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 2019 to June 2020
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	495.931	4000 kSBU	389.785
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 activities. 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*

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

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

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

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

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

Mahura A., R. Nuterman, G. Nerobelov, M. Sedeeva, S. Smyshlayev, M. Savenets, L. Pysarenko, S. Krakovska, S. Ivanov, S. Michaelides, I. Ruban, A.S. Sassi, R. Makkonen, A. Baklanov, T. Petaja, S. Zilitinkevich, M. Kulmala (**2019**): Integrated Multi-Scale Modelling for Meteorology-Chemistry-Aerosols Interactions. *In Proceedings of the CoE-ATM 2019, pp. 425-429; (Eds) T. Laurila, A. Lintunen, M. Kulmala. Report Series in Aerosol Science, N226 (2019), 817 p., ISBN 978-952-7276-34-1*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Summary of results (from July 2019 to June 2020)

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., 2018abc; 2019, 2020ac*). 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. In particular, the revision of the PEEX-View platform is undergoing with a possibility to include DIVA (Data

Integration-Visualization-Analysis) service for in-situ, remote, sensing, and modelling data. 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 geographical domain of interests.

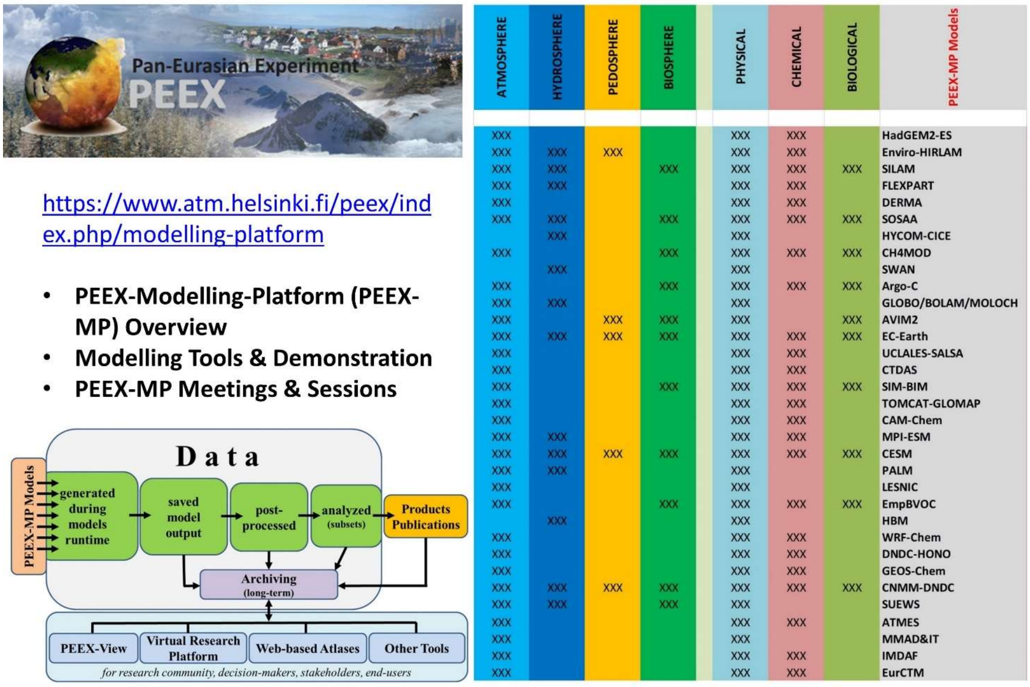


Figure 1: *PEEX-Modelling-Platform (PEEX-MP): modelling data flow including generation, storage, post-processing analyzing, and visualization steps & different types of models for multi-components, -processes and -scales modelling.*

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 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 (Figure 1) 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).

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: "Implementation of weather radar assimilation into weather prediction system"

Quantitative precipitation forecasting is among the most central challenges of atmospheric prediction systems. The main aim is a generation of accurate estimates of heavy precipitation events associated with severe weather, atmospheric fronts and heavy convective rainfalls. Weather radars are useful for short-range forecasting and nowcasting. Radars have the capability to monitor precipitation, resolving local scale features, with good spatio-temporal details and a wide scanning range.

In this study, the first results with the regional radar signal processing chain that provides the radar data assimilation (RDA) in the HARMONIE model are presented (*Ivanov et al., 2020*). The Data Assimilation (DA) technique includes 1D retrieval followed by a 3D variational assimilation of a volume of radar reflectivity data. The pre-processing approach additionally creates a regular cube grid in which the horizontal mesh size coincides with the corresponding model resolution. This minimizes the error arising due to resolution mismatch between different data sources.

The numerical experiments exhibit effective simulation of precipitable water at different stages of the cyclone development. In particular, the major rain volume is related to the cyclone frontal zone followed by weaker precipitation and secondary enhanced rainfall. During the whole severe weather period, the rainfall minimum was kept over highlands, reflecting the importance of interactions and feedbacks between the air flow and orography.

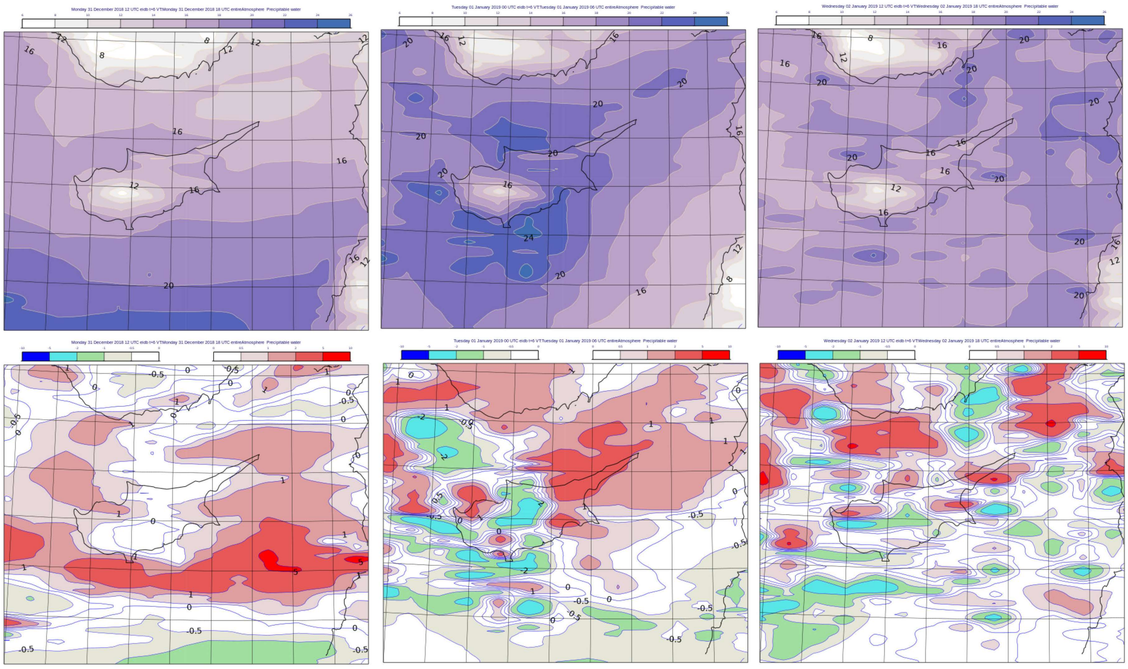


Figure 2: *Example of the HARMONIE modelled precipitable water vapor field (top) & impact of the radar data assimilation (bottom) over the Eastern Mediterranean.*

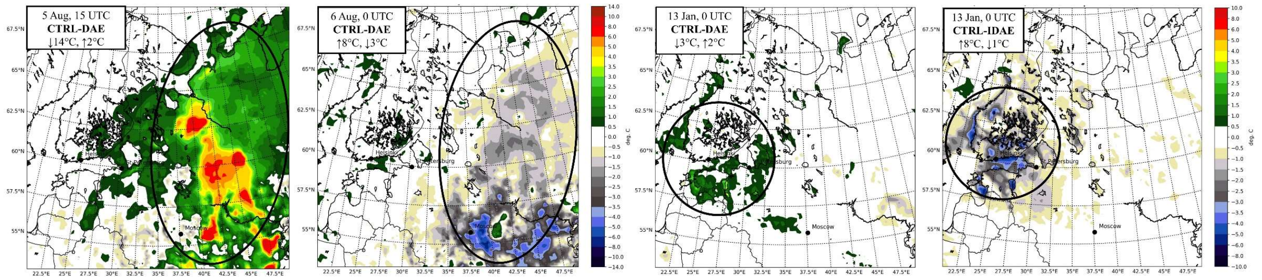
The RDA influences the results of the simulations, and an example of the HARMONIE modelled precipitable water vapor field and impact of the radar data assimilation over the Eastern Mediterranean region is shown in Figure 2. This depends on a particular area, stage of cyclone genesis and precipitation intensity. The largest changes due to RDA occur with the cyclone's frontal zone approach. Enhancement of rainfall can be observed over a large area, but it is more pronounced in weaker precipitation locations. The impact is associated with the shift of the precipitation maximum toward higher values in the rain rate distribution, which is accompanied with enlarged sizes of areas with stronger precipitation. During the mature stage and at rear zone of cyclone, the integrated RDA impact over the whole domain is almost negligible but takes the form of mesoscale patches of opposite signs. At this stage, radar measurements yield an alteration of both the positions and rates of spatial precipitation fields, which result in intermittent mesoscale changes.

3. Study: "Aerosols influence on meteorological parameters"

The territory of the North-West Russia contains a plenty of different industries and this region together with Finland was chosen to investigate aerosol effects. In addition, influence of aerosols on selected Russian (St.Petersburg and Moscow) and Finnish (Helsinki) metropolitan areas. In general, summer and winter months in 2010 showed unfavourable meteorological situations more frequently compared with other months. In this study, the main aim was to evaluate the aerosols influence on the meteorological parameters related to temperature, humidity, cloudiness, and precipitation). For simulations, the Enviro-HIRLAM model was used in 4 model runs: control/reference (CTRL); with the direct aerosol effect (DAE), with the indirect aerosol effect (IDAE), and with both effects included (COMB). Results of analysis are summarized by *Nerobelov (2019); Nerobelov et al. (2019, 2020ab).*

It was revealed that aerosols' influence was more significant in August 2010. The DAE effect decreased air temperature, when the IDAE and COMB increased it. DAE also increased specific humidity. By contrast, the IDAE and COMB decreased specific humidity in this month. All 3 effects can lead to both increase and decrease of cloudiness, and especially over the urban areas. And all 3 effects can lead to changes in precipitation patterns, both in intensity and spatio-temporal distribution.

For 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. All changes have also showed some variability on a diurnal cycle.



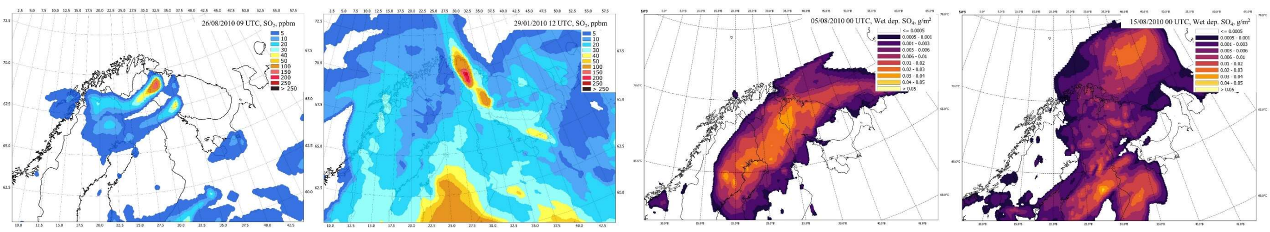
(a) (b) (c) (d)

Figure 3: *Difference fields for the air temperature at 2 m between the control/reference vs. modified runs (a,c) CTRL-DAE and (b,d) CTRL-IDAE for selected dates in (a,b) August and (c,d) January 2010.*

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 changes in air temperature at 2 m. The changes could be both positive and negative. In particular, such changes for simulations with direct aerosol vs. indirect effects included could be leading to cooling and warming over different geographical regions of the modelling domain. In summer (August) these changes are larger compared to winter (January). Changes in meteorological parameters (air temperature – 3-8°C, specific humidity – 2-6 g/kg, precipitation – 1.5-10 mm) were more visible in August for the Moscow and St.Petersburg metropolitan areas. For DAE, the air temperature, cloudiness, specific humidity, precipitation patterns - showed a decrease for St.Petersburg. Similarly, except temperature, for Moscow; and similarly, except precipitation, for Helsinki. For IDAE, the temperature and cloudiness showed increase for Moscow and Helsinki; and for most parameters, except cloudiness, showed decrease for St.Petersburg. For COMB effects, all parameters, except total cloud cover showed decrease for St.Petersburg and Helsinki; and temperature and cloudiness increased for Moscow.

4. Study: "Atmospheric transport of pollution and wet deposition"

The territory of the Kola Peninsula of Russia contains two large industrial enterprises (with mining and smelting activities) and pollution from these can be transported over territories of the three nearest countries - Finland, Norway and Sweden. To study spatial-temporal variation of sulphur dioxide concentration and sulfates wet deposition, in this study, the modelling (with Enviro-HIRLAM) of atmospheric transport, dispersion and deposition was carried out. Sources considered include continuous emissions from the enterprises on the Kola Peninsula. The months considered are January and August 2010. Analysis of the modelling results was performed through their integration into GIS environment (with QGIS package) as independent layers of selected meteorological parameters and chemical species and re-projecting data to unique spatial grid. The results are summarized by *Sedeeva (2019); Sedeeva et al. (2019); Nerobelov et al. (2020a)*.



(a) (b) (c) (d)

Figure 4*: Examples of Enviro-HIRLAM modeled (a,b) SO_2 concentration and (c,d) SO_4 wet deposition for (a) 26 August 2010, 09 UTC and (b) 29 January 2010, 12 UTC & for (c,d) 5 and 15 August 2010, 00 UTC, respectively.*

Examples of Enviro-HIRLAM model simulations for concentration and wet deposition patterns for SO_2 and SO_{4-} sulphates, respectively for selected dates in January and August months of 2010 are shown in Figure 4. Here, territories of the region in focus under larger loadings are well underlined.

Analysis showed that more transboundary atmospheric pollution episodes took place between Russia and Scandinavian countries in August. And on average, more higher concentrations were observed over the territories of the Kola Peninsula (15 days in August vs 9 days in January). In January, the atmospheric transport of pollution more frequently took place towards the seas, surrounding the Kola Peninsula (20 in January vs 5 days in August). The wet deposition was larger in August. Large amounts of sulphates on some days were deposited (wet deposition) on surfaces of lakes, rivers and water reservoirs in the studied region. 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. And in total (i.e. over the entire area of the lake or areas of grid-cells counted) the deposited amount was 49.3 and 2.46 tonnes for the same months. For the Kola Peninsula (on Russian territory), for the Verkhnetulomskoe/ Upper-Tuloma reservoir it was about 22.5 and 0.8 kg/km^2, with totals of 19.73 and 0.68 tonnes. The values for Norwegian Lake Iesjavri are comparable with Russian, and these are about 24.5 and 2 kg/km^2, although due to differences in the areas of the lakes, the total amount was 1.67 and 0.11 tonnes, respectively. For Swedish Stora Lulevatten, it was the minimal among all considered water objects - 5.6 and 0.6 kg/km^2 for August and January, respectively, with the lowest (0.14 and 0.02) total amounts deposited.

5. Study: "Energy flux balance scheme for stable boundary layer"

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.

This study is continued. 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 tested with the HARMONIE modelling system for cases of idealised and stable conditions (using GABLS dataset). The implementation of the EFB module requires modification in physics subroutines, prognostic variables, and matching length scales between boundary layer's stable/ neutral/ convective conditions. The 1D MUSC is ongoing steps of implementation in the HARMONIE-43h model. A series of sensitivity tests will be performed. The interest is also on a 3D case, where the HARMONIE model setup can be linked to domain of AROME-Arctic (with focus on the northern territories of the Scandinavian and Kola Peninsulas). The selected period for simulations to be used is December-January with prevailing low wind conditions. A series of sensitivity will be on-going for different horizontal resolutions of 2, 1.5 and 1 km with tuning of the model at finer scales.

6. Study: "Estimation of elevated black carbon episodes"

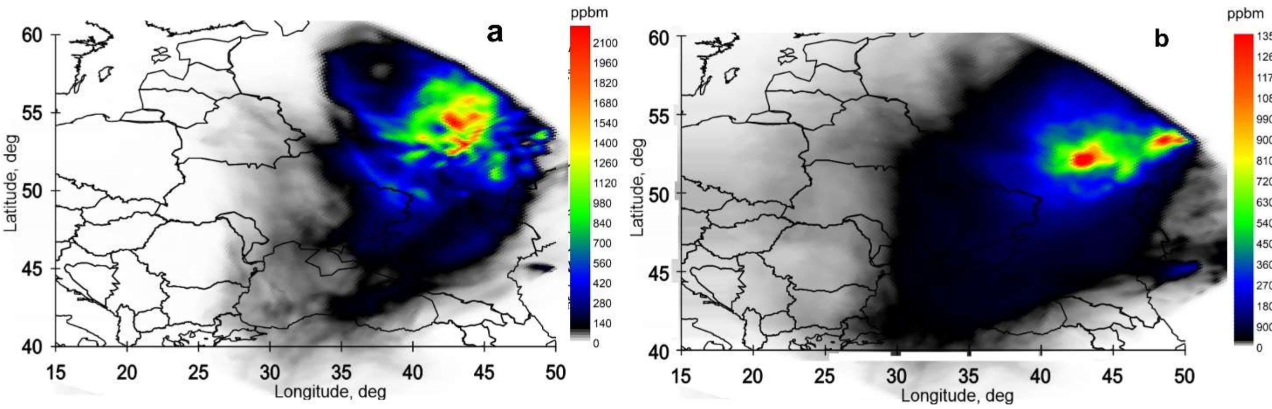
Black carbon (BC) is the component of fine particulate matter (PM2.5) considered as one of the contributors to climate forcing and highly probable harmful health impact. Wildfires are one of the biggest contributors to BC emissions. The case study (*Savenets et al., 2020*) describes main features of BC vertical and horizontal distribution over Ukraine during a wildfire episode in August 2010.

The case study is based on results from Enviro-HIRLAM model simulations for the period of 2–18 August 2010. BC was analyzed for accumulation and coarse modes. Model domain consists of 500x400 grids along longitude vs. latitude, and has 15-km horizontal resolution. Additional data for analyses include in-situ dust measurements in 20 Ukrainian cities, information from 6 radiosounding stations, and burning fraction derived from Global Fire Emissions Database (GFED4). The main source of wildfire emissions was located outside of the Ukraine's territory. BC atmospheric transport and dispersion observed under unfavorable anticyclonic conditions with low humidity content, high air temperature and clear sky. Clockwise air movement caused intensive atmospheric transport towards Ukraine during 7-8 and 13-16 August 2010.

The study found that the highest values for BC near active fires exceeded 400-600 ppbm and 300-450 ppbm for accumulation and coarse modes, respectively. Over the territory of Ukraine the values were lower: 70-150 ppbm and 50-80 ppbm, respectively. During unfavorable weather conditions, the BC plumes were transported and dispersed at distances more than 2000 km away from the original burned areas. Air temperature surface inversions caused diurnal variations of BC content in the boundary layer with maxima during nighttime. During 4–7 and 16 August inversions reached 655 m depth with the difference of 12.5°C between upper and lower inversion levels Usually, during 4–17 August 2-m air temperature was colder by 3–4°C than at 500 m above surface. Elevated pollution levels were detected up to 630 hPa for the coarse mode and 590 hPa for the accumulation mode. On these levels wildfire emissions was detected constantly during daytime. Rarely, it was observed higher BC content up to 590 hPa and 550 hPa for coarse and accumulation modes, respectively.

In general, the wildfire emissions have large accumulative effect in the near-surface layer. Total accumulated amount of black carbon for the period 3–18 August 2010 reached 13500 ppbm (for accumulation mode) and 2200 ppbm (coarse mode) in the lower tropospheric layer near the burning areas (see Figure 6). In Ukraine the highest accumulated values 800 and 150 ppbm for accumulation and coarse modes, respectively. Due to smaller sizes of the particles, the accumulation mode had larger spatial coverage than the coarse mode.

Ground-based dust measurements also showed elevated levels and were 27–47% higher than average dust content in 2010 and 23–72% higher than multi-year average concentrations for month of August. On the east and south-east dust concentrations were higher on 0.05–0.25 μg/m^3 than average values, and on up to 0.05 μg/m^3 on the rest of the territory. During the studied period of elevated pollution episodes in August 2010, there were observed a large number of local fires. They had not so large impact, however the fingerprint of local fires was found in BC concentrations. The largest of them covered 10–13% of the area (burned fraction up to 0.13) and caused higher BC summed content on the north-eastern and eastern parts of Ukraine.



(a) *(b)*

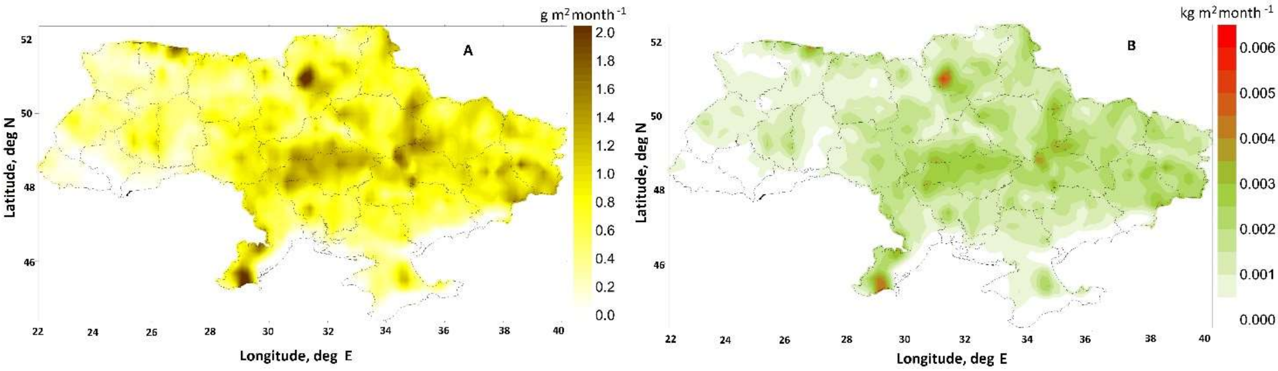
Figure 6: *The integral value of the near-surface black carbon concentrations for the coarse (a) and accumulation (b) modes for the period 3-18 August 2010.*

7. Study: "Fires in ecosystems and influence on the atmosphere"

Many countries worldwide, including Ukraine, suffer from numerous wildfires and agriculture open burning every year. During last decades, these became more frequent and severe due to climatic changes. Fires in ecosystems caused a number of negative atmospheric impacts. Such include pollutants' emission, changes of radiative transfer and clouds' formation. The study (*Pysarenko et al., 2020*) analyzed the influence of fires in ecosystems on substances' fluxes and possible changes of meteorological processes.

A burning fraction from the Global Fire Emission Database (GFED4s) was used for analyses of wildfires and open burning on territory of Ukraine for grid-cells of 0.25°x0.25° resolution. Within each grid-cell, dry matter and carbon emissions were estimated for a period of 1997–2016. Estimation of negative impact on atmospheric processes were made using Absorbing Aerosol Index (AAI) data derived from the Ozone Monitoring Instrument (OMI) with 1°x1° horizontal spatial resolution; and ground-based meteorological measurements (2-m air temperature, cloudiness, and precipitation).

In general, 20-30% of the territory (within 0.25°x0.25° grid-cell) usually burned during fires in ecosystems. In the Carpathian region of the country and along the Black Sea's seashore, each fire caused burning of up to 10% of the area. However, there are some regions on the east of the country where 50% of the territory were totally burned during fire events. About 90% of the fires occurred on agricultural lands, and mostly as an open burning. Seasonal variability showed two maxima: in March–April (man-made open burning) and in July–August (under dominated hot and dry weather conditions). As consequence of these fires, it was found that on average the carbon emissions in Ukraine varied from 0.2 to 1.0 $g \cdot m^2 \cdot month^{-1}$, and dry matter emissions from 0.001 to 0.003 $kg \cdot m^2 \cdot month^{-1}$ (see Figure 7).



(a) *(b)*

Figure 7*: Average carbon (a) and dry matter (b) emissions after biomass burning.*

The lowest emissions observed along the shoreline and on the west of the country. However, western regions have one of the highest positive trends of fires frequency and pollutants' emissions. There are several localizations, mainly in the central part, where emissions reached 1.4–1.8 $g \cdot m^2 \cdot month^{-1}$ and 0.003–0.004 $kg \cdot m^2 \cdot month^{-1}$ for carbon and dry matter, respectively. The central part has one of the largest values of burning area occurred on agricultural lands. Nevertheless, negative trends are observed for these regions. Analysis showed that emissions from agriculture open burning are comparable to wildfire emissions. Moreover, areas under open burning are significantly larger, and thus, more population could be affected by pollutants' emissions.

The combined analysis of AAI satellite data and GFED emissions showed a spatial coherence. For each grid-cell correlation coefficients for AAI and emission data series are significant and relatively strong with values about 0.65. Usual dry matter emissions of 0.005–0.01 kg·m^2·month^{-1} correspond to AAI of about 0.2. Dry matter flux more than 0.02 kg·m^2·month^{-1} observed when AAI exceed 0.6. In general, AAI over the territory of Ukraine is a good indicator of biomass burning emissions, thus might be used for studying aerosol – atmosphere feedbacks using empirical material. It was found that during fires events, air temperature is characterized by anomaly decreasing if monthly average AAI exceeded 0.9. E.g. temperature anomaly of about 0.7°C correspond to AAI of about 0.9; 0.3–0.4°C in case AAI equals 1.1, and 0.1°C if AAI exceed 1.2. Hence, fires in ecosystems with huge burning products emission may cause local temperature decreasing due to changes in radiative transfer. Second mechanism which night take place is local decreasing of the days with precipitation in the next month after severe fire events. Overall, it was found twofold decreasing of days with precipitation if monthly AAI exceeded 1.2 (from 13-14 days to 7 days). The reason of such feedback may be connected with low ability of carbonaceous aerosol for condensation.

8. Study: "Aerosols feedbacks and interactions in Arctic-boreal domain"

Aerosols have influence on weather, air quality and climate. Modelling of aerosols' atmospheric transport, dispersion, and deposition is a challenge for regions of the northern latitudes. It is due to complexity of various processes such as meteorological, chemical, biological, etc. occurred in these geographical regions. To study aerosol feedbacks and interactions at regional scale in the Arctic-boreal domain, the Enviro-HIRLAM model was employed (*Mahura et al., 2019, 2020ab*). It is run in a long-term mode for reference /CTRL/ and aerosols effects (direct /DAE/, indirect /IDAE/, and both direct and indirect included /DAE+IDEA/) and at resolution of 15-5 km. Meteorology and atmospheric composition output (at 40 model levels) are simulated simultaneously. The initial and boundary conditions are from ECMWF; and anthropogenic, biogenic, and natural emissions are pre-processed.

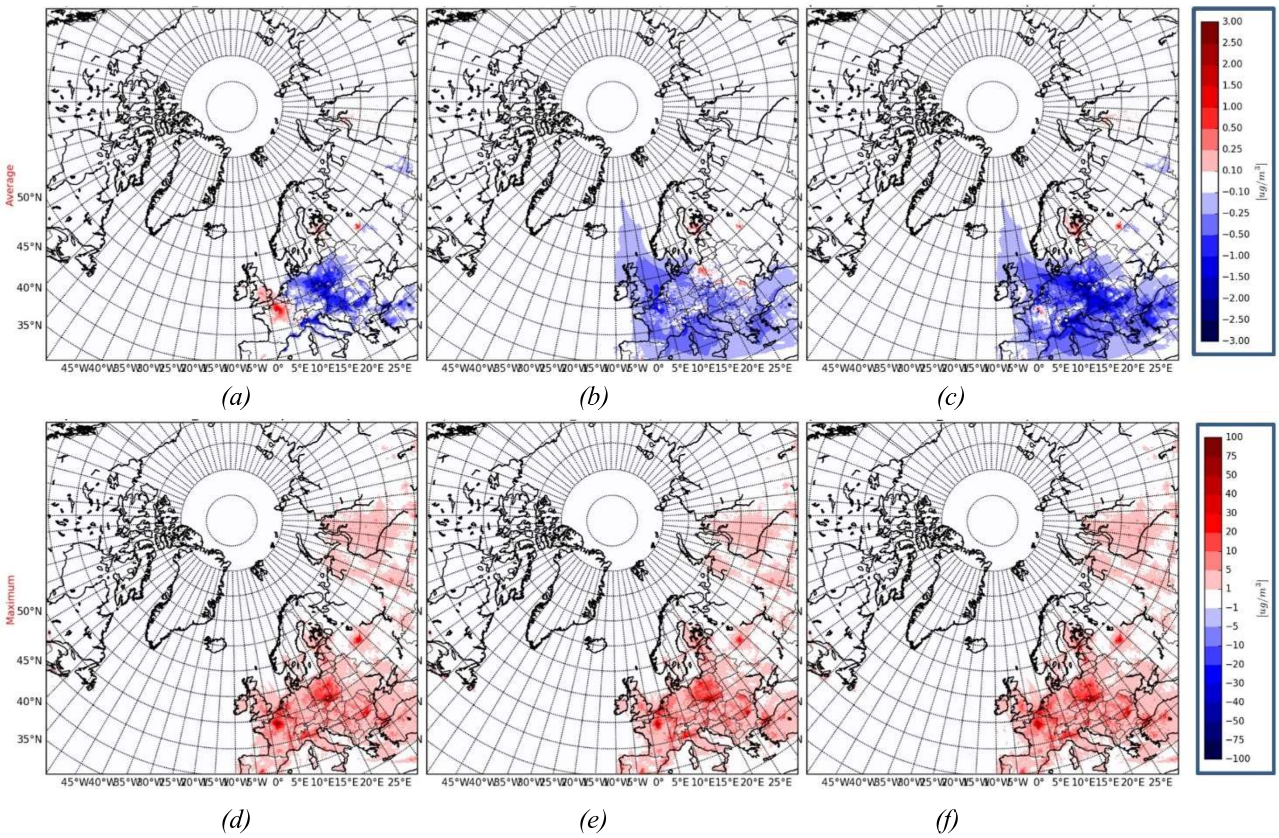


***Figure 8**: Difference fields between CTRL&DAE (a,d), CTRL&IDAE (b,e), CTRL&DAE+IDEA (c,f) runs with the Enviro-HIRLAM model for January's monthly averaged (a,b,c) and maximum (d,e,f) concentration of black carbon.*

Analysis of variability for basic statistics (average, median, max, min, standard deviation) was performed for all model runs and differences between the model runs (Figure 8). In winter, the differences between runs are less pronounced for average concentration of black carbon in the Arctic regions compared with other regions; but these differences are observed for maximum concentration, and especially for the Siberia and Ural regions of Russia. The average sulphur dioxide monthly concentration is larger over mid-latitudes (presence of anthropogenic sources), but maximum is also observed due to long-range atmospheric transport. The average particular matter concentration is lower in the Arctic compared with mid-latitudes, but their composition is dominated by sea salt aerosols.

9. Science education activities on modelling

The research tools/ models of the PEEX-Modelling-Platform are also very actively promoted through the science education activities such as organization of training courses and schools for young researchers, including MSc, PhD students and PostDocs. During reporting period several events were organized. In particular, the research training course on "Seamless / Online Integrated Meteorology-Chemistry-Aerosols Multi-Scale and -Processes Modelling" was carried out during 24-29 June 2019 (Tyumen, Russia) with focus on the Enviro-HIRLAM modelling system (Figure 9). See more details in summary at: https://www.atm.helsinki.fi/peex/index.php/education/16-courses/188-june-2019-research-training-course-seamless-online-integrated-meteorology-chemistry-aerosols-multi-scale-and-processes-modelling.

Two events were also prepared (programmes including lectures, practical exercises, supplementary materials) for spring-summer 2020, and these temporarily postponed due to covid19 situation. The 1st event is the intensive research training course on "Multi-Scales and -Processes Modelling and Assessment for Environmental Applications" (24-25 Apr 2020, St.Peterburg, Russia; https://www.atm.helsinki.fi/peex/index.php/education/16-courses/184-april-2020-peex-ac-research-training-intensive-course) and the 2nd event is the young scientist summer school on "Multi-Scales and Processes Integrated Modelling, Observations and Assessment for Environmental Applications" (27 Jul – 7 Aug 2020, Moscow, Russia; https://www.atm.helsinki.fi/peex/index.php/education/16-courses/185-jul-aug-2020-young-scientist-summer-school-on-multi-scales-and-processes-integrated-modelling-observations-and-assessment-for-environmental-applications). During these events, several PEEX-MP models (Enviro-HIRLAM, EC-Earth, MALTE-Box) will be employed for small-scale research projects to be realised by groups of students. The practical realization includes: introduction into projects (with background discussions); analysis of meteorological situations for selected cases/ dates; technical aspects of modelling and modules implementation; model runs for selected dates/cases/periods; visualization of model output/ results and analysis; and oral presentations with defence of projects.

***Figure 9**: Science education activities on online integrated modelling - research training course for the Enviro-HIRLAM modelling system (summer 2019, Tyumen, Russia).*