A. Skorohod, S. Smyshlyaev, J.H. Sørensen, D. Spracklen, H. Su, J. Tonttila, E. Tsvetova, S. Wang, J. Wang, T. Wolf-Grosse, Y. Yu, Q. Zhang, W. Zhang, W. Zhang, X. Zheng, P. Zhou, S. Zilitinkevich, M. Kulmala (**2018c**): PEEX Modelling Platform for Seamless Environmental Prediction. *Atm Chem & Phys Discuss, acp-2018-541, 49 p., Manuscript in Review.*

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

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

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

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

Nerobelov G., A. Mahura, R. Nuterman, S. Smyshlyaev (**2019a**): Online-integrated modeling of aerosols feedbacks for the St. Petersburg, Moscow and Helsinki metropolitan areas. *Manusript in preparation.*

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

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

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

Sedeeva M., Mahura A., Nuterman R., Mostamandi S., Smyshlyaev S. (**2019b**): "Modelling and GIS evaluation of regional pollution from Kola peninsula". *RSHU Scientific Reports (in Russian), In Review.*

Summary of results

(from July 2018 to June 2019)

1. Conceptual continued: "The Pan-Eurasian Experiment Modelling Platform (PEEX-MP)"

The PEEX-MP (https://www.atm.helsinki.fi/peex/index.php/modelling-platform) is one of key blocks of the PEEX Research Infrastructure. It includes more than 30 different models. The approach taken is directed towards the concept of the online integrated or seamless environmental prediction (*Mahura et al., 2018acd*). The PEEX-MP models cover several main components of the Earth's system such as the atmosphere, hydrosphere, pedosphere and biosphere and resolve the physical-chemical-biological processes at different spatial and temporal scales and resolutions. The Earth system, online integrated, forward/ inverse, and socio-economical modelling, and other approaches are applicable for the PEEX domain studies. The employed high performance computing facilities and capabilities as well as dataflow for modelling results are of importance. Several virtual research platforms are useful for handling modelling and observational results. The proposed combined overall approach allows to better understand physical-chemical-biological processes, Earth's system interactions and feedbacks, and to provide valuable information for assessment studies on evaluation of risks, impact, consequences, etc. for population, environment and climate in the PEEX domain of interests.

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 (Figure 1). The on-line integrated/ 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 models runs 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. The models are also planned to be further developed and applied for different research tasks according to the PEEX Science Plan (https://www.atm.helsinki.fi/peex/images/PEEX_Science_Plan.pdf).

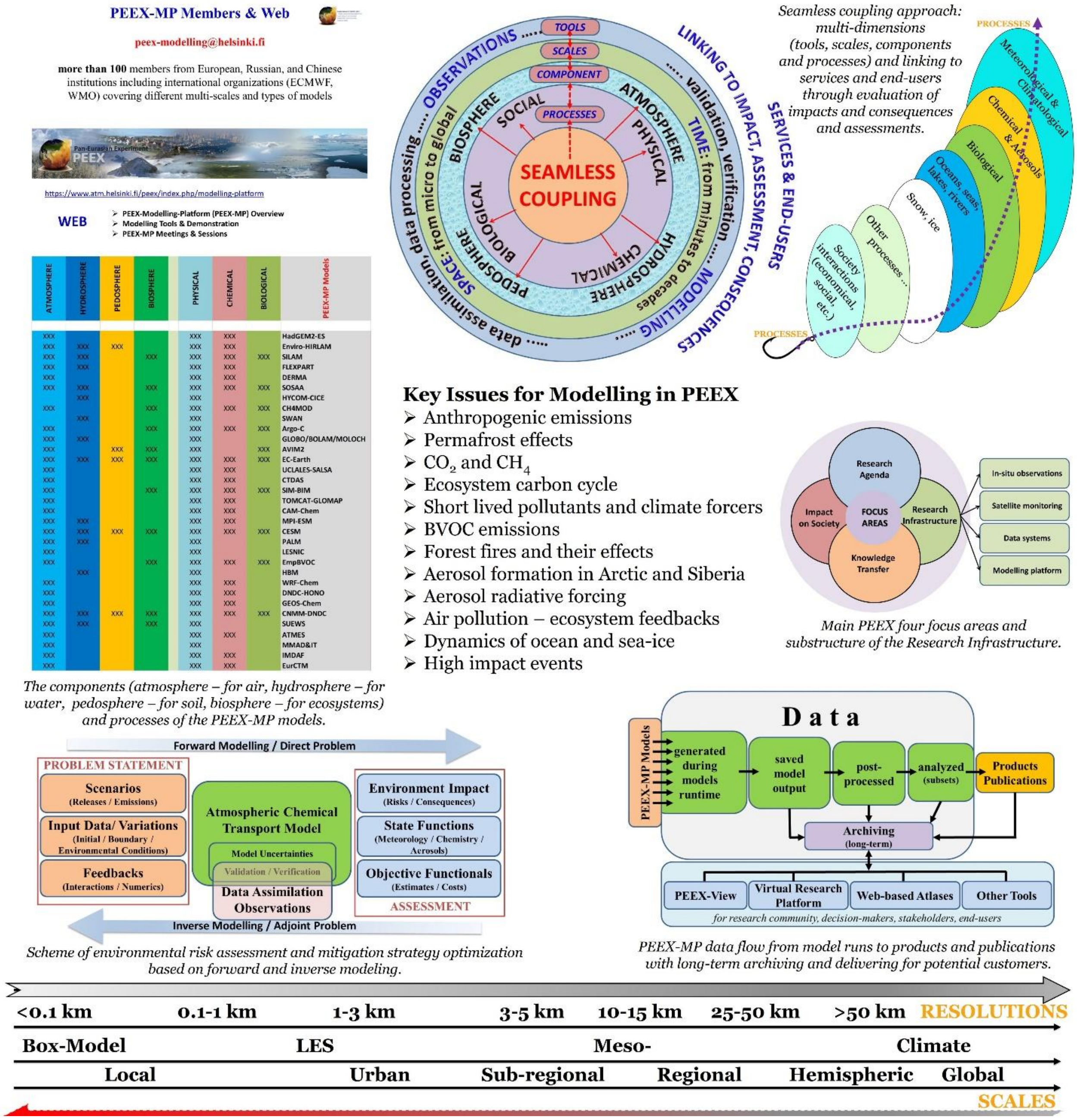

Figure 1: *PEEX-MP approach for multi-scale and –processes modelling.*

At INAR-UHEL, in particular, a number of application areas of new integrated modelling developments are expected, including research and developments for: (i) improved numerical weather prediction and chemical weather forecasting with short-term feedbacks of aerosols and chemistry on meteorological variables; (ii) two-way interactions between atmospheric pollution/ composition and climate variability/ change; (iii) better prediction of atmosphere and/or ocean state through closer coupling between the component models to represent the two-way feedbacks and exchange of the atmospheric and ocean boundary layer properties; (iv) more complete/ detailed simulation of the hydrological cycle, through linking atmospheric, land surface, ecosystems, hydrological and ocean circulation models.

2. Study: “Mesoscale resolution radar data assimilation experiments with the HARMONIE modelling system”

The quality of numerical weather forecasts is crucially dependent on several factors, and data assimilation remains in the first line, and especially for mesoscale atmospheric modeling with a fine resolution of order a kilometer.
In this study, a pre-processing approach was adopted for the radar reflectivity data assimilation and results of simulations with the HARMONIE numerical weather prediction model are analysed (*Ivanov et al., 2018b)*. Briefly summarising, the proposed method creates a 3D regular grid in which a horizontal size of meshes coincides with the horizontal model resolution. This minimizes the representative error associated with the discrepancy between resolutions of informational sources. After such pre-processing, horizontal structure functions and their gradients for radar reflectivity maintain the sizes and shapes of precipitation patterns similar to those of the original data. The method shows an improvement of precipitation prediction within the radar location area in both the rain rates and spatial pattern presentation. It redistributes precipitable water with smoothed values over the common domain since the control runs show, among several sub-domains with increased and decreased values, correspondingly. It also reproduces the mesoscale belts and cell patterns of sizes from a few to ten kilometers in precipitation fields. With the assimilation of radar data, the model simulates larger water content in the middle troposphere within the layer from 1 km to 6 km with major variations at 2.5 km to 3 km. It also reproduces the mesoscale belt and cell patterns of precipitation fields.

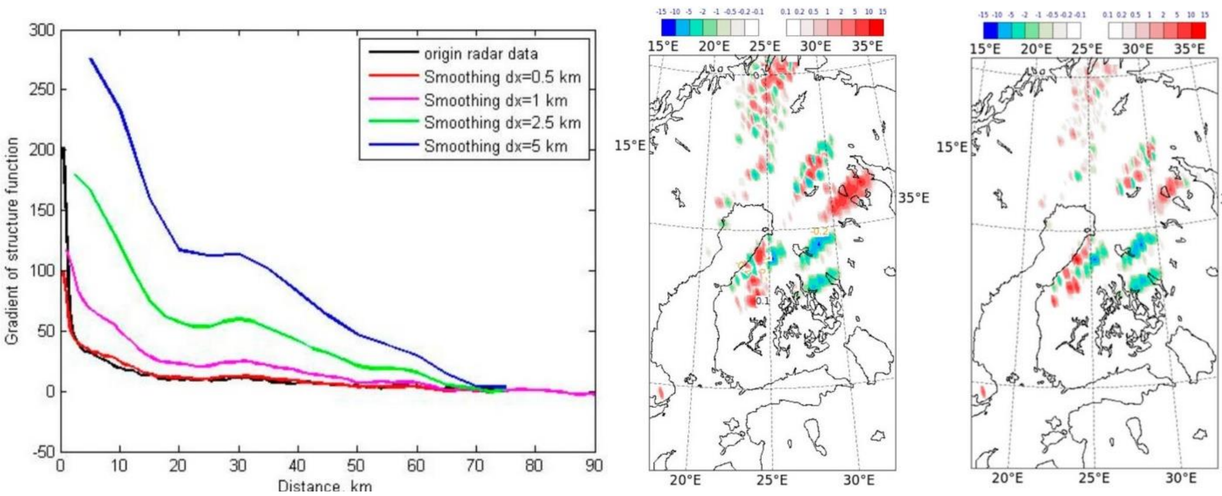

Figure 2: *(left) Gradients of structure functions of radar reflectivity measurements for original data and after pre-processing with various smoothing parameters; & Spatial distribution of surface precipitation over the Finnish domain for 14 August 2010, 18 UTC for differences between runs: (middle) FINE-CNTR, (right) COARSE-CTRL.*

In this research, the focus was on optimizing the inner parameters of the pre-processing procedures. In pursuing the compatibility between the model resolution and smoothed radar observation density, the “cube-smoothing” approach has been proposed. It promotes the presentation of radar measurements on a regular grid at a resolution equal to that of the model’s grid. This ensures the equivalent presentation of precipitation (reflectivity) structures in both spaces such as the model and observation in the sense of equally preserving the scales of precipitation patterns. From the spectral point of view for spatial frequencies (wave numbers), this implies an equal cut-off of a high-frequency band in the model and in the observation fields. In this way, at least, one component of the forecast error associated with the representativeness error minimized.
The carried out numerical experiments exhibited better simulation of mesoscale cells and belts of precipitation vs. the respective control/ reference runs (Figure 2). In particular, instead of one large area with smoothed values for rain rates, the improved assimilation approach was allowed to specify and redistribute precipitable water among several sub-areas. However, precise verification still remains an issue due to several reasons including being the instrumental error and transient functions for radar measurements as well as the dominating sizes of precipitation patterns in particular regions and under certain atmospheric flow regimes. The latter will be the focus of further studies.

3. Study: "Modelling of aerosols impact on atmospheric processes on regional and urban scales with focus on metropolitan areas"

In this study, the main aim was to evaluate the aerosols influence on the meteorological parameters (such the air temperature on 2 m, specific humidity, total cloud cover, and precipitation) with regional focus and then zooming for the St. Petersburg and Moscow (Russia) and Helsinki (Finland) metropolitan areas. The modelling of the aerosols influence was performed using the Enviro-HIRLAM modelling system, which was setup over domain covering most of the European part of Russia, Scandinavia, and Eastern European countries. These simulations were realized in long-term (months of January and June 2010) modes. The simulation as 4 model runs were made: control/reference (CTRL); with the direct aerosol effect (DAE), with the indirect aerosol effect (IDAE), and with both effects included (COMB).

Analysis of the modelling results was performed and the most important findings on the aerosols influence are the following (*Nerobelov 2019; Nerobelov et al., 2019ab*). On the regional scale, in August the influence of aerosols mostly showed decrease in the air temperature and total cloud cover due to DAE and increase due to IDAE and COMB effects. In general, the specific humidity increased for DAE, but decreased for IDAE and COMB. As for precipitation, it showed decrease under all these effects. In January, the influence of aerosols showed mainly decrease in air temperature, specific humidity, and total cloud cover due to DAE and increase due to IDAE and COMB effects. Similarly to summer month, precipitation showed decrease for all three effects compared with CTRL run.

When approaching and downscaling to selected urban areas, in August, the observed changes of meteorological parameters were more pronounced for Moscow compared with St. Petersburg and Helsinki. In case of DAE, all considered meteorological parameters showed decrease for St.Petersburg; for Moscow – all, except the air temperature; and for Helsinki – all, except precipitation. In case of IDAE, all, except the total cloud cover, showed decrease for St.Petersburg; and all, except specific humidity and precipitation, showed increase for Moscow and Helsinki. As for COMB effects, all parameters, except total cloud cover showed decrease for St.Petersburg and Helsinki; and all except specific humidity and precipitation showed increase for Moscow. In January, in case of DAE, for all 3 considered metropolitan areas all parameters showed mostly decrease, except precipitation for St.Petersburg. In case of IDAE, all parameters showed increase except precipitation in Helsinki. And in case of COMB, all parameters showed also decrease except precipitation in Helsinki and air temperature in Moscow.

As shown on example, the differences between the Enviro-HIRLM model runs (simulation outputs) is shown in Figure 3, where aerosol effects can lead to decreases in precipitation up to 20 mm. sim

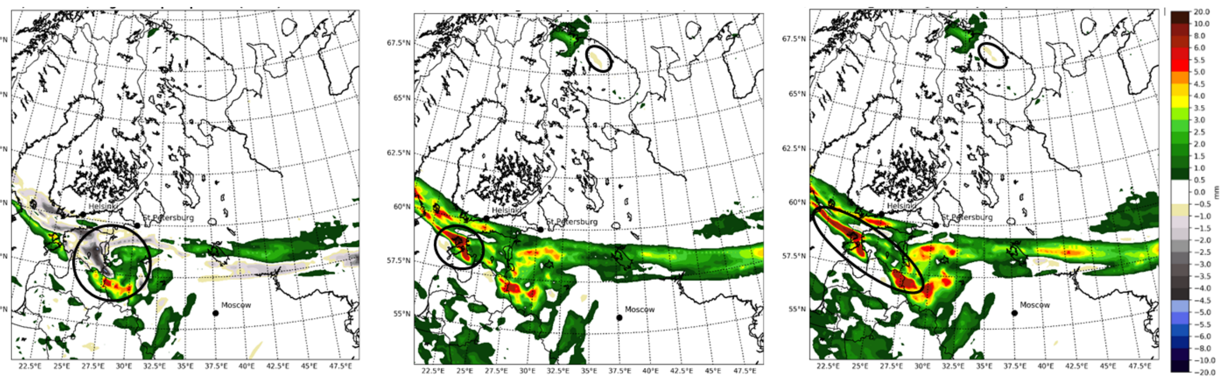

Figure 3: *Difference fields for precipitation between the control/reference vs. (from left to right) DAE, IDAE, and COMB Enviro-HIRLAM model runs on 18 August 2010, 18 UTCs.*

Participation in the Enviro-HIRLAM/ HARMONIE research training (2-28 April 2019) at the Institute for Atmospheric and Earth System Research (INAR), University of Helsinki (UHEL) provided useful theoretical and practical aspects of the modelling system adaptation, testing and running.

4. Study: "Modelling and evaluation of aerosols impact vs. atmospheric pollution on regional scale"

In this study, the main aim was to model and evaluate atmospheric pollution from continuous sources of emissions (linked to enterprises on the Kola Peninsula, Russia) and wet deposition of sulphates aerosols on surfaces of water objects. The Enviro-HIRLAM model was setup over domain covering the North-West Russia and Scandinavian countries. Long-term regional scale simulations were performed for months of January and June 2010. The obtained modelling results were integrated into GIS environment (with QGIS tool) as independent layers of meteorological and pollution parameters. and analysis of spatio-temporal changes in concentration of sulphur dioxide vs. meteorological parameters and wet deposition of sulphates over water objects were investigated.

Analysis of the modelling results was performed and the most important findings are the following (*Sedeeva 2019; Sedeeva et al., 2019ab*). Terms with elevated concentrations of SO_2, had more frequently corresponded to terms with maximum air temperature in January and August 2010. In August, the larger number of tansboundary atmospheric transport episodes between Russian and Scandinavian countries were observed. On average, more higher concentrations were observed over the Kola Peninsula in a proximity to sources compared with January. In January compared with August the atmospheric transport of pollution more frequently took place towards aquatorias of Barents, Norwegian, and White Seas. Analysis of permissible levels for SO_2 concentration showed that more frequently it was observed for Kola (12 cases) compared with norther provinces of Norway (1 case) for both summer and winter months combined. The largest number of cases as well as maximum concentrations were identified for settlement of Nickel (in August) and Zapolyarnyy (in January). Examples of Enviro-HIRLAM model simulations for both pollution and meteorology for selected dates of January and August 2010 are shown in Figure 4.

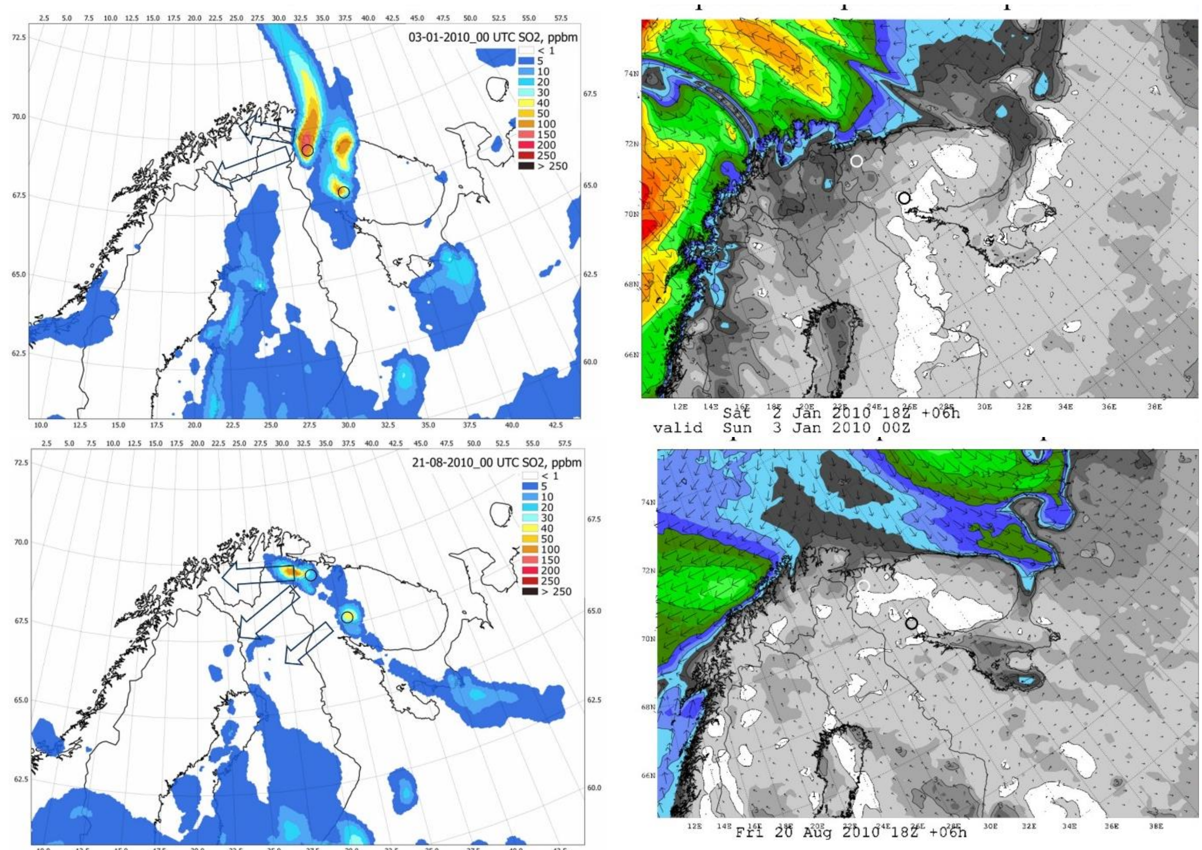

Figure 4. *Examples of Enviro-HIRLAM simulated (left-column) sulphur dioxide concentration and (right-column) wind characteristics (i.e. wind speed and wind direction, by arrows) within the periods (top: 3-4 January & bottom: 21-7 August 2010).*

The wet deposition more frequently took place in August, and larger amounts of sulphates on some days were washout/rainout on the underlying surface, and in particular, of water objects such as lakes, river and water reservoirs. In particular, the largest amount was for the Finnish Lake Inarijarvi and corresponded to 47 and 2.4 kg/km^2 in August and January, respectively. In Murmansk region, for the Verkhnetulomskoe reservoir it was 22.5 and 0.8 kg/km^2 for the same months. The values for

Norwegian Lake Iesjavri are comparable with Russian, and these are about 24.5 and 2 kg/km^2. For Swedish Lule River, it was 5.6 and 0.6 kg/km^2 for August and January, respectively.

Participation in the Enviro-HIRLAM/ HARMONIE research training (2-28 April 2019) at the Institute for Atmospheric and Earth System Research (INAR), University of Helsinki (UHEL) provided useful theoretical and practical aspects of the modelling system adaptation, testing and running.

5. Study: "Energy Flux Balance scheme for stable boundary layer in the northern latitudes"

In the northern latitudes, and especially in Arctic and Sub-Arctic regions, the operational forecasting of weather conditions requires improvements in the physics core of numerical weather prediction models. During winter-time, and especially, during polar night period the stable boundary layer conditions might be dominating in these high-latitudes areas.

The Energy Flux Balance (EFB) scheme is implemented and tested for the HARMONIE model at high horizontal resolution of 2 km. The 1D MUSC single column model is to be tested with the HARMONIE modelling system for cases of idealised and stable conditions (using GABLS dataset). For the EFB module implementation, the focus was on modification in physics subroutines, prognostic variables, and matching length scales between stable/ neutral/ convective conditions.

At second stage, the same 1D MUSC will be implemented in the HARMONIE-43h model. This version of the model is to be used as one of operational model setups at FMI. A series of sensitivity tests will be performed. At third stage, the focus is on 3D case, and the HARMONIE model setup will be linking to domain of AROME-Arctic (with focus on the northern territories of the Scandinavian and Kola Peninsulas). The selected period for simulations is December-January with prevailing low wind conditions. Moreover, the sensitivity tests will be also done for different horizontal resolutions of 2, 1.5 and 1 km with tuning of the model at finer scales.

6. Study: "Modelling elevated pollution episodes due to forest fires emissions from remote sources"

Forest fires might have natural and man-made causes of origin. Uncontrollable and lengthy in time emissions due to forest fires can lead to increased levels of pollution not only in a vicinity, but also can be transported through the atmosphere on long distances from the original source location.

The Enviro-HIRLAM model was run for elevated pollution period in Ukraine (7–17 August 2010) in two modes: reference/control and direct aerosol effect (DAE) included. The chosen model domain (Figure 5) almost covers European territory, and is elongated for considering the atmospheric circulation in middle latitudes. It consists of 190 x 240 grids along longitude x latitude with 15-km horizontal resolution, and time step of 120 sec; and vertically covers 40 levels. There were analyzed black carbon distribution in Aitken and accumulation modes above territory of Ukraine during selected period of August 2010. The observed and modelled elevated pollution levels at measurement stations were the result of atmospheric transport of the forest fire emissions from the northeast towards Ukraine (Figure 5).

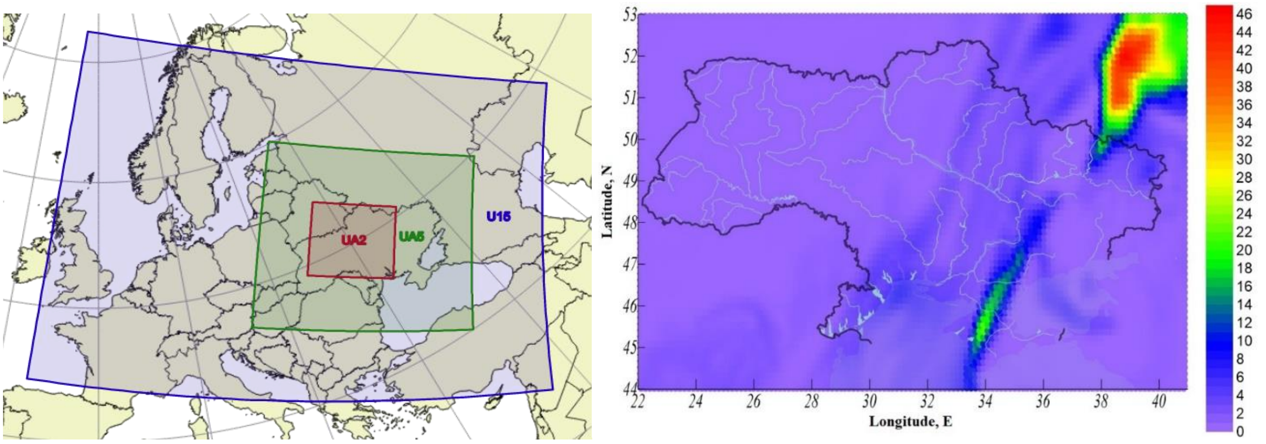

***Figure 5**. (left) Setup for downscaling over 3 geographical areas, and (right) Enviro-HIRLAM modelled black carbon concentration (in ppbm) in accumulation mode zoomed over the Ukrainian territory on 8 August 2010.*

Three main burning areas were identified, which caused intense black carbon atmospheric transport towards Ukraine during August 7-8 and August 13-16. Dominating during these periods anticyclonic conditions and regional circulation patterns determined features of the black carbon dispersion. In Ukraine, maximum values of accumulation mode were observed in the boundary layer in the northern part of domain and these reached concentrations of 70–150 ppbm. The analysis of vertical distribution showed clear identification of elevated black carbon content in the lower and middle troposphere up to the 600 hPa level.

Participation in the Enviro-HIRLAM/ HARMONIE research training (20–25 August 2018) at the Institute for Atmospheric and Earth System Research (INAR), University of Helsinki (UHEL) provided useful theoretical and practical aspects of the modelling system setup, testing and running. Enviro-HIRLAM model generated output was also used for realization of research project "*Influence of Land cover changes on Atmospheric Boundary Layer and Regional Climate Characteristics*" (InLandOnABL&RCC) within the Environmental Research Infrastructures across Europe (ENVRIplus).