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 2015 to June 2016
Project Title:	**EnviroAerosols on ECMWF** *(Enviro-HIRLAM/ HARMONIE model research and development for online integrated meteorology- chemistry/ aerosols feedbacks and interactions in weather and atmospheric composition forecasting)*
Computer Project Account:	SPDKSASS
Start Year - End Year :	Jul 2015 – Dec 2017
Principal Investigator(s)	Mr. Bent Hansen Sass (DMI) *Reported by Bent Hansen Sass & Alexander Mahura (DMI)*
Affiliation/Address:	Danish Meteorological Institute (DMI) Research and Development Department (RDD) Lyngbyvej 100, Copenhagen DK-2100, Denmark
Other Researchers (Name/Affiliation):	Alexander Mahura DMI; Kristian Pagh Nielsen DMI; Roman Nuterman UoC; Eigil Kaas UoC; Alexander Kurganskiy UoC/RSHU; Velle Toll UoT; Svitlana Krakovska UHMI; Serguei Ivanov OSEU; Alexey Penenko ICMMG; Suleiman Mostamandy RSHU; Noel Aquilina UoM; Huseyin Toros ITU; Kairat Bostanbekov KazNRTU; Nellie Edvardsson UoL; HIRLAM-C members

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

(if applicable)
Please answer for all project resources

		Previous year		**Current year** (until 20 June 2016)	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)			4000000	2909519
Data storage capacity	(Gbytes)				

Summary of project objectives

The overall objectives are to analyse the importance of the meteorology-chemistry/aerosols interactions 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 both the numerical weather prediction and atmospheric composition forecasts.
Two main application areas of the on-line integrated modelling are considered: (i) improved numerical weather prediction with short-term feedbacks of aerosols and chemistry on formation and development of meteorological variables, and (ii) improved atmospheric composition forecasting with on-line integrated meteorological forecast and two-way feedbacks between aerosols/chemistry and meteorology. Modelling systems: Enviro-HIRLAM/HARMONIE

Summary of problems encountered (if any)

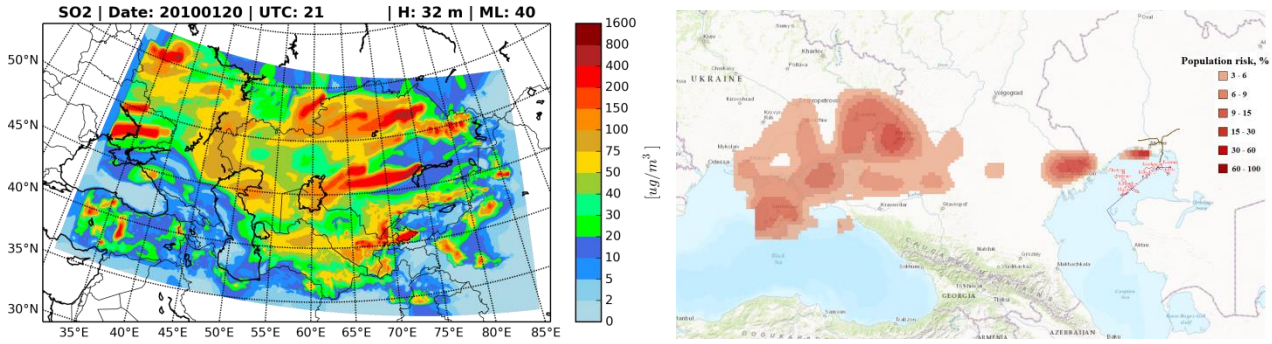
Although the SP project started as planned, realisation of some experiments at the beginning was going slower than expected due to complexity of the operational system environment and lack of experience for new members of the project with the use of ECMWF HPC equipment. Following decision of the HIRLAM Consortium to move from the NWP platform HIRLAM to HARMONIE, the focus is shifting toward building blocks for new version of online-coupled ACT-NWP model (after the Enviro-HIRLAM system) based on the HARMONIE platform (Enviro-HARMONIE). This requires additional new model development works. Also the involvement of new collaborating groups that did not originally participate in the project, from the Lund University (Sweden) and Kazakhstan National Research Technical University (Kazakhstan) has implied additional efforts. These institutions are being involved in case studies.

Summary of results of the current year (from July 2015 to June 2016)

Based on recent Enviro-HIRLAM/HARMONIE scientific developments and working plan the following topics important for operational numerical weather prediction and atmospheric composition forecasting, were investigated with a close collaboration with Universities during the 1st year of the Special Project:

1. Study "On-line Meteorology-Chemistry/Aerosols Modelling and Integration for Risk Assessment: Case Studies". On regional level, and especially in areas with potential diverse sources of industrial pollutants, the risk assessment of impact on environment and population is critically important. During normal operations, the risk is minimal. However, during accidental situations, the risk is increased due to releases of harmful pollutants into different environments such as water, soil, and atmosphere where it is following processes of continuous transformation and transport. In study by *Bostanbekov et al. (2015, 2016)* the Enviro-HIRLAM model was adapted and employed for assessment of scenarios with accidental and continuous emissions of sulphur dioxide for selected case studies during January of 2010 (Fig. 1a). The following scenarios were considered: (i) control reference run; (ii) accidental release (due to short-term 1 day fire at oil storage facility) occurred at city of Atyrau (Kazakhstan) near the northern part of the Caspian Sea; and (iii) doubling of original continuous emissions from three locations of metallurgical enterprises on the Kola Peninsula (Russia). The implemented aerosol microphysics module M7 uses 5 types – sulphates, sea salt, dust, black and organic carbon; as well as distributed in 7 size modes. Removal processes of aerosols include gravitational settling and wet deposition. As the Enviro-HIRLAM model is the on-line integrated model, both meteorological and chemical processes are simultaneously modelled at each time step. The modelled spatio-temporal variations for meteorological and chemical patterns were analyzed for both European and Kazakhstan regions domains. The results of evaluation of sulphur dioxide concentration and deposition on main populated cities, selected regions, countries were analyzed with GIS tools (Fig. 1b). And finally, the

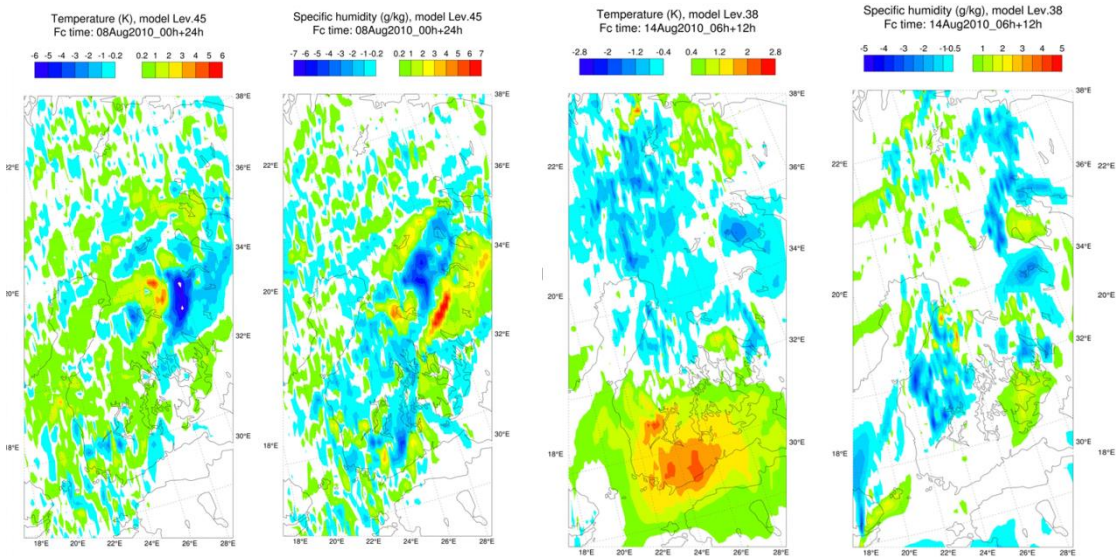
modelling results for accidental release near the Caspian Sea were integrated into the RANDOM (Risk Assessment of Nature Detriment due to Oil spill Migration) system.



(a) (b)

Figure 1: (a) Example of Enviro-HIRLAM modelled (for 20 Jan 2010, 21 UTC) sulphur dioxide concentration fields over domain with focus on Kazakhstan; and (b) Results of GIS integration of modelled results and estimation of risks for population resulted from accidental release from oil refinery at city of Atyrau (Kazakhstan).

2. Studies "The sensitivity of precipitation simulations to the soot aerosol presence" & "The precipitation forecast sensitivity to data assimilation on a very high resolution domain". The role of aerosols in non-linear feedbacks on atmospheric processes is important, and in particularly, the importance of black carbon particles for evolution of physical weather including precipitation formation and release. In study by *Palamarchuk et al. (2015, 2016a)*, the HARMONIE-38h1.2 model with the AROME physics package was used to study changes in precipitation life-cycle under black carbon polluted conditions. A model configuration includes a radar data assimilation procedure on a high resolution domain covering the Scandinavia region. Model results showed that precipitation rate and distribution as well as other variables of atmospheric dynamics and physics are sensitive to aerosol concentrations (Fig.2a). The attention should also be paid to numerical aspects, such as a list of observation types involved in assimilation. The use of high resolution radar information allows to include mesoscale features in initial conditions and to decrease the growth rate of a model error with the lead time.

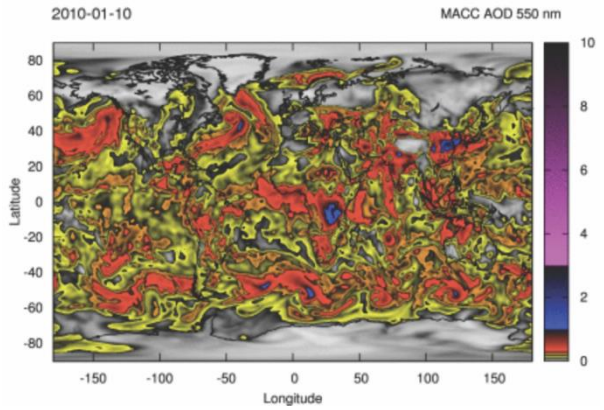


(a) (b) (c) (d)

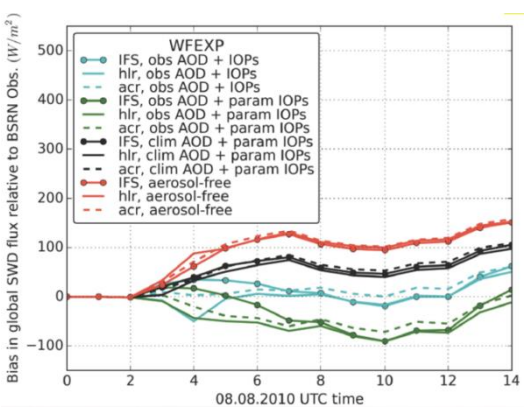
Figure 2: Results of the HARMONIE model experiments with simulated differences (ab – with/without soot & cd – with/without data assimilation) fields for (ac) air temperature and (bd) specific humidity on (ab) 9 Aug 2010, 00 UTC and (cd) 14 Aug 2010, 18 UTC at about height /model level/ of (ab) 1 km /lev 45/ and (cd) 2 km /lev 38/.

Moreover, recent developments in computing technologies allow implementation of a very high resolution in NWP models which is crucially important in studies of precipitation including their life-cycle. New opportunities generate prerequisites to revise existing knowledge both in meteorology and numerics, and in particular, with formulation of initial conditions involving data assimilation (DA). Depending on applied techniques, observational data types and spatial resolution the precipitation prediction appears quite sensitive. In study by *Palamarchuk et al. (2016b),* the impact of data assimilation on resulting fields is analysed using the HARMONIE-38h1.2 model with the AROME physics package. The numerical experiments were performed for the Nordic domain (with focus on Finland) with horizontal resolution of 2.5 km and 65 vertical levels for selected period in Aug 2010 (covering the BaltRad experiment). The initial conditions formulation included downscaling from the MARS archive and involving observations through 3DVAR data assimilation. The treatment of both conventional and radar observations in numerical experiments was used. The background error covariances required for the variational assimilation have already been computed from the ensemble perturbed analysis with the purely statistical balance. Deviations among the model runs started from the MARS, conventional and radar DA were complex (Fig.2b). The contribution from observed variables included in the control vector, such as humidity and temperature, was expected to be largest, but nevertheless, revealing of such impact is not so straightforward task. Major changes occur within the lower 3-km layer of the atmosphere for all predicted variables. However, those changes were not directly associated with observation locations, as it often shows single observation experiments. Moreover, the model response to observations with lead time produces weak mesoscale spots of opposite signs. Special attention was paid to precipitation, cloud and rain water, vertical velocity fields. A complex chain of interactions among radiation, temperature, humidity, stratification and other atmospheric characteristics resulted in changes of local updraft and downdraft flows and following cloud formation processes and precipitation release. One can assume that those features would arise due to both, atmospheric physics and numeric effects; the latter becomes more evident in simulations on very high resolution.

3. Study "Aerosol effects over China investigated with a high resolution convection permitting weather model". In study by *Nielsen et al. (2016),* the aerosol effects was investigated in the operational high resolution (2.5 km) convection permitting non-hydrostatic weather model HARMONIE. Aerosol input from the global C-IFS model was downscaled and used (Fig. 3a). The impact of using realistic aerosols on both the direct and the indirect aerosol effects is studied and compared with default simulations that include only the direct aerosol effect of climatological aerosols. The study is performed for a selected region of China during months January and July 2010, where in particular January 2010 was characterized by several cases of high anthropogenic aerosol loads. The impact of accounting for realistic aerosol single scattering albedos and asymmetry factors in the simulations of the direct aerosol forcing was also investigated. In many studies only variations in the aerosol optical depth are accounted for. It is shown that this is to be inadequate, when the assumed aerosol types have different optical properties than the actual aerosols.



(a)



(b)

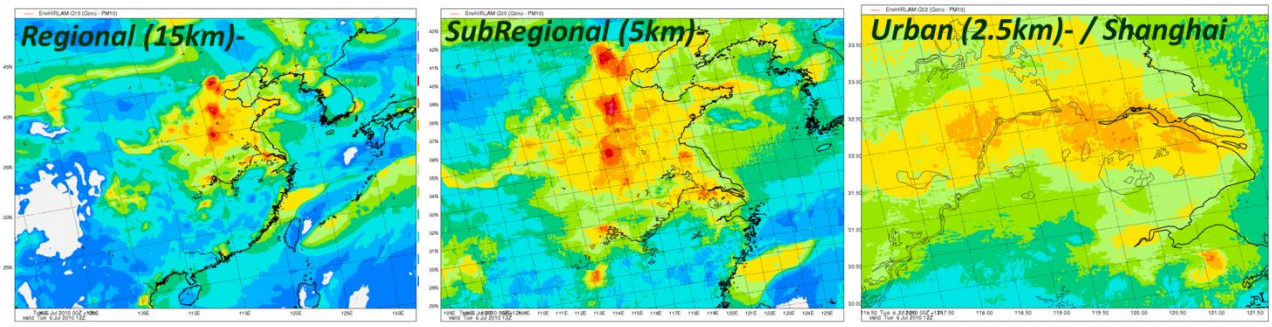
Figure 3: Aerosol optical depth - AOD (a) at 550 nm from the MACC reanalysis data set from 1 Jan 2010; and (b) scaling sensitivity test results for HARMONIE /importance of the AOD scaling is just as large as getting the AOD at 550 nm right/.

4. Study "Effects of aerosols on clear-sky solar radiation in the ALADIN-HIRLAM NWP system". In study by *Gleeson et al. (2016),* the direct shortwave radiative effect of aerosols under clear-sky conditions in the Aire Limitee Adaptation dynamique Developpement InterNational (ALADIN) –HIRLAM NWP system was investigated using three shortwave radiation schemes in diagnostic single-column experiments: the Integrated Forecast System (IFS), acraneb2 and the hlradia radiation schemes (the latter two are broadband schemes) (Fig.3b). The strengths and weaknesses of NWP system regarding aerosols were evaluated for use of real-time aerosol information. The experiments were run with focus on the Russian wildfires (Aug 2010). Each of 3 schemes accurately (within ±4 % at midday) simulated the direct shortwave aerosol effect when observed aerosol optical properties are used. When the aerosols were excluded from the simulations, errors of more than +15 % in global shortwave irradiance were found at midday, with the error reduced to +10 % when standard climatological aerosols were used. An error of −11 % was seen at midday if only observed aerosol optical depths at 550 nm, and not observation-based spectral dependence of aerosol optical depth, single scattering albedos and asymmetry factors, were included in the simulations. This demonstrates the importance of using the correct aerosol optical properties. The dependency of the direct radiative effect of aerosols on relative humidity was tested and shown to be within ±6 % in this case. By modifying the assumptions about the shape of the IFS climatological vertical aerosol profile, the inherent uncertainties associated with assuming fixed vertical profiles were investigated. The shortwave heating rates in the boundary layer changed by up to a factor of 2 in response to the aerosol vertical distribution without changing the total aerosol optical depth. Finally, we tested the radiative transfer approximations used in the three radiation schemes for typical aerosol optical properties compared to the accurate DISORT model. These approximations are found to be accurate to within ±13 % even for large aerosol loads.

5. Study "Impacts of the direct radiative effect of aerosols in numerical weather prediction over Europe using the ALADIN-HIRLAM NWP system". In study by *Toll et al. (2016),* the aerosol feedbacks were included in NWP in order to improve the accuracy of weather forecasts. The default set-up in the ALADIN-HIRLAM NWP system included monthly aerosol climatologies to account for the average direct radiative effect of aerosols. This effect was studied using the default aerosol climatology in the system and compared to experiments run using the more up-to-date Max-Planck-Institute Aerosol Climatology version 1 (MACv1), and time-varying aerosol data from the Monitoring Atmospheric Composition and Climate (MACC) reanalysis aerosol dataset during time period with near-average distribution of aerosol optical depth over Europe. Accounting for the direct radiative effect using monthly aerosol climatologies or near real-time aerosol distributions improved the accuracy of the simulated radiative fluxes and temperature and humidity forecasts in the lower troposphere. However, the dependency of forecast meteorological conditions on aerosol dataset itself was found to be weak.

6. Study "Meteorological and chemical urban scale modelling for Shanghai metropolitan area". Urban air pollution is a serious problem in megacities and major industrial agglomerations of China. Therefore, air quality information is important for public. In study by *Mahura et al. (2016),* in particular, the Shanghai metropolitan area was studied as well-known megacity having severe air pollution episodes. The Enviro-HIRLAM model was applied for on-line integrated meteorology and atmospheric composition forecasting for this region of China. The model setup includes the urban Building Effects Parameterization module, describing different types of urban districts with its own morphological and aerodynamical characteristics. The model is running in downscaling chain from regional-subregional-urban scales (Fig. 4 a-b-c) for selected periods in summer and winter of 2010 having both elevated pollution levels as well as unfavorable meteorological conditions. For these periods, the effects of urbanization are analyzed for spatio-temporal variability of atmospheric and chemical/ aerosols patterns. The formation and

development of meteorological (air and surface temperature, relative humidity, wind speed, cloud cover, boundary layer height) and chemical/aerosol patterns (concentration and deposition) due to influence of the metropolitan area was evaluated. The impact of Shanghai region on regional-to-urban scales as well as relationship between air pollution and meteorology was estimated.



(a) (b) (c)

Figure 4: Example of Enviro-HIRLAM modelled PM10 concentration fields on 6 Jul 2010, 12 UTC for the downscaling chain at (a) regional - 15 km, (b) sub-regional - 5 km and (c) urban - 2.5 km resolution scales.

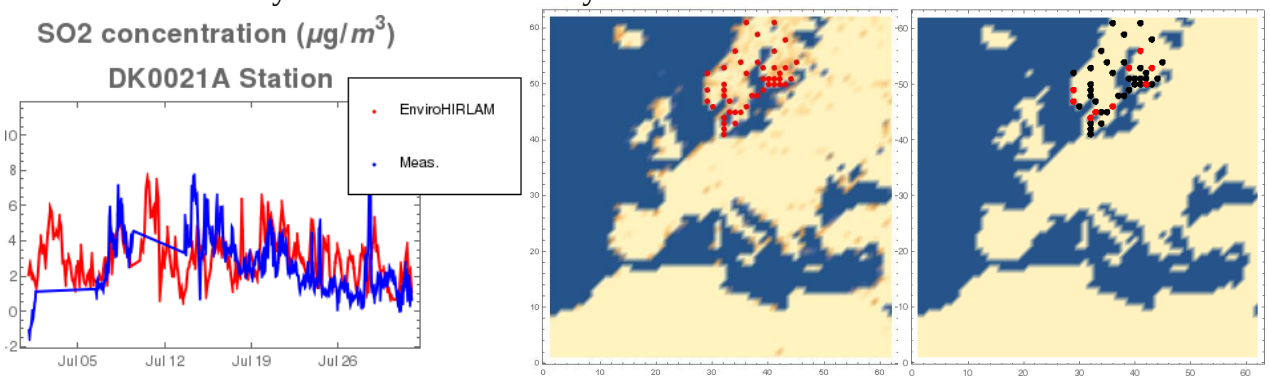
7. Study "Direct variational data assimilation algorithm for atmospheric chemistry data with transport and transformation model". Results of numerical experiments with chemical data assimilation algorithm of in situ concentration measurements on real data scenario are presented in studies by *Penenko et al. (2015ab).* The algorithm is based on the variational approach and splitting scheme. This allows avoiding iterative direct problems solution for transport and transformation model and the algorithm becomes a "real-time algorithm". In order to construct test scenario, meteorological data has been taken from Enviro-HIRLAM model output, initial conditions from MOZART model output and measurements from Airbase database.

Following classes of problems associated to the inverse modeling were considered: (i) Direct problems: system's behavior has to be forecasted and studied with a mathematical model and prescribed parameters; (ii) Inverse problems: model parameters must be adjusted to fit model forecasts to the corresponding measurement data. It may take to solve series of direct problems with various model parameters; and (iii) Data assimilation problems: a forecast has to be improved (on-line) by adjusting model parameters with incoming measurement data; it may take to solve series of inverse problems with various measurement data.

To construct a data assimilation algorithm, the following features were taken into account: (i) atmospheric composition is being changed rapidly, therefore current and future system state is of interest; (ii) stiff chemical kinetics equations (different time scales), various chemical mechanisms and their nonlinear behavior; (iii) uncertainties are not only in initial conditions but also in model coefficients (reaction rates) and in emission rates; (iv) high dimensionality ($\approx 10^7$) of modern atmospheric chemistry transport models due to high number of spatial variables and different species, imposes requirements to the computational performance; (v) relatively small number of chemical species in a small number of spatial points can be measured; (vi) data assimilation algorithms must be embedded in existing models; and (vii) multidisciplinary nature of the study.

Combination of splitting and data assimilation schemes let us construct computationally effective algorithms for data assimilation of in situ measurements to convection-diffusion models. A complete data assimilation scenario has been compiled with meteorological data from Enviro-HIRLAM model, initial concentration data from MOZART model and in situ measurement data from Airbase (Fig. 5 a-b-c). We carried out series of numerical experiments in which we tested DA algorithms on different divisions of measurement data into assimilated and reference datasets. Data assimilation was able to improve modeling results with imperfect (approximate) models and model parameters. The advantage of data assimilation algorithm that includes chemical transformations was identified for ozone concentrations modeling. Among the future steps to improve data assimilation results we can identify: (i) inclusion of more realistic boundary conditions is required; (ii) additional tuning is essential for coefficients of chemical reactions; (iii) quality control of chemical data measurements at stations is recommended for excluding of "extreme" data; (iv)

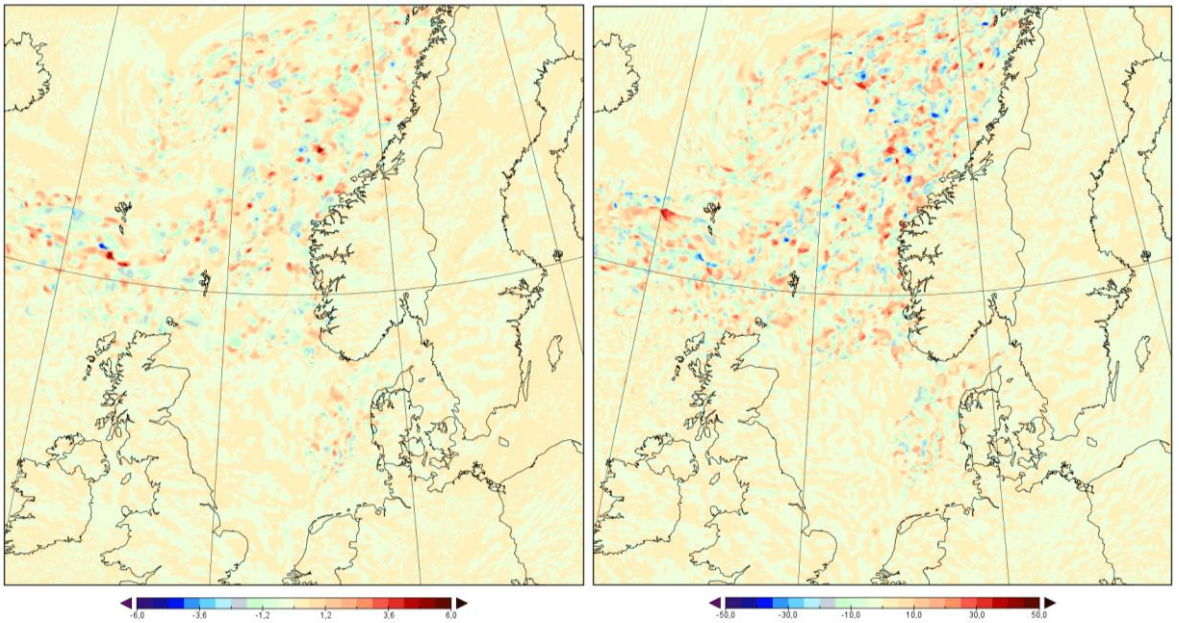
revision of implementation procedure/steps for chemical model is required; (v) additional evaluation of monthly and seasonal variability is needed.



(a) (b) (c)

Figure 5: (a) Example of Enviro-HIRLAM modelled vs. observation (at DK0021A station) time series for Jul 2010; (bc) Assimilated measurement sites locations (black dots) and reference measurement sites locations (red dots).

8. Study "Aerosol influence on High Resolution NWP HARMONIE Operational Forecasts". The main aim of *Edvardsson (2016)* study was to investigate the impact of sea salt aerosols on numerical weather prediction during low precipitation events. Two dates (also referred to as cases), one in winter (7 Dec 2014) and one in summer (31 May 2015) were selected. For the two cases, the HARMONIE NWP model was configured at the ECMWF HPC for a domain covering the northern European area. Model runs were made (for the full day with 6 hour spin-up) with and without sea salt aerosols. The modelling results were evaluated for changes in short wave solar radiation, air temperature and relative humidity on a diurnal cycle at the surface and at selected vertical levels within the atmosphere.



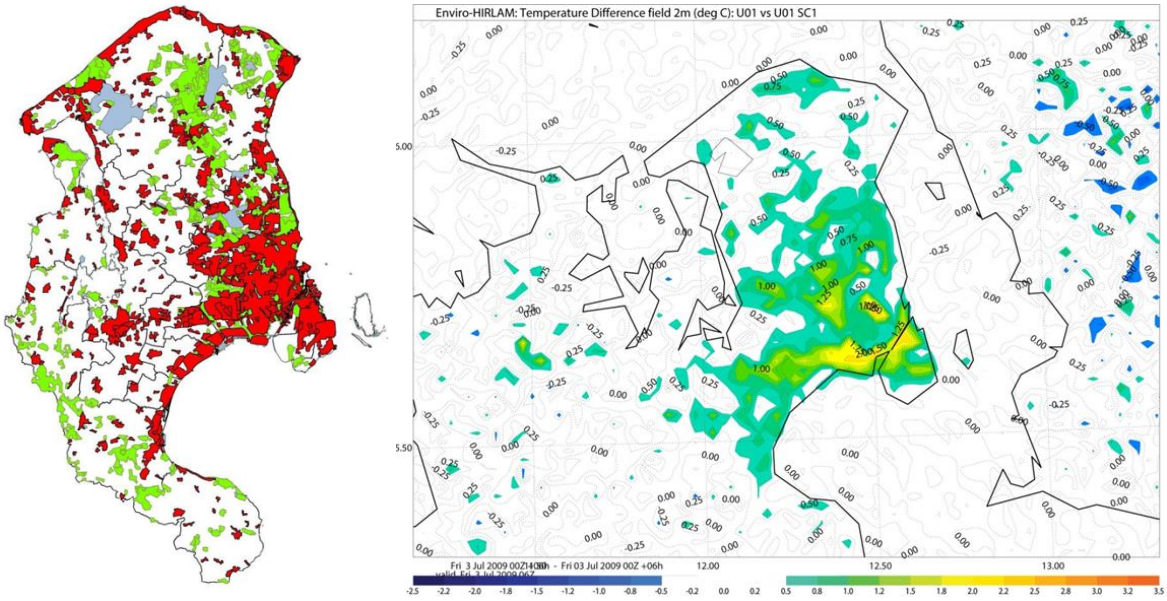
(a) (b)

Figure 6: Winter case study: example of HARMONIE modelled difference (control vs. sea salt aerosols excluded) fields for (a) air temperature (deg C) and (b) relative humidity (%) at 2m on 7 Dec 2014, 12 UTC.

In summary, variability in sea salt aerosol impact over the model domain was found for all meteorological parameters during both cases. In winter, the impact mainly occurred over sea-ocean areas, where the low pressure system was located. In the summer case, two low pressure systems were located in the area of study, one over the sea-ocean area and one over land, and the impact occurred in these two regions. The impact on air temperature in levels of the atmosphere was found to be the strongest in the PBL and the impact on relative humidity was found to be strongest at the levels of 850-500 hPa. The impact on air temperature and relative humidity was stronger during the

winter case than in the summer case. Low pressure systems tend to be deeper in the winter compared to the summer. Deeper low pressure systems leads to higher wind speeds, causing more sea salt aerosols to be produced which is the reason for a stronger impact on air temperature and relative humidity during winter. Regarding short wave radiation flux, the impact was found to be stronger in the summer. The few hours of sunlight during winter is the reason for a lower impact on short wave radiation flux during winter compared with summer. This study showed importance of sea salt aerosol inclusion in numerical weather prediction. These aerosols are important for precipitation formation in both winter and summer conditions.

9. Study "Impact of regional afforestation on climatic conditions in metropolitan areas: case study of Copenhagen". As European metropolitan areas will face a range of climate–related challenges over the next decades that may influence the nature of urban life across the continent, under future urbanization and climate change scenarios the well-being and comfort of the urban population might become progressively compromised. In urban areas, the effects of climate change will be accelerated by a combination of urban heat island (UHI) effect and extreme heat waves. The land cover composition will be playing an important role in modulating local and regional climatic conditions, and to be vital factor in the process of adapting cities to warming climate. In study by *Stysiak (2015) & Stysiak et al. (2015, 2016)* the impact of forest and land-cover change on formation and development of temperature regimes in the Copenhagen Metropolitan Area (CPH-MA, Denmark) was studied. Potential to modify the UHI effect in CPH-MA was estimated. Using 3D meteorological data and up-to-date 2012 high resolution land-cover CORINE dataset, the Enviro-HIRLAM model was run to simulate air temperature at 2 meter for a selected period in July 2009. The influence of different afforestation (Fig. 7a) and urbanization scenarios (with new forests being placed following the Danish national afforestation plan, proximity to the city center, dominating wind characteristics, and urbanization taking place as densification of the existing conurbation) was investigated. It was found that temperature difference (Fig. 7b) can be up to 3.25°C (for extreme urbanization scenario), and decrease in spatial extent of temperature fields up to 68%, depending on selected scenario. Performed simulations demonstrated that well-positioned and well-sized afforestation at the regional scale can significantly affect the spatial distribution, structure and intensity of the air temperature field. This study points to vegetation having practical applications in urban and regional planning for modifying local climatic conditions.



(a) (b)

Figure 7: (a) Spatial representation of the Copenhagen Metropolitan Area and surroundings (baseline scenario: red – urban, light green – forest, blue - water bodies) on a Zealand Island of Denmark; and (b) Enviro-HIRLAM modelled difference in air temperature field at 2m (°C) for 3rd of July 2009 at 06 UTC for the baseline scenario.

List of publications/reports from the project with complete references

Bostanbekov K., Mahura A., Nuterman R., Nurseitov D., Zakarin E., Baklanov A. (**2015**): On-line Meteorology-Chemistry/Aerosols Modelling and Integration for Risk Assessment: Case Studies. *DMI Scientific Report 15-06 (in finalization).*

Bostanbekov K., Mahura A., Nuterman R., Nurseitov D., Zakarin E., Baklanov A. (**2016**): On-line Meteorology-Chemistry/Aerosols Modelling and Integration for Risk Assessment: Case Studies. *Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2016, Vienna, Austria; Geophysical Research Abstracts, Vol.18, EGU2016-1392*

Edvardsson N. (**2016**): Investigation of Aerosol Influence on Operational Weather Forecasts. *BSc Thesis; Faculty of Science, Department of Physics, Lund University, Sweden, 41p; Supervisors –Alexander Mahura and Elna Heimdal Nilsson.*

Gleeson, E., Toll, V., Nielsen, K. P., Rontu, L., & Mašek, J. (2016). Effects of aerosols on clear-sky solar radiation in the ALADIN-HIRLAM NWP system. *Atmospheric Chemistry and Physics*, *16*(9), 5933-5948.

Mahura A., Nuterman R., I. Gonzalez-Aparicio, Amstrup B., Yang X., Baklanov A. (**2016**): Meteorological and Chemical Urban Scale Modelling for Shanghai Metropolitan Area. Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2016, Vienna, Austria; Geophysical Research Abstracts, Vol.18, EGU2016

Nielsen K.P., Mahura A., Yang X. (**2016**): Aerosol effects over China investigated with a high resolution convection permitting weather model. *Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2016, Vienna, Austria; Geophysical Research Abstracts, Vol.18, EGU2016-15398*

Palamarchuk J., Ivanov S., Kaas E., Nuterman R., Mahura A. (**2015**): HARMONIE Case Study: Aerosol Impact on Atmospheric Meso-scale Circulation for Nordic Countries. *DMI Sci.Report 15-02, ISBN:978-97-7478-659-7, 23p, http://www.dmi.dk/dmi/sr15-02.pdf*

Palamarchuk J., Ivanov S., Mahura A**.,** Ruban I. (**2016a**): The sensitivity of precipitation simulations to the soot aerosol presence. *Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2016, Vienna, Austria; Geophysical Research Abstracts, Vol.18, EGU2016-13386*

Palamarchuk J., Ivanov S., Ruban I. (**2016b**): The precipitation forecast sensitivity to data assimilation on a very high resolution domain. *Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2016, Vienna, Austria; Geophysical Research Abstracts, Vol.18, EGU2016-9902*

Penenko A., Penenko V., Nuterman R., Baklanov A., Mahura A. (**2015a**): Direct variational assimilation algorithm for atmospheric chemistry data with transport and transformation model. *Proceedings of the 21st International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, 22-26 Jun 2015, Tomsk, Russia*

Penenko A., Penenko V., Nuterman R., Baklanov A., Mahura A. (**2015b**): Direct variational assimilation algorithm for atmospheric chemistry data with transport and transformation model. *SPIE Vol 9680, Atmospheric and Ocean Optics: Atmospheric Physics, 968076, Nov 2015, 12p., doi: 10.1117/12.2206008*

Stysiak A., Jensen M.B., Mahura A. (**2016**): Impact of regional afforestation on climatic conditions in metropolitan areas: case study of Copenhagen. Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2016, Vienna, Austria; Geophysical Research Abstracts, Vol.18, EGU2016-345

Stysiak A. (**2015**): Impact of regional afforestation on metropolitan climatic conditions: case study of Copenhagen. *MSc thesis; Faculty of Science, Department of Geosciences and Nature Resource Management, University of Copenhagen, Denmark, 93 p.; Supervisors - Marina Bergen Jensen and Alexander Mahura.*

Stysiak A., Bergen M.J., Mahura A. (**2015**): Impact of regional afforestation on climatic conditions in Copenhagen Metropolitan Area. *DMI Sci.Report 15-07, ISBN:978-87-7478-665-8, 30p, http://www.dmi.dk/dmi/sr15-07.pdf*

Toll, V., Gleeson, E., Nielsen, K. P., Männik, A., Mašek, J., Rontu, L., & Post, P. (2016). Impacts of the direct radiative effect of aerosols in numerical weather prediction over Europe using the ALADIN-HIRLAM NWP system. *Atmospheric Research*, *172*, 163-173.

Summary of plans for the continuation of the project

During this and next years (next reporting period: Jul 2016 – Jun 2017) the following outlined tasks of the SP project will be continued:

- Evaluate importance of aerosol radiative effects over Europe through numerical experiments and objective verification for different radiation parameterisations with HARMONIE model using aerosol climatology and aerosol data from MACC-IFS reanalysis (*UoT*);
- Study aerosols impact on changes in atmospheric meso-scale circulation and life-time and physical parameters of convective cells with a focus on physical and dynamical mechanisms of feedbacks due to direct and indirect aerosol interactions on weather prediction (*OSEU, UHMI*);
- Implementation and testing of cold-phase microphysics into the STRACO cloud scheme and coupling to aerosol scheme including dust particles (*UoC, UoM, UHMI*);

- Evaluate Enviro-HARMONIE for selected cases (weak precipitation, active formation and intense release events) using radar data (from BaltRad experiment) for inter-comparison with modelling results for Nordic domain (*OSEU, UHMI*);
- Implement birch pollen emission module in Enviro-HIRLAM model and test its performance for Nordic countries with focus on Denmark (*UoC, RSHU*);
- Study influence of selected metropolitan areas on formation and development of meteorological and chemistry/aerosols fields due to effects from existing and developing urban land-use/infrastructure in a changing climate (*ITU, RSHU, UHMI*);
- Study impact of black carbon on air quality and climate in Northern Europe and Arctic through short-term/episode sensitivity studies on interactions between black carbon and meteorological processes as well as mechanisms of Arctic haze formation (*UoC, RSHU*);
- Perform sensitivity tests for different meteorological situations and episodes for accidental and continuous emissions on regional and meso-scales (*KazNRTU*);
- Study aerosol influence on high resolution NWP HARMONIE operational forecast (*UoL*).