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 2021 to June 2022
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
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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	221.28	4000 kSBU	901.182
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.

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

The workplan outlined in the original proposal has been accurately revised (because participation with partners from Russia was frozen at this stage), and for other partners/ contributions the work 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 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.*

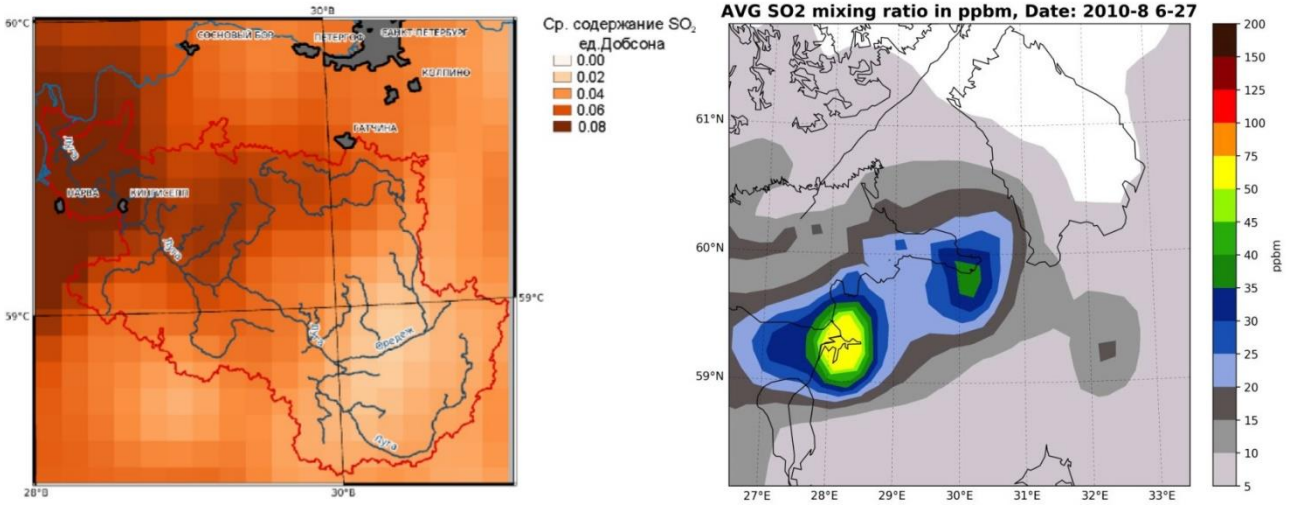
Summary of results (from July 2021 to June 2022)

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., 2021ab, 2022*) for different research tasks according to the PEEX Science Plan (https://www.atm.helsinki.fi/peex/images/PEEX_Science_Plan.pdf).

2. 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 spatio-temporal SO_2 patterns, the online integrated Enviro-HIRLAM model was run at 15 km horizontal resolution for August 2010. Preliminary results (see Fig. 1) 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 1**: (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.*

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

This study (*Losev et al., 2022*) 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. Based on simulation results for July 2017, spatio-temporal 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. 2) are constructed and analyzed. In addition, at the model levels and surfaces of land and water bodies of the Kola Peninsula, concentrations and depositions of aerosol components (sulfates, organic and black carbon, etc.) on underlying surfaces are also analyzed.

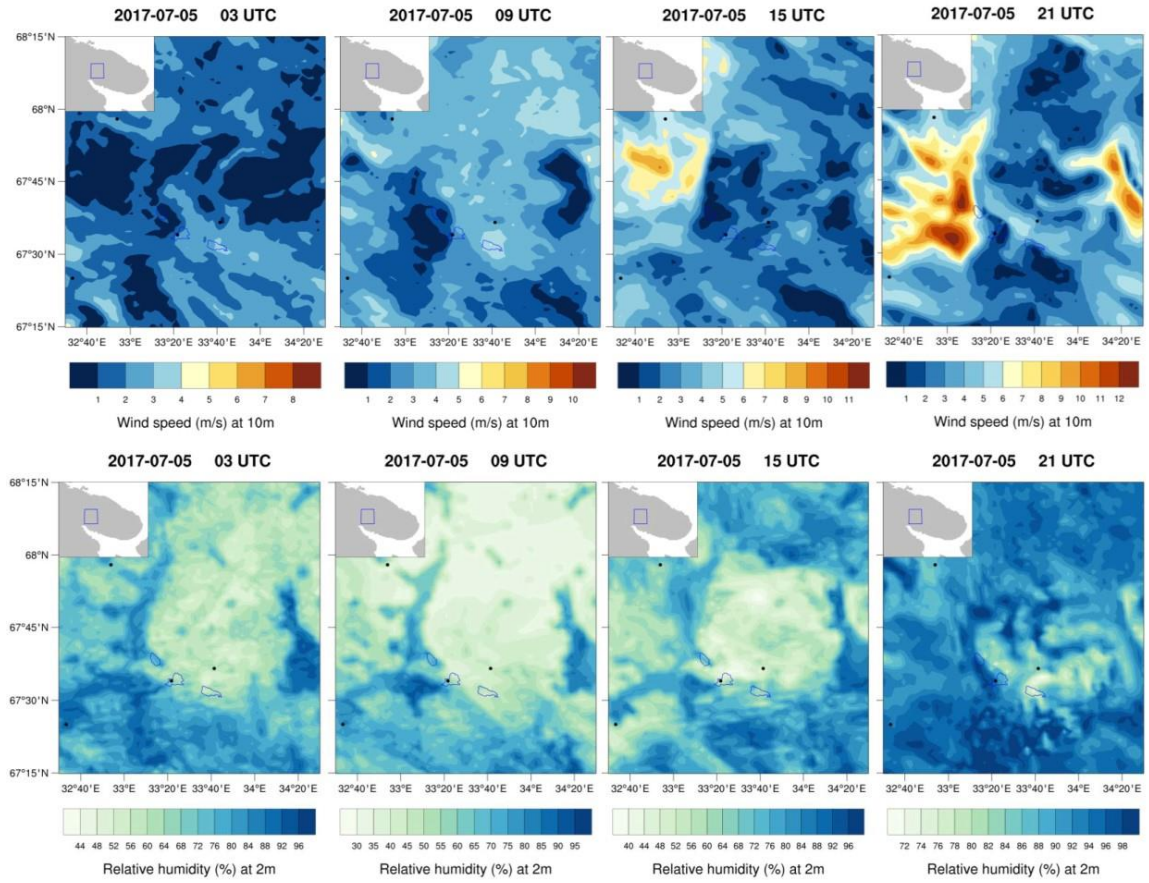


***Figure 2**: Example of Enviro-HIRLAM model output for diurnal cycle (on 5 July 2017) for wind speed at 10 m and relative humidity at 2 m over the Khibiny mountains area (Kola Peninsula).*

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

This study (*Amosov et al., 2022)* 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. 3).

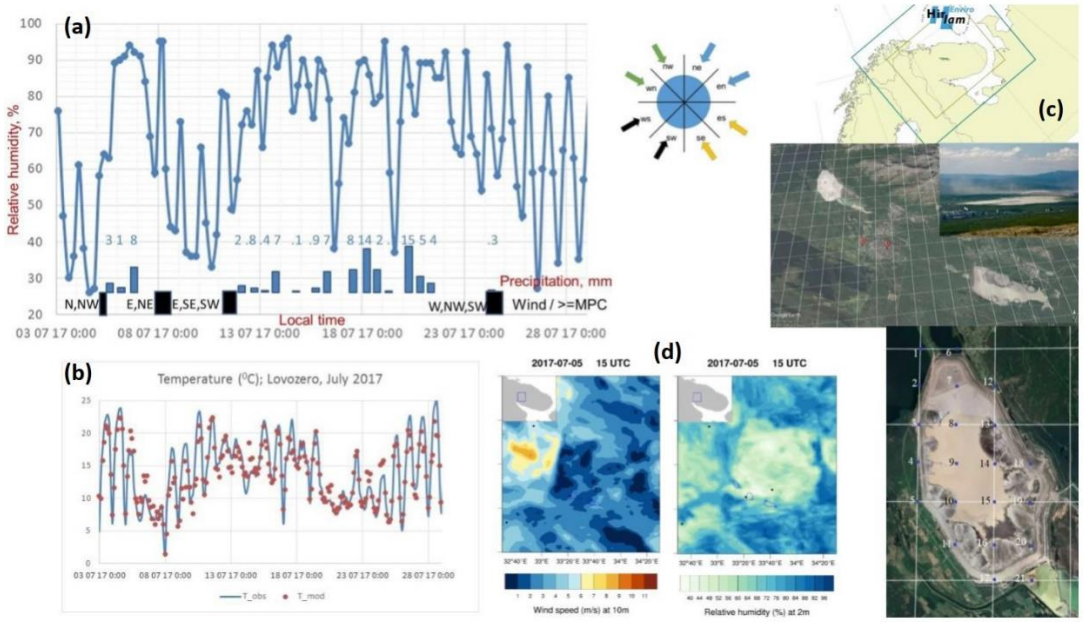


***Figure 3**: (a) Time-series of relative humidity, total precipitation and wind direction vs. concentration of dust during July 2017 (at the Apatity meteorological and air quality station); (b) observed vs. modelled air temperature (at the Lovozero meteorological station); (c) geographical domains - 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.*

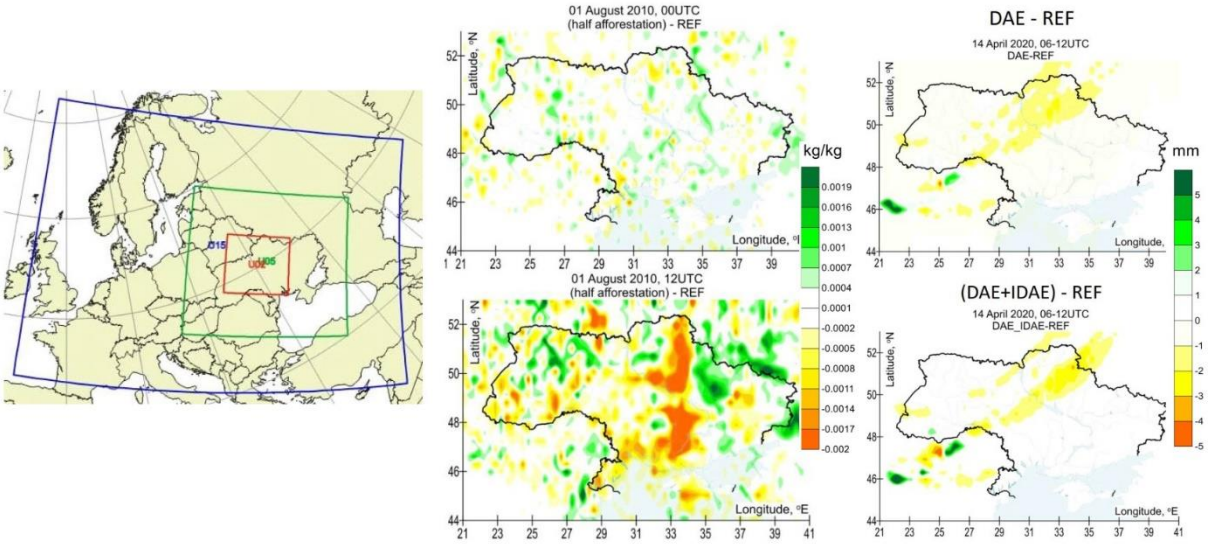
Enviro-HIRLAM (Environment – High Resolution Limited Area Model) model is used to simulate atmospheric transport, dispersion and deposition of dust. To perform numerical experiments, two regions with resolutions of 5-1.5 km were built on the Kola Peninsula's territory.

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.

5. Study: "Integrated Modelling for Assessing Aerosol Feedbacks on Regional Scale Resulted from Accidental Wildfires and Land Cover Changes"

This study (*Savenets et al., 2022*) aims to (1) investigate influence of land cover changes (current vs. scenarios, including hypothetical ones) and its consequences on meteorology for cases of extreme (with heatwave, heavy rains and snowfall) meteorological situations and air quality/ atmospheric composition, and (2) to analyse the regional influence of wildfire emissions occurred in the Chornobyl Exclusion Zone and to identify the affected territories in case of active wildfires near, within radioactive polluted spots and in a close proximity to the nuclear power plant.

The Enviro-HIRAM model is utilized for simulating extreme meteorological situations with currently existing (and modified by scenarios) land cover to estimate impact on regional weather patterns. Necessary initial and boundary conditions for meteorology and atmospheric composition were extracted from the ECMWF's ERA5 and CAMS, and pre-processed for the model runs. The selected study period includes Jul-Aug 2010, Mar-Apr 2013, and 2-30 Apr 2020. The scenarios considered are the following: deforestation total and half, afforestation total and half. The types of model runs: reference (REF), direct (DAE), indirect (IDAE) and both (DAE+IDAE) aerosol effects included. A series of sensitivity tests (with time steps of 300-240-180 sec (15 km), 150-120-90 (5), 90-60-30 (2 & 1.5) will be performed.



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

***Figure 4**: Enviro-HILRAM (a) downscaling modelling domains (with 15-5-2.5 km horizontal resolutions & Difference between the Enviro-HILRAM model output (b) on 1 Aug 2010 for specific humidity at night- (00 UTC) and day (12 UTC)-time for the reference (REF) – half-afforestation scenario model runs; and (c) on 14 Apr 2020 for accumulated total precipitation (06-12 UTCs) for the DAE-REF & DAE+IDAE-REF model runs /DAE – direct & IDAE – indirect aerosol effects/.*

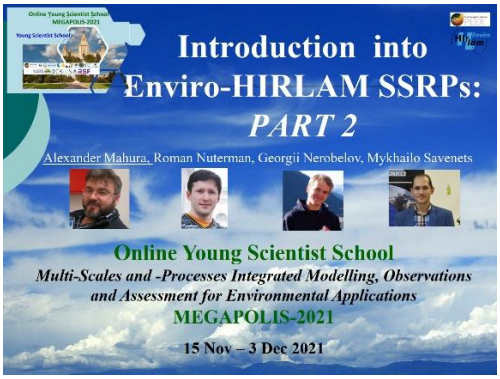
Preliminary analysis of modelling results (see Fig. 4) showed that (1) land cover changes significantly impact regional weather patterns through changes in radiation, moisture, temperature and wind regimes; (2) land cover changes can enhance the consequences of extreme meteorological conditions, (3) outcomes – showed consequences of deforestation and give solid ground for decision-makers in planning adaptation measures to climate change and developing possible recommendations for national forestry service; (4) numerous feedbacks revealed in the atmosphere enhanced by aerosol compounds (emitted from wildfires); (5) aerosol

effects show spatial non-homogeneity dependence on meteorological conditions and ratio of species; and (6) outcomes – crucial for improving weather prediction considering aerosols' influence and valuable for impact assessment on health and ecosystems in decision-making.

6. Science Education: Using Enviro-HIRLAM for Small-Scale Research Projects

The Online Young Scientist School (YSS) MEGAPOLIS-2021 (https://megapolis2021.ru) on "*Multi-Scales and -Processes Integrated Modelling, Observations and Assessment for Environmental Applications*" in Memory of Professor 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). More than 50 young researchers (advanced BSc, MSc and PhD students as well as PostDocs) from 22 Universities and research organizations/ institutions from Russia, China, Austria, Ethiopia, Switzerland, Ukraine, and UK participated in YSS. 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; https://megapolis2021.ru/ssrp) by students in groups/teams, with bi-weekly online consulting (by teachers), and in particular, SSRPs with the Enviro-HIRLAM model:

- Introduction lecture on Enviro-HIRLAM and model application (https://megapolis2021.ru/media/MEGAPOLIS-2021_Enviro-HIRLAM-model_intro_vd2.pdf)
- Introduction into SSRPs with the Enviro-HIRLAM model (https://megapolis2021.ru/media/MEGAPOLIS_Intro_Enviro-HIRLAM-SSRPs_part1_vf.pdf)
- Introduction into SSRPs with the Enviro-HIRLAM model (https://megapolis2021.ru/media/MEGAPOLIS_Intro_Enviro-HIRLAM-SSRPs_Part2_vf.pdf)



The final presentation/ defence of completed SSRPs (with the Enviro-HIRLAM model) included: "*Effects of model resolution on meteorology and pollution dispersion over the Kola Peninsula*", "*The influence of anthropogenic heat flux on meteorological patterns on the metropolitan area of Paris*" and "*The influence of black carbon and mass concentration of dust on meteorological parameters*". A published summary for the PEEX community is: https://peexhq.home.blog/2021/12/15/megapolis-2021-school