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 2016 to June 2017
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 (University of Helsinki, UHEL)*
Affiliation/Address:	Danish Meteorological Institute (DMI) Research and Development Department (RDD) Lyngbyvej 100, Copenhagen DK-2100, Denmark
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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 2017)	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	4000000	4032575	4000000	427623
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

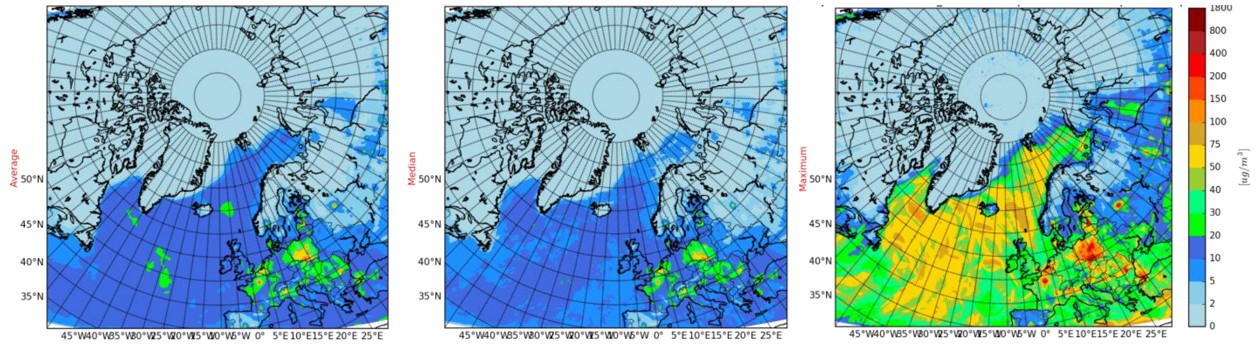
Summary of problems encountered (if any)

No problems observed

Summary of results of the current year (from July 2016 to June 2017)

Based on recent Enviro-HIRLAM/HARMONIE (the latest overview of the model is given by *Baklanov et al., 2017*) 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 the Universities and research organizations during the 2nd year (note that summary of the 1st year reporting period was presented in *Sass et al., 2017*) of the Special Project:

1. Study "Spatio-temporal variability of aerosols in the Arctic and boreal regions".
Aerosols have influence on weather, air quality and climate. Multi-scale modelling, and especially long-range atmospheric transport, dispersion, and deposition of aerosols from remote sources is especially challenging in northern latitudes. It is due to complexity of meteorological, chemical and biological processes, their interactions and especially within and above the surface layer, linking to climate change, and influence on ecosystems. The online integrated meteorology-chemistry-aerosols model Enviro-HIRLAM (Environment – High Resolution Limited Area Model) was employed. The model setup covers domain having 510 x 568 grids of latitude vs. longitude, horizontal resolution of 0.15 deg (appx 15 km), 40 vertical hybrid levels, time step of 360 sec, 6 h meteorological surface data assimilation. In particular, the focus was on studying spatio-temporal distribution of the concentration and deposition patterns of the particular matter (PM2.5 and PM10) for the winter and summer months (an example is shown in Figure 1). The model was employed in 4 modes: the reference run (e.g. without aerosols influence on meteorology) and 3 modified runs (direct aerosol effect (DAE), indirect aerosol effect (IDAE), and both effects DAE and IDAE included). The differences between the reference run and the runs with mentioned aerosol effects are statistically estimated on a day-by-day, monthly and diurnal cycle bases over the domain (*Mahura et al., 2017ab*).



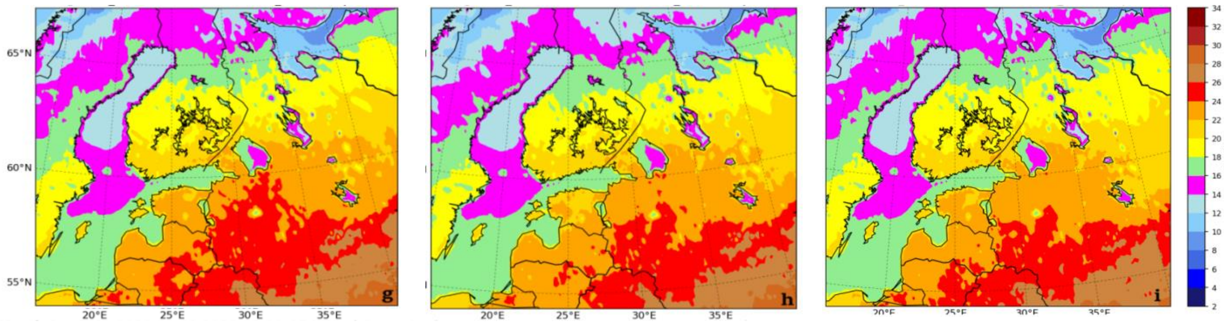
(a) *(b)* *(c)*

Figure 1*: Spatio-temporal distribution of the PM2.5 concentration field at 12 UTC - (a) average, (b) median, and (c) maximum for the Enviro-HILRAM long-term run for the month of January 2010 / at the 1st model level, 32 m/.*

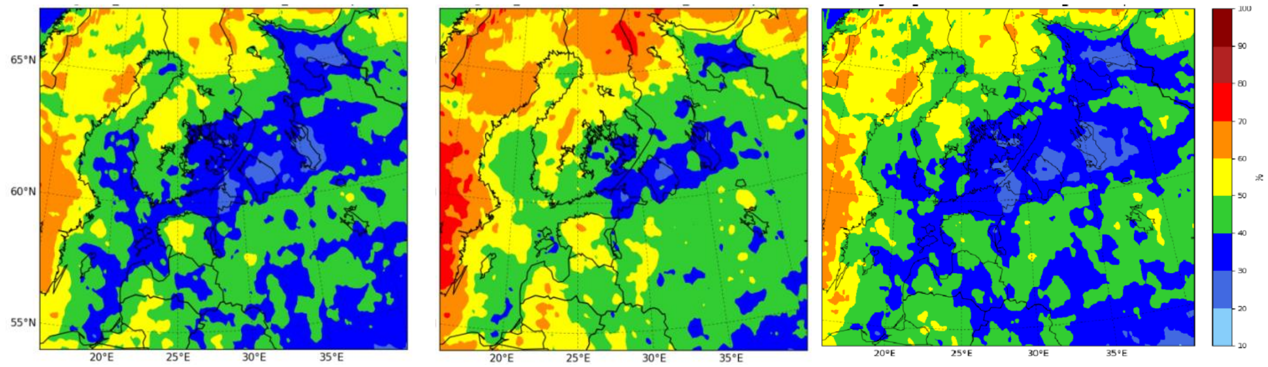
2. Study "Aerosols regional influence in North-West Russia"

In 21st century, the industrial development has reached the higher levels. In particular, almost all cities of Russia have own industrial enterprises. These produce large amounts of anthropogenic emissions. For megacities, there are several sources of such emission such as transport, energy and heating production from combustion, etc. St. Petersburg is one of such megacities. In this study the evaluation of pollutants influence (on example of the North-West Russia /NWRu/ as well as St. Petersburg megacity) has been realized through the online integrated modelling (employing the Enviro-HIRLAM model) of aerosols influence on regional and megacity scales and analysis of their influence on meteorological patterns, For NWRu region in focus, for episode 10-12 Jul 2010 and summer month of August 2010, four runs of the model were performed: CTRL (or control/ reference run, e.g. without any aerosols effects included), DAE (direct aerosols effects), IDAE (indirect aerosols effects) and DAE+IDAE (combined effects of both direct and indirect aerosols effects included). The analysis focused on evaluation of influence on key meteorological parameters such as air temperature at 2 m (T2m) and total cloud cover (TCC) (*Nerobelov, 2017; Nerobelov et al., 2017*). As an example, the monthly averaged T2m and TCC for the studied region as well as difference fields between the reference and direct/ indirect aerosol effects for the Enviro-HIRLAM model runs are shown in Figures 2-3.

For IDAE, for the short-term episode, on average, the TCC had changed by increasing up to 10-20% on a regional outlook. For the St. Petersburg megacity such change was about 3-6%. For the August 2010, this change was about 6-9% (with local maxima up to 20%) over NWRu in focus. For T2m, such aerosol effect was not well seen. In general, the IDAE led to changes of 0.4-1°C on regional scale in the northern and south-eastern territories of NWRu, and up to 1.2°C for the megacity. For DAE, the influence had the opposite effect than the IDAE for the case study. On regional scale, the TCC had reduced by 10-20%, as well as decreased on the boundaries of the megacity and surroundings. For August, the change was small in general, although in the western territories of NWRu it was showing a decrease up to 12%. For T2m, the DAE effect was more visible and stronger. It has been reflected in decrease of temperature by 2-3°C (for case study with unfavorable conditions) and by 2-2.5°C (for August). The combined effect (DAE+IDAE) for the case study, showed more influence on a regional scale, and the area of its influence is clearly depends on merging and overlapping areas of independent influence of indirect and direct effects, where changes are observed over larger size territories and the value of such changes became also larger by magnitude.

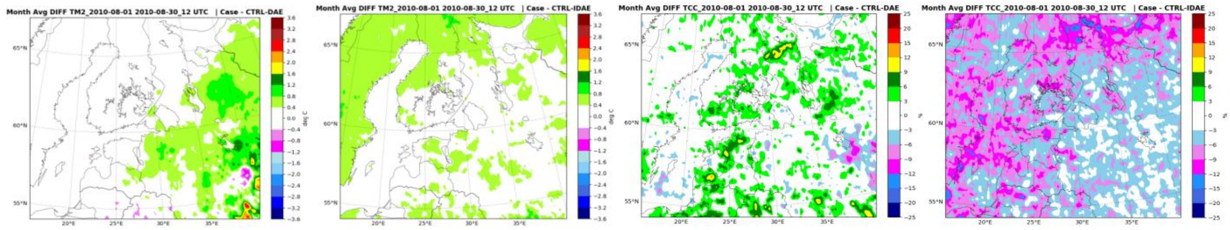


CTRL **IDAE** **DAE**



CTRL **IDAE** **DAE**

Figure 2: *Monthly averaged (at 12 UTC) (top) air temperature and (bottom) total cloud cover fields for - (left) CTRL, (middle) IDAE, and (right) DAE - Enviro-HIRLAM model runs.*

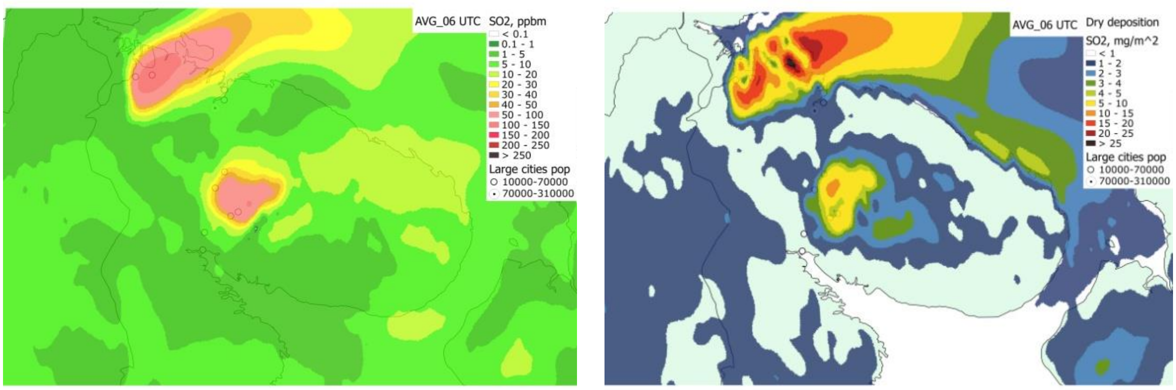


(a) *(b)* *(c)* *(d)*

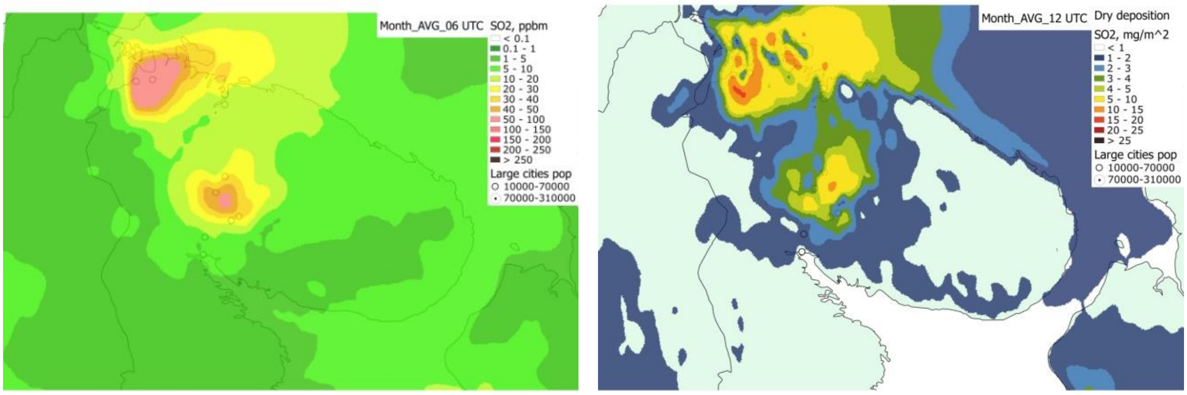
Figure 3: *Difference fields (at 12 UTC) for monthly averaged air temperature (a,b) and total cloud cover (cd) for the Enviro-HIRLAM model runs (a,c) CTRL vs. DAE and (b,d) CTRL vs. IDAE over 30 day period (1-30 Aug 2010).*

3. Study “Atmospheric transport and deposition patterns of SO_2 on the Kola Peninsula”

The Kola Peninsula (Murmansk region, Russia) has several sources of continuous emissions. Among such sources are the enterprises “Severonickel” (city of Monchegorsk) and “Pechenganickel” (cities of Nickel and Zapolayrnyy). These emit substantial amounts of sulphur dioxide (SO_2) and other chemical species, which are transported though the atmosphere, dispersed, and deposited on underlying surface. This study has been realized through Enviro-HIRLAM modelling and GIS evaluation of SO_2 pollution over the Kola Peninsula for episode 22-24 Jan 2010 and month of July 2010. For that, only the reference run was performed, and the analysis focused on evaluation of atmospheric concentration and deposition patterns for SO_2. For this study, the Enviro-HIRLAM modeling results (concentration and deposition fields) were also integrated into the GIS environment (using QuantumGIS) for further planned analysis of potential impact on environment and population (*Sedeeva, 2017; Nerobelov et al., 2017*). The spatio-temporal distribution of the averaged concentration and deposition patterns is shown on examples in Figure 4: for the episode and January 2010.



(a) *(b)*



(c) *(d)*

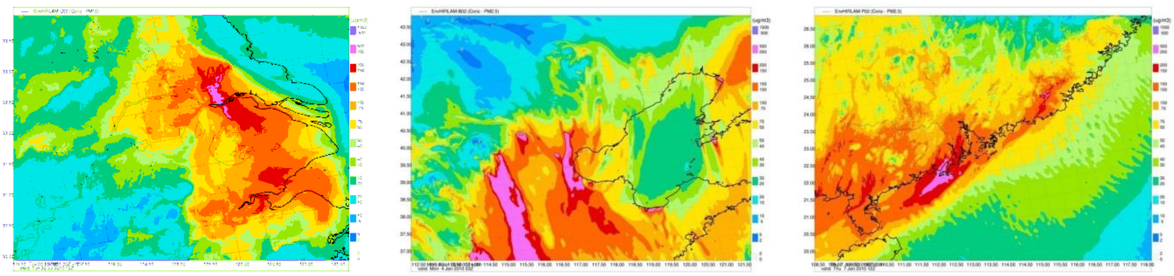
Figure 4*: Examples of the spatio-temporal distribution of SO2 averaged (a,c) concentrations and (b,d) deposition patterns for the (ab) case study/ episode 22-24 Jan 2010 and (cd) full month of January 2010.*

Analysis of short-term episode with unfavorable meteorological and air pollution conditions showed that averaged concentration of SO_2 was about 141 and 89 ppbm for the Nickel-Zapolayrnyy and Apatity-Kirovsk settlements (populated areas), respectively. The maximum on a diurnal cycle was observed at 12 UTC (15 pm of local time). The dry deposition were about 21 and 14 ug/m^2 for the first and the second areas mentioned above, respectively, with elevated values during the daytime. For Jan 2010, the daily averaged concentration was about 100 and 55 ppbm for the Nickel-Zapolayrnyy and Apatity-Kirovsk (cities located to S-E from the "Severonickel" smelters) settlements, respectively. The deposition was higher during 06-18 UTCs period, and it was higher for the first area compared with the second: 87 vs. 50 mg/m^2).

4. Study "Enviro-HIRLAM downscaling to metropolitan areas".

The most serious air pollution events occur in cities where there is a combination of high population density and air pollution. The pollutants can lead to serious human health problems. Due to constantly increasing supercomputer power modern nested numerical meteorological and air pollution models realize model nesting/down-scaling from the global to urban scale and approach the necessary horizontal and vertical resolutions to provide weather and atmospheric composition forecasts for urban scales. It will bring strong support for continuous improvement of the forecast modelling systems for weather and air quality worldwide, and underline clear perspectives for future multi-scale air quality core-downstream services for end-users.

In studies by *Mahura et al. (2017cd)*, the evaluation of formation and development of meteorological and chemical/aerosol patterns due to influence of the metropolitan areas is performed employing the urbanized version of the Enviro-HIRLAM. For urbanization of this model, several options are used such as modifications of the anthropogenic heat flux and roughness, building effects parameterisation (BEP), modified soil model for urban areas having improved urban heat and water budgets, and others. In particular, the BEP module was implemented in the model and used in several studies with a focus on metropolitan areas. The downscaling approach is useful for both research and operational forecasting tasks. In particular, originally, the model is running at a low resolution, and then the same model (but with urbanization included) is running at the finer scale (using generated 3D fields from the outer model runs). The model is run at regional, sub-regional and urban scale (at resolutions of 15, 5, and 2.5 km). Examples of Enviro-HIRLAM runs at the urban scale for selected Chinese metropolitan areas are shown in Figure 5.



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

***Figure 5**: Examples of Enviro-HILRAM urban scale forecast for atmospheric composition (PM10 and PM2.5) to selected metropolitan areas of (a) Shanghai, (b) Beijing, and (c) Perl River Delta of China.*

Finer scale resolution modelling allows to simulate influence of metropolitan areas on both meteorological and chemical patterns: (i) on meteorology - these effects are more visible at low wind conditions and above/ closer downwind distances to urban areas; (ii) on chemistry - higher concentrations of maxima at finer resolutions and more complex non-homogeneous structure of pollutant plumes are both observed. The effects of urbanization are important for atmospheric transport, dispersion, deposition, and chemical transformations, in addition to better quality emission inventories (in especially, within the urban areas). Such forecasting is important for metropolitan areas, where formation and development of meteorological and chemical/aerosol patterns are especially complex. It also provides information for evaluation impact on selected megacities as well as for investigation relationship between air pollution and meteorology on urban scales. Tested downscaling modelling system for regional-meso-urban scales can be applied for advanced planning safety measures, post-accidental analysis and health/environment impact assessment, and operational forecasting and emergency preparedness, and others.

List of publications/reports from the project with complete references

NEW ADDED REFERENCES

Baklanov, A., Korsholm, U. S., Nuterman, R., Mahura, A., Nielsen, K. P., Sass, B. H., Rasmussen, A., Zakey, A., Kaas, E., Kurganskiy, A., Sørensen, B., and González-Aparicio, I. (**2017**): The Enviro-HIRLAM online integrated meteorology–chemistry modelling system: strategy, methodology, developments, and applications, *Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-319; in review, 2017; http://www.geosci-model-dev-discuss.net/gmd-2016-319/, in press*

Mahura A., R. Nuterman, A. Baklanov (**2017a**): High Resolution Modelling of Aerosols-Meteorology Interactions over Northern Europe and Arctic regions. *Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2017, Vienna, Austria; Geophysical Research Abstracts, Vol.19, EGU2017-9607.*

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Mahura A., Amstrup B., Nuterman R., Yang X., Baklanov A. (**2017c**): Multi-Scale Enviro-HIRLAM Forecasting of Weather and Atmospheric Composition over China and its Megacities. *Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2017, Vienna, Austria; Geophysical Research Abstracts, Vol.19, EGU2017-9564.*

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Sass B.H., Mahura A., Nuterman R., Baklanov A., Palamarchuck J., Ivanov S., Nielsen K.P., Penenko A., Edvardsson N., Stysiak A., Bostanbekov K., Amstrup B., Yang X., Ruban I., Jensen M.B., Penenko A., Nurseitov A., Zakarin E. (**2017**): Enviro-HIRLAM/ HARMONIE Studies in ECMWF HPC EnviroAerosols. *Abstracts of European Geosciences Union (EGU) General Assembly, 17-22 Apr 2017, Vienna, Austria; Geophysical Research Abstracts, Vol.19, EGU2017-15675.*

Sedeeva M. (**2017**): Regional modelling and GIS evaluation of environmental pollution fom sources of the Kola Peninsula. *BSc Thesis; Russian State Hydrometeorological University (RSHU), St. Petersburg, Russia; 64 p.; Supervisors – Suleiman Mostamandy, Alexander Mahura, Roman Nuterman, Alexander Ugryumov*

PREVIOUS REPORT 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*

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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*

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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.*

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Summary of plans for the continuation of the project

During this year (next reporting period: Jul 2017 – Dec 2017; which is the final reporting and will include combined and summarized material from all previous reporting and will cover the entire period from Jul 2015 until Dec 2017) the following outlined tasks of the SP project will be continued:

- 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, FMI, UHMI*);
- Evaluate 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, FMI, UHMI*);

- 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 (*RSHU*, *UHEL*);
- 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 (*RSHU*, *UoC*, *UHEL*);
- 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 (*RSHU*, *UHEL*).