SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	**EnviroChemistry on ECMWF** (*Enviro-HIRLAM: development and test of an NWP model system accounting for aerosol-meteorology interactions*)
Computer Project Account:	SPDKBAKL
Start Year - End Year :	Apr 2012 – Dec 2014
Principal Investigator(s)	Prof., Dr. Alexander Baklanov *Reported by Alexander Mahura (DMI) and Roman Nuterman (Univ of Copenhagen, UCPH)*
Affiliation/Address:	Danish Meteorological Institute (DMI) Research and Development Department (RDD) Lyngbyvej 100, Copenhagen DK-2100, Denmark
Name of ECMWF scientist(s) collaborating to the project	Dr. Johannes Flemming
Other Researchers (Name/Affiliation):	Kristian Pagh Nielsen (DMI), Alexander Mahura (DMI), Ashraf Zakey (DMI), Ulrik Korsholm (DMI), Xiaohua Yang (DMI), Eigil Kaas (UCPH), Roman Nuterman (UCPH), Alexander Kurganskiy (UCPH), Brian Sørensen (UCPH), Sergey Ivanov (OSEU), Julia Palamarchuk (OSEU), HIRLAM-B members

The following should cover the entire project duration.

Summary of project objectives
(10 lines max)

The emphasis in the "**EnviroChemistry on ECMWF**" Special Project at ECMWF was primarily on the evaluation and testing of the online integrated Enviro-HIRLAM (Environment – HIgh Resolution Limited Area Model) / HARMONIE modelling system and sensitivity analyses of the feedback mechanisms for Numerical Weather prediction (NWP) and Chemical Weather Forecasting (CWF). Two main application areas of the integrated modelling are expected to be considered: (i) improved NWP with short-term feedbacks of aerosols and chemistry on meteorological variables, and (ii) improved CWF with online integrated meteorological forecast and two-way feedbacks between aerosols/chemistry and meteorology. Specific objectives focused on - short-term episodes/case studies and chemical and physical weather forecasting for study of sensitivity of the aerosol feedback effects on meteorology and air quality; long-term simulations for testing the model for long-term effects and climate scenarios; for testing boundary conditions and chemical data assimilation in Enviro-HIRLAM.

Summary of problems encountered
(If you encountered any problems of a more technical nature, please describe them here)

The SP project started with some delay (e.g. from Apr 2012). At the start, because of software and hardware upgrade of High Performance Facility at ECMWF there were multiple technical difficulties with model setup, testing and running. At the beginning, the realisation of some experiments was going slower than expected due to complexity of the operational system environment and lack of experience with the use of ECMWF HPC equipment.
Later (in 2013), due to the decision of the HIRLAM Consortium to move from the NWP HIRLAM to the NWP HARMONIE platform, the focus started to shift toward building a new version of online-coupled ACT-NWP model (after the Enviro-HIRLAM system) based on the HARMONIE platform (AROMA-C or Enviro-HARMONIE). This work requires a lot of new model development works, involvement of new collaborating groups originally not participated in the project (see section **Future plans**).

Experience with the Special Project framework
(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

Reporting forms/ templates are freely available at ECMWF website, the corresponding notification e-mails about status on project resources usage, updates of the ECMWF HPC system, and requests for SP reporting were sent in due time.

Summary of results
(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

Reporting period 1: Apr 2012 – July 2012

Because the project started in April 2012 the reporting period includes only a few months of the projects relevant activities. According to the plans the following processes, which are of importance in NWP and CWF applications, are (or being) implemented in the Enviro-HIRLAM model:
- Implementation of simplified aerosol scheme for use in NWP models (in progress);
- Direct aerosol-radiation interactions including both short and long wave radiation (done);
- Semi-direct aerosol-radiation interactions (done);

- Aerosol-cloud interactions with respect to precipitation and radiation (1st version done);
- Implementation of cold-phase microphysics into the STRACO cloud scheme and coupling to the aerosol scheme (in progress).

New effective numerical scheme (a new mass conserving semi-Lagrangian version) was realised in Enviro-HIRLAM (Sørensen et al., 2012). Meteorological MACC/ECMWF IFS and AQMEII Phase1 chemical boundary conditions were pre-processed and several test model runs were performed. The new emission inventory for year 2010 next started to be pre-processed as well as chemical boundary conditions from AQMEII Phase2 and further model tests. Implementation and evaluation of new gas-phase chemistry in the Enviro-HIRLAM was done. A condensed version of the CBMZ chemistry scheme has been implemented. The main difference to the original version is a simplified organic phase. Preliminary results looked promising and the model was ready for comprehensive testing. An extensive online integrated ACT-NWP model evaluation exercise is being setup together with the AQMEII program, COST action ES1004 and MACC/ECMWF (J. Flemming).

Reporting period 2: July 2012 – July 2013

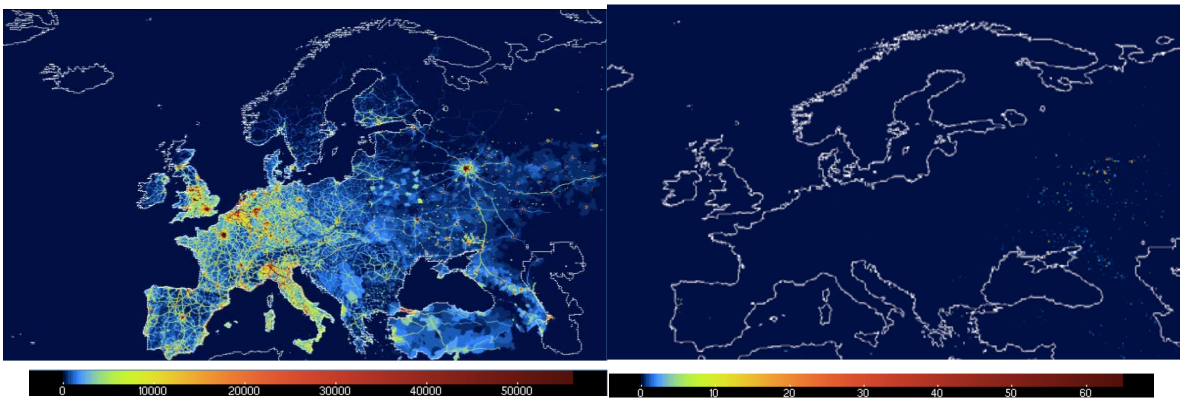
The prediction and simulation of the coupled evolution of atmospheric dynamics, pollutant transport, chemical reactions and atmospheric composition will remain one of the most challenging tasks in environmental modelling over the next decades, but is of great importance for air quality assessment, climate change studies and weather forecasting as they all involve strongly integrated processes. Meteorology and chemistry feedbacks are important in the context of many research areas and applications, including numerical weather prediction (NWP), air quality (AQ) forecasting as well as climate and Earth system modelling. For example, in NWP community it is recognized that atmospheric composition can influence both weather and climate by directly changing the atmospheric radiation budget or indirectly affecting cloud, fog, visibility, and precipitation formation. However, the relative importance of online integration and of the priorities, requirements and level of details necessary for representing different processes and feedbacks can greatly vary for these related communities.

Following the HIRLAM development strategy and according to the project plans two main lines of model developments and simulations were realised:

1. Further developments and sensitivity runs of the Enviro-HIRLAM online coupled ACT-NWP modelling system (from the start of the project);
2. New testing and developments based on the HARMONIE modelling platform (starting 2013).

Enviro-HIRLAM: The main model testing and feedback sensitivity studies have been decided to realise within the new initiative AQMEII Phase-2. The Air Quality Model Evaluation International Initiative (AQMEII) aims to evaluate regional scale air quality models and to develop a common evaluation framework across European and North American atmospheric modelling communities. AQMEII Phase-2 focuses on inter-comparison of on-line coupled regional-scale models. Around 20 groups from EU (including Enviro-HIRLAM) and 4 from NA are participating in the second phase with annual simulations for the years 2006 (NA) or/and 2010 (EU). Common chemical boundary conditions from MOZART-IFS modelling system, anthropogenic emissions from TNO-MACC database, forest fires emission by FMI and domain configuration (30W- 60E, 25N-70N at 0.25 x 0.25 horizontal resolution) are pre-defined and provided by AQMEII (Figure 1).

The COST Action ES-1004 “European framework for online integrated air quality and meteorology modelling” (EuMetChem - http://eumetchem.info; Baklanov et al., 2013) is coordinating the European models intercomparison effort within the AQMEII-Phase2 international initiative. The main objectives are the intercomparision of on-line models to better understand the impact of feedbacks on both meteorology and chemistry processes when ones solved in an integrated approach. An extensive online integrated ACT-NWP model evaluation exercise is being setup together with the AQMEII program, COST action ES1004 and MACC/ECMWF (J. Flemming).



(a) *(b)*

Figure 1*: (a) Annual anthropogenic* $PM_{2.5}$ *emissions (in Mg/year) from road transport from TNO-MACC database (resolution: 0.0625^o x 0.12^o); (b) IS4FIRES (http://is4fires.fmi.fi) forest fires total PM emissions (in kg/s) for Jul 28, 2010 (resolution: 0.5^o x 0.5^o).*

The following processes, which are of importance in NWP and chemical weather prediction, are (or being to be) implemented in the model (Nuterman et al., 2013): i) implementation of simplified aerosol microphysics M7 scheme for use in NWP models (done); ii) implementation of simple tropospheric sulphur cycle chemistry, used with M7 only (done); iii) implementation of wet-/dry-deposition schemes as well as sedimentation for both gases and aerosols for use in NWP models (done); iv) aerosol activation scheme and cloud processing with respect to precipitation & radiation (done); v) implementation of cold-phase microphysics into the STRACO cloud scheme and coupling to the aerosol scheme (in progress).
Both the meteorological (ECMWF-IFS) and chemical boundary conditions (IFS-MOZART) as well as new emission inventory (TNO/MACC for AQMEII Phase-2) for the year 2009 were pre-processed and several test model runs were performed.

For test runs, modelling domain, which covers Europe, Northern Atlantics and Western Russia (69W- 78E, 26N-79N) was used. Horizontal grid resolution is 0.15^o x 0.15^o with 40 hybrid sigma levels (up to 10 hPa). Simulations were performed with and without feedbacks (indirect effects). In Figure 2 shows total particulate matter of size 2.5 um, total cloud cover and cloud water content and difference contour plots (Enviro-HIRLAM – Reference HIRLAM) of total cloud cover and cloud water content. In Figure 2ab, the highest $PM_{2.5}$ concentrations are observed over North Sea (caused mainly by sea salt emissions as well as oil extraction), UK and inland Europe around urbanized or industrial areas. Figure 2cd shows cloudy areas with largest cloud water content over Atlantic, Biscay Bay, and Northern Scandinavia and Central Europe. As seen from the Figure 2ef there is cloud cover and cloud water content increase due to existence of natural and anthropogenic aerosol which are activated and used as cloud condensation nuclei.

HARMONIE: additionally to the original plans the following testing and developments based on the HARMONIE modelling platform (mostly based on an 1D version at start) were done by our collaborators (e.g. PhD and MS students) from the Odessa State Environmental University, OSEU.

Summary of Results (July 2012 – July 2013)

The preliminary experiments with the MUSC model (1D single column version of HARMONIE) have been performed. The focus was on the investigation of the interaction between aerosols and physical atmospheric characteristics such as the solar radiation distribution and precipitation. Different concentrations and types of aerosols by their origin were considered. Results have shown that incoming solar radiation below of about 2000 m is absorbed more intensively by land aerosols comparing with sea ones. The opposite behavior of absorbing properties was revealed in the middle and upper troposphere due to the more homogeneous vertical distribution of marine aerosols. The presence of aerosols leads to changes in precipitation rate and shifting in time events occurring.

However, in higher humidity atmosphere effects of aerosols diminish due to increasing the role of pure physical processes in the atmosphere.

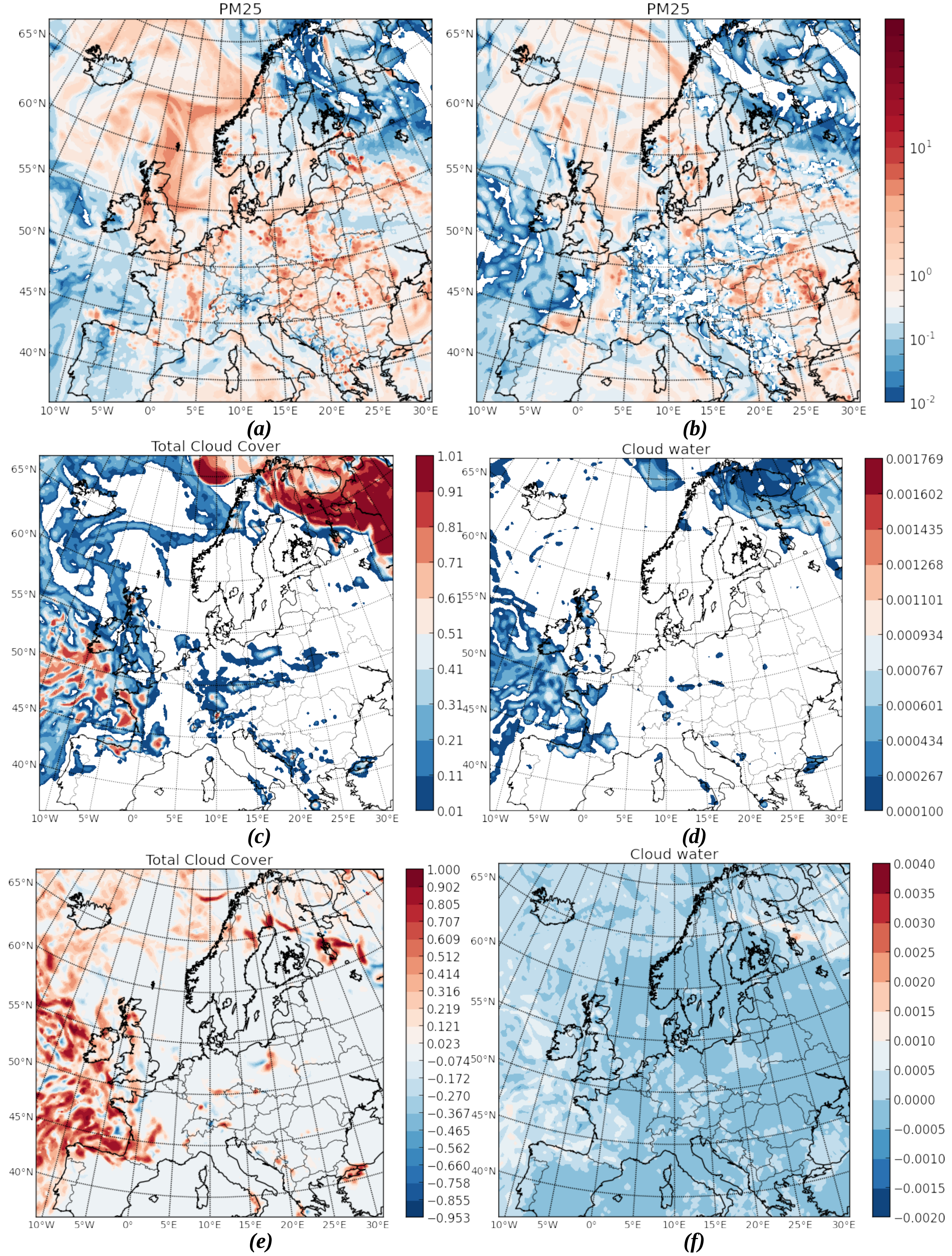


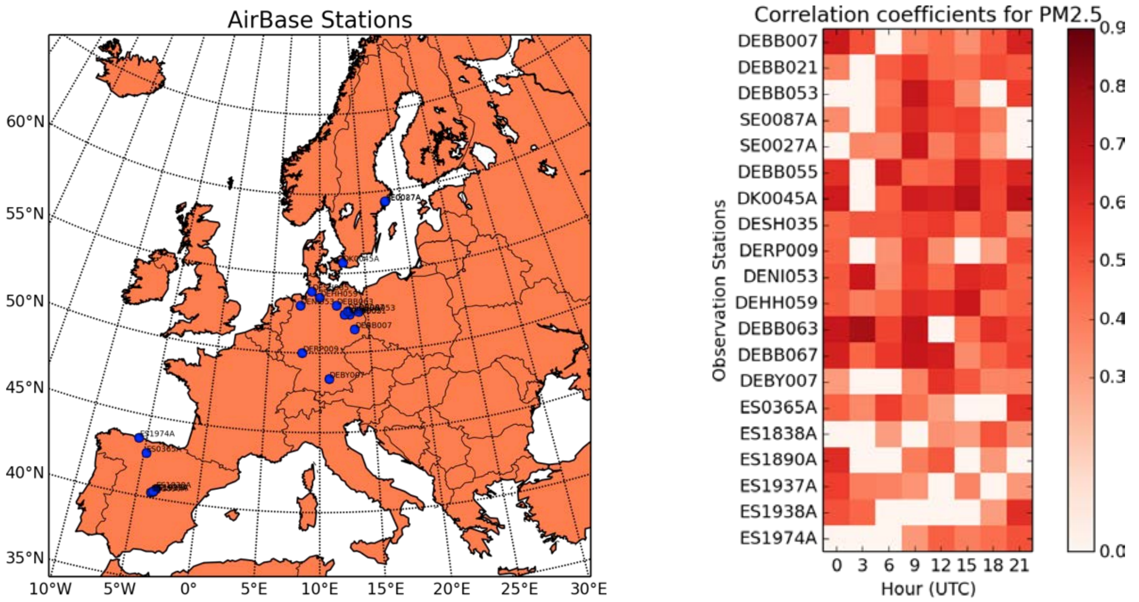
Figure 2: *Concentration [in ppbm] of total PM$_{2.5}$ at 500 m (a) and 1000 m (b); total cloud cover [on scale 0-1] (c) and cloud water content [in kg/m2] (d) at 500 m; difference contour plots (Enviro-HIRLAM – Reference HIRLAM) of total cloud cover (e) and cloud water content (f) at 500 m; simulation was performed for July 3, 2009 (with 2 day spin-up), 09 UTC.*

Reporting period 3: July 2013 – July 2014

Enviro-HIRLAM: During previous year, the following was implemented in the Enviro-HIRLAM model: i) simplified aerosol microphysics M7 scheme; ii) simple tropospheric sulphur cycle chemistry; iii) wet-/dry- deposition schemes; iv) sedimentation for both gases and aerosols; v) aerosol activation scheme and cloud processing with respect to precipitation and radiation.

To perform analysis of atmospheric aerosol effects at fine spatial-temporal scales on clouds and precipitation, the year 2010 was selected. That year, especially summer, was characterized by severe weather events such as floods, heat waves and droughts across Middle East, most of Europe and European Russia. The Enviro-HIRLAM (Environment – HIgh Resolution Limited Area Model; http://www.hirlam.org) model was employed for the analysis. It was forced by boundary and initial conditions produced by ECMWF IFS (http://www.ecmwf.int/research/ifsdocs) and MOZART (http://www.acd.ucar.edu/gctm) models for meteorology (horizontal resolution - 0.15° x 0.15°) and atmospheric composition (horizontal resolution - 1.125° x 1.125°), respectively. The Enviro-HIRLAM modelling domain with horizontal resolution of 0.15° x 0.15° and 40 vertical hybrid levels covers Europe, North of Sahara, and Central Russia. The model includes HAM-M7 aerosol microphysics module (*Vignati et al., 2004*) and emissions from anthropogenic sources by TNO (*Kuenen et al., 2011*) and from wildfires by FMI (http://is4fires.fmi.fi) as well as interactive sea-salt (*Zakey et al., 2008*) and dust (*Zakey et al., 2006*) emissions.

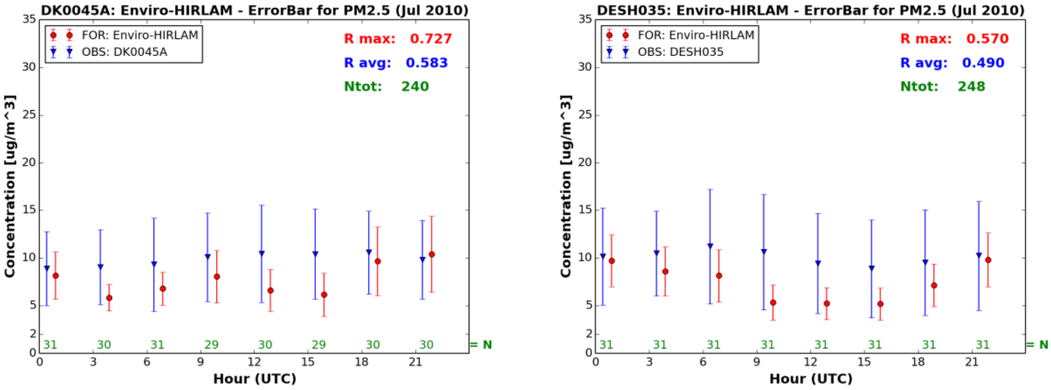
For ground-based $PM_{2.5}$, the Enviro-HIRLAM model was evaluated for Jun 2010 vs. observations from EU AirBase air-quality network (http://acm.eionet.europa.eu/databases/airbase), with a number of stations located in Denmark, Sweden, Germany and Spain (see Fig. 3a). Fig. 3b shows correlation coefficients on a diurnal cycle for $PM_{2.5}$ concentrations at selected measurement sites. In general it shows a fairly good positive correlations (more than +0.3), except for several Spanish stations (such as ES1938A at daytime, and ES1974A - at nighttime).



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

Figure 3: *(a) Map of selected AirBase air-quality monitoring stations (http://acm.eionet.europa.eu/databases/airbase/) across Europe; (b) $PM_{2.5}$ correlation coefficient on diurnal cycle for selected AirBase observation stations.*

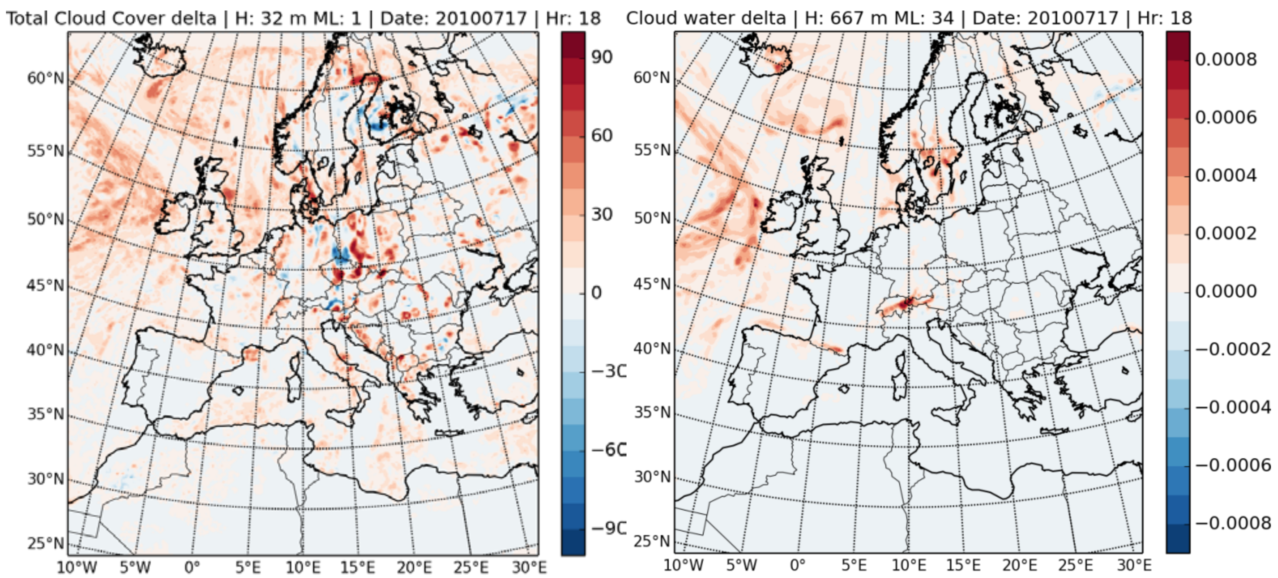
The model predicts well $PM_{2.5}$ day-to-day variability, but always has negative bias (Fig. 4). This underprediction is due to several reasons: i) simple aerosol microphysics without secondary organic aerosols; ii) partitioning of ammonium nitrate; iii) crude model resolution, which still cannot capture small-scale effects like complex orography and urbanized regions (in particular, due to lack of fine-resolution emissions from anthropogenic sources, like urban traffic). For instance, the model shows negative bias of $PM_{2.5}$ during daytime at Danish urban station (Fig. 4a) apparently due to crude model resolution. It was also found that $PM_{2.5}$ value is very influenced by changes in atmospheric stability conditions, which difficult to predict accurately in many NWP models. This can be observed from correlation coefficient decrease at stations during nighttime (at 03 UTC) or from underestimation of elevated concentrations. In spite of these issues, the model can well reproduce diurnal cycle of aerosols at different sites (urban (Fig. 4a, coastal and rural (Fig. 4b)) and shows overall good performance.



(a) *(b)*

Figure 4: *Error-bar concentrations [ug/m^3] on diurnal cycle for AirBase observations vs. Enviro-HIRLAM modeling results; (a) Danish urban station and (b) German rural station; Right top corner indicates maximum and average correlation coefficients for the station as well as total number of analysed observation samples; Green numbers along X axis indicate number of observation samples per time slice.*

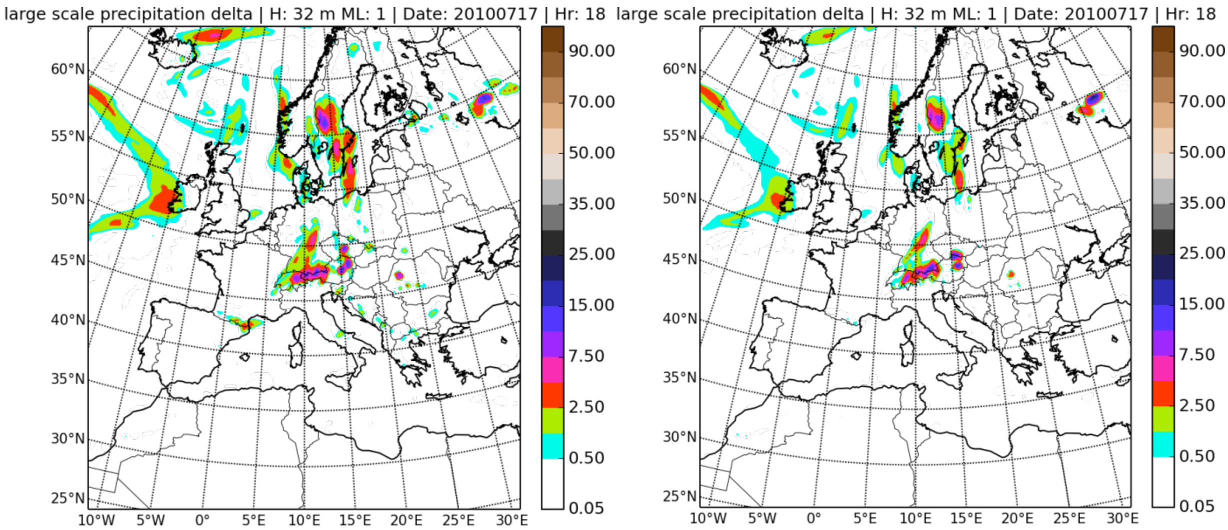
For aerosol-cloud interactions, these were estimated also for Jul 2010 by means of delta function, i.e., difference between outputs of models: Enviro-HIRLAM with aerosol-cloud interactions (ENV) and Reference-HIRLAM (REF). During previous month June, there were several heat waves over Western and Eastern Europe followed by heavy precipitation events in Switzerland, Germany and Poland. Fig. 5a shows deltas (ENV–REF) of total cloud cover over model domain, which is mainly increased (with local maxima up to 90%) except several inland areas (such as Finland, borders of Germany, Poland and Austria), where cloud cover decreased by almost 10 fold. The ENV runs revealed the increase of average cloud top height by approximately 2%. The delta function of cloud water content at average cloud base shows (Fig. 5b) its increase compared to REF and local maxima over North Atlantic, North Sea, Sweden, Switzerland, and Austria. These areas are occupied by precipitating clouds as seen in Fig. 6.



(a) *(b)*

Figure 5: *Delta (Enviro-HIRLAM – Reference-HIRLAM) of vertically integrated total cloud cover [%] (left) and cloud water content [kg/kg] (right) at average cloud base (667 m) on 17 Jul 2010, 18 UTC.*

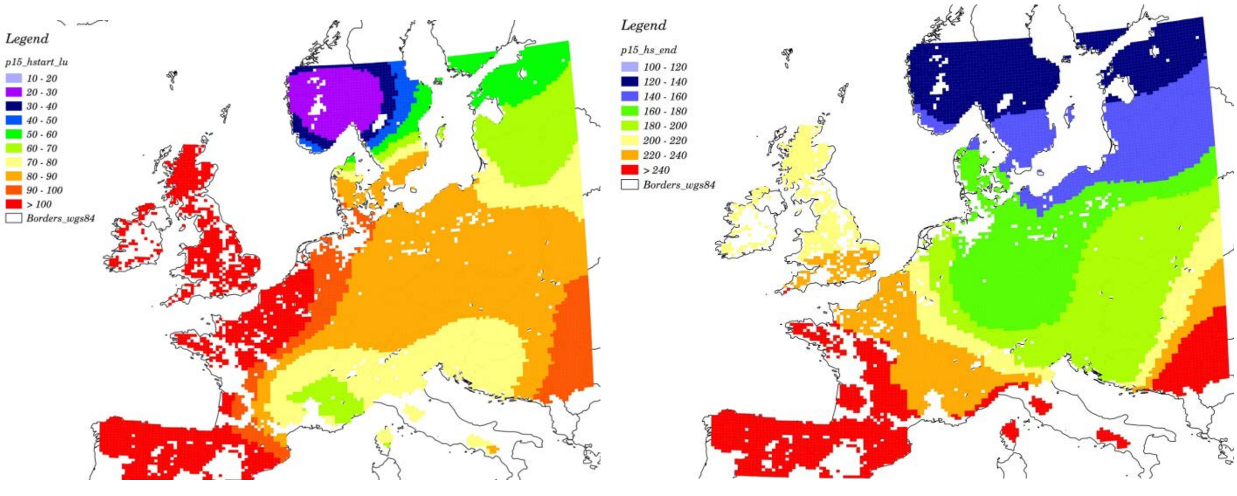
The absolute frequencies of stratiform and convective precipitation over computational domain are decreased compared to REF model, while the amount of convective precipitation during heavy precipitation events is increased. Hence, the wet deposition of particles decreases in summer because it rather depends on precipitation frequency than on its amount. The REF model run tends to overpredict both frequency and amount of precipitation. The inclusion of aerosol-cloud interactions can improve general model performance, i.e., the ENV run bias for precipitation with respect to its frequency and amount has been decreased compared to REF model run (Fig. 6).



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

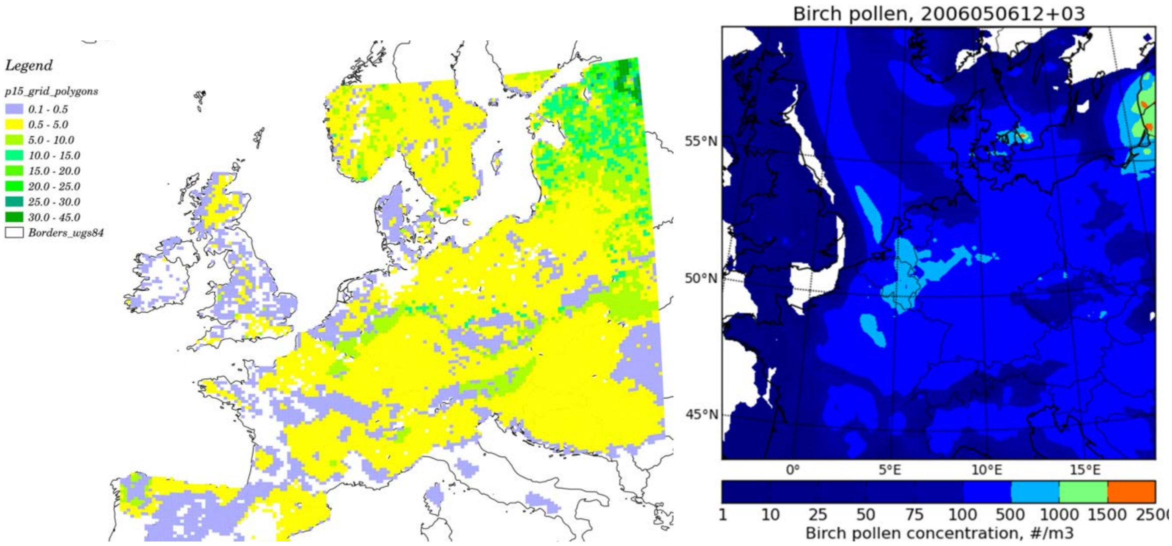
Figure 6: *Accumulated (3 hour) precipitation patterns from Reference-HIRLAM (REF) and Enviro-HIRLAM with aerosol-cloud interactions (ENV) on 17 Jul 2010, 18 UTC: stratiform precipitation: (a) – REF, (b) – ENV.*

For birch pollen studies, the domain covering Europe and having 15-km horizontal resolution was selected, and several cases studies for year of 2006 were performed with the Enviro-HIRLAM model. The corresponding domain with fractions (%) of birch trees is shown in Fig. 8a. This Figure/map is a result of combining three GIS databases: 1) Tree Species Inventory (TSI) (*Skjøth et al., 2008*), 2) European Forest Institute (EFI) (*Päivinen et al., 2001*), and 3) Global Land Cover (GLC). The air temperature sum thresholds (in degree-days) for the start of flowering season are shown in Fig. 7a, and the temperature sum thresholds for the end of flowering season are shown in Fig. 7b. Note that data were plotted for each grid cell containing fraction of birch forest. An example of Enviro-HIRLAM run is shown in Fig. 8b. For this run, the temperature threshold for the start of the season was equal to 60 degree-days (e.g. 1440 degree-hours) for the entire domain.



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

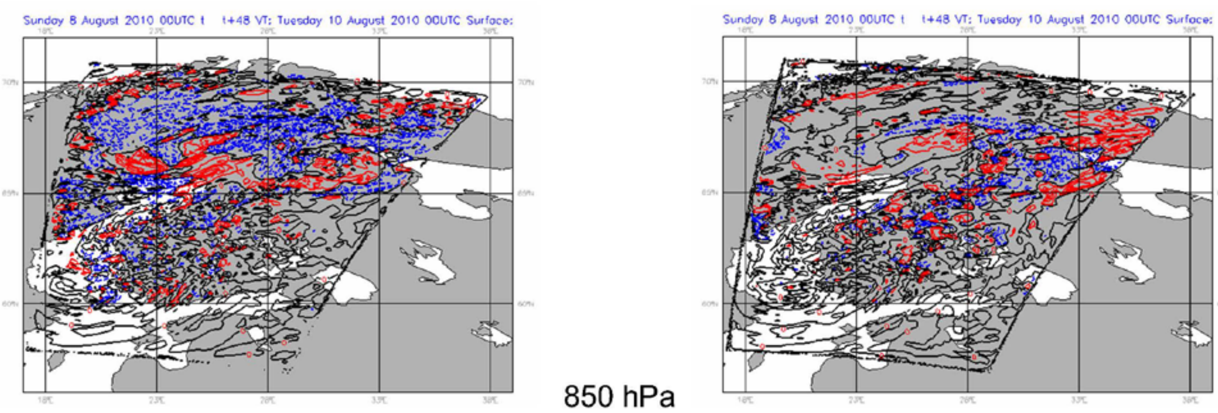
Figure 7: *Accumulated temperature sum thresholds for the (a) start & (b) end of the birch flowering season.*



(a) *(b)*

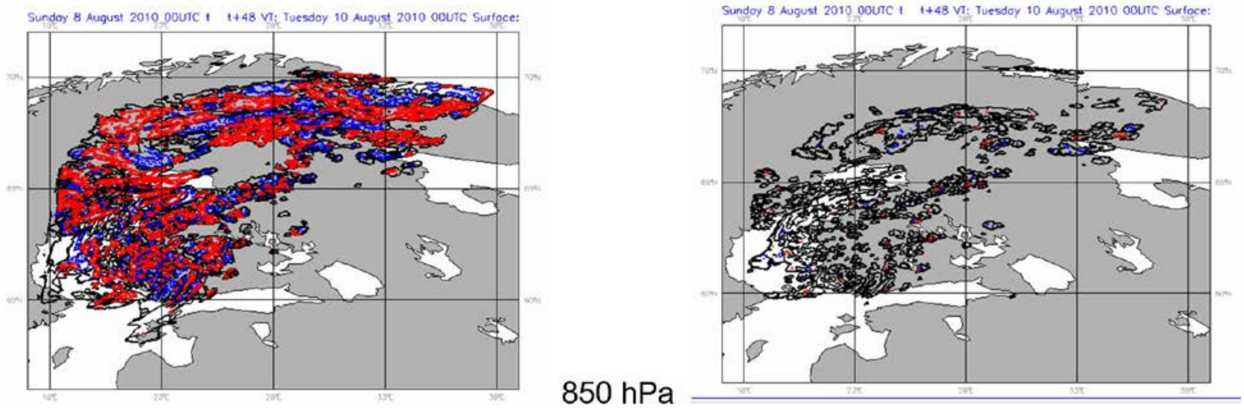
Figure 8: *(a) fraction of birch trees, & (b) birch pollen concentration (grains/m3) on 6 May 2006, 15 UTC.*

HARMONIE: During reporting period the further development, integration, testing, and optimization continued for aerosol module in the HARMONIE modelling system. After that a series of numerical experiments for case studies and episodes with updated aerosol data was carried out. Analysis of convective cell life-time with the focus on aerosol impact on physical variables such as temperature, water mass content, precipitation rate, heat and mass fluxes, vertical speed, etc. was performed. In particular, numerical experiments (for Aug 2010 over Finland) with aerosol-physics interactions were performed including climatological and zero values as well as increased black carbon and organic matter content. The comparison of results with zero aerosol concentrations vs. climatological values is given in Figs. 9-10. Analysis shows presence of aerosols changes for most of atmospheric fields such as for temperature, humidity, cloud cover, precipitation, short- and long-wave radiation fluxes through the troposphere. The most visible effect from aerosols is an increase of cloud cover mainly in the lower part of atmosphere accompanied by decrease of precipitation rate. This confirms well known fact that aerosols serve as CCNs, with following changes in radiation processes. Note, the impact is observed in a form of meso-scale non-homogeneity in the domain and associated with specific areas of synoptic patterns. Non-linear and multi-level response in meteorological variables can occur due to a chain of interactions. The generated model output with hourly temporal resolution could allow to track evolution and life-cycle of synoptic systems as well as to account changes in heat and mass fluxes due to the aerosol impact.



(a) *(b)*

Figure 9: *Differences between HARMONIE runs with zero vs. climatological aerosol concentrations for (a) air temperature and (b) specific humidity at 850 hPa level on 10 Aug 2010, 00 UTC /blue – negative, and red – positive/.*



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

Figure 10: *Differences between HARMONIE runs with zero vs. climatological aerosol concentrations for (a) total cloud cover and (b) rain water at 850 hPa level on 10 Aug 2010, 00 UTC /blue – negative, and red – positive/.*

Summary of Results (Jul 2013 – July 2014)

Enviro-HIRLAM: The preliminary fine-scale NWP-ACT model runs showed that the atmospheric aerosol substantially influence both total cloud cover and cloud water content leading to increase of their amounts. The average cloud top height has the same tendency as well. Future urbanization and industrialization in Europe will cause more emissions of anthropogenic aerosols. As a result, the absolute precipitation frequency will decrease, while the precipitation during heavy rains, for instance after heat weaves, will likely to increase its amount. The atmospheric aerosols scavenging will decrease, because it rather depends on the precipitation frequency than on its amount. The influence of greenhouse gases on clouds and precipitation was not considered because the time-scales of the model runs are not large enough to see any effects from long-term changes in the atmospheric composition.

HARMONIE: The installing and exploring of full 3D HARMONIE model with the AROME physics on the ECMWF platform was done. Numerical experiments over the North Atlantic - European domain, according to AQMEII evaluation requirements, have been run. Results of these experiments showed prominent influence of aerosols on majority of physical atmospheric variables in the model forecasts. The impact appears in a form of irregularly distributed meso-scale patterns with opposite signs. In particular, after 5-day integration the deviation in temperature within these patterns increased up to 7-10 K, vertical speed changed by 3-5 cm/s, precipitation varied depending on a rain-rate. Aerosols can lead to increased heavy precipitation, while tend to smooth weaker rains. Integrated analysis revealed a complex set of interactions and feedbacks between aerosols, radiation processes, vertical profiles, convective regimes, which lead to changes in a life-cycle of cloud and precipitation systems.

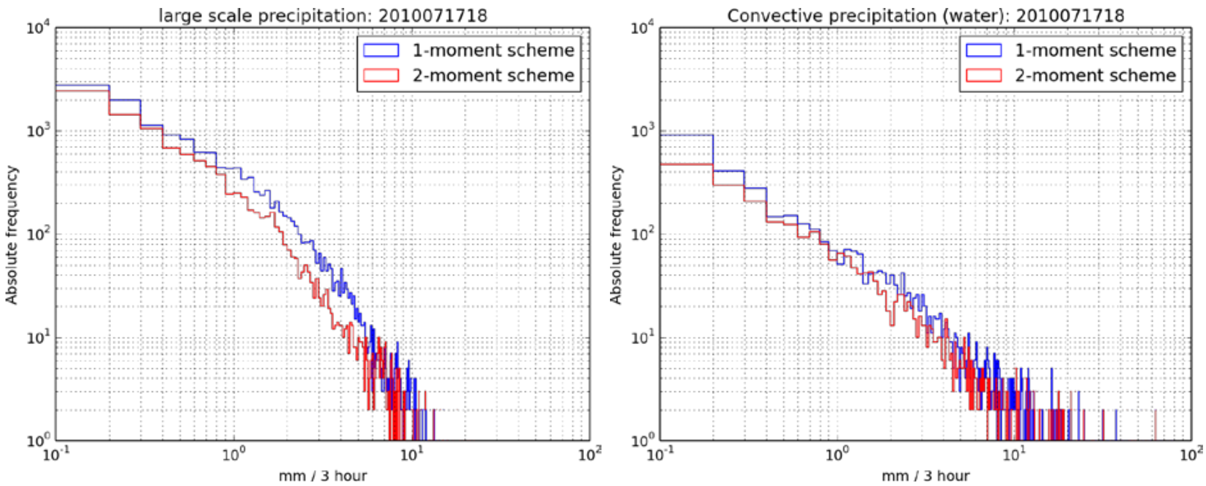
Reporting period 4: July 2014 – December 2014

Enviro-HIRLAM: During the last 6 month period, the online integrated Enviro-HIRLAM model was run (for selected months of 2010 for the Northern Hemisphere and European domains) to study dynamic interaction of aerosols and meteorology in Nordic conditions. For pollen applications, additional model evaluation was performed for spring 2006 flowering season, with further improvements of birch pollen emission module and accumulated air temperature threshold sums for start of the pollen season.

The analysis of atmospheric aerosol effects at fine spatial-temporal scales on clouds and precipitation was performed for year 2010 (which was characterized by severe weather events such as floods, heat waves and droughts across Middle East, most of Europe and European Russia). The Enviro-HIRLAM (Environment – HIgh Resolution Limited Area Model; http://www.hirlam.org) model was employed for the analysis. It was forced by boundary and initial conditions from models

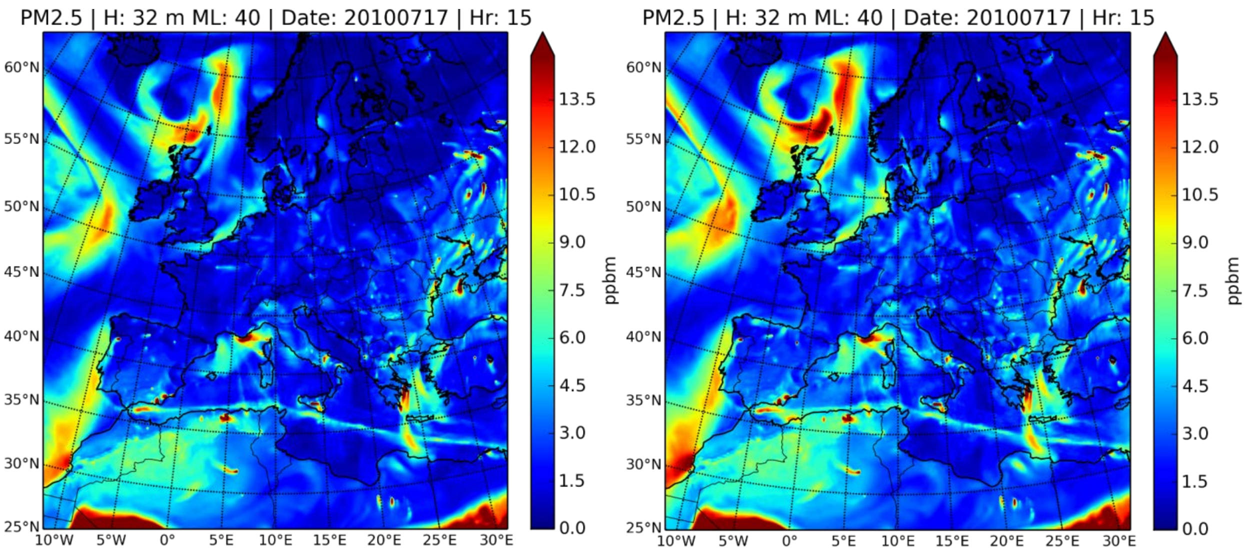
ECMWF IFS (http://www.ecmwf.int/research/ifsdocs) and MOZART (http://www.acd.ucar.edu/gctm) for meteorology (horizontal resolution - 0.15^o x 0.15^o) and atmospheric composition (horizontal resolution - 1.125^o x 1.125^o), respectively. The Enviro-HIRLAM modelling domain with horizontal resolution of 0.15^o x 0.15^o and 40 vertical hybrid levels covers Europe, North of Sahara, and Central Russia. The model includes HAM-M7 aerosol microphysics module (*Vignati et al., 2004*) and emissions from anthropogenic sources by TNO (*Kuenen et al., 2011*) and from wildfires by FMI (http://is4fires.fmi.fi) as well as interactive sea-salt (*Zakey et al., 2008*) and dust (*Zakey et al., 2006*) emissions.

For ground-based $PM_{2.5}$, for European domain the Enviro-HIRLAM model was evaluated vs. observations from EU AirBase air-quality network (http://acm.eionet.europa.eu/databases/airbase). In general, the model predicts well $PM_{2.5}$ day-to-day variability, but mostly has negative bias. For aerosol-cloud interactions, these were estimated also for Jul 2010 by means of delta function, i.e., difference between outputs of models: Enviro-HIRLAM with aerosol-cloud interactions and Reference-HIRLAM (REF). The REF model run tends to over-predict both frequency and amount of precipitation.



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

Figure 11: *Frequency distribution of stratiform precipitation (a) and convective precipitation (b). Comparison of 1-moment (REF-HIRLAM) and 2-moment (Enviro-HIRLAM with cloud-aerosol interactions) cloud STRACO schemes.*

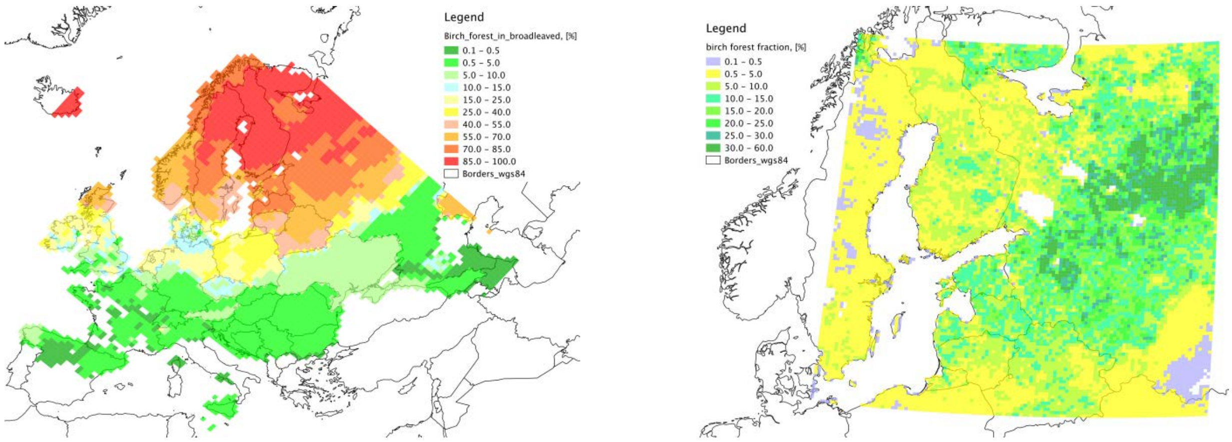


(a) ***(b)***

Figure 12: *Spatial distribution of aerosol (PM2.5) patterns in the surface layer for the HIRLAM (a) reference and (b) Enviro- runs at 17 Jul 2010, 15 UTC for studying aerosol-cloud interactions over the European domain.*

The inclusion of aerosol-cloud interactions can improve general model performance, i.e., the Enviro- run bias for precipitation with respect to its frequency and amount has been decreased compared to REF model run. The absolute frequencies of stratiform and convective precipitation over computational domain are decreased compared to REF model run (see Fig. 11), while the amount of convective precipitation during heavy precipitation events is increased. Hence, the wet deposition of particles decreases in summer because it rather depends on precipitation frequency than on its amount. Therefore, the concentration of PM2.5 is increased over areas with decreased precipitation of both forms, although larger for the stratiform clouds (see Fig. 12).

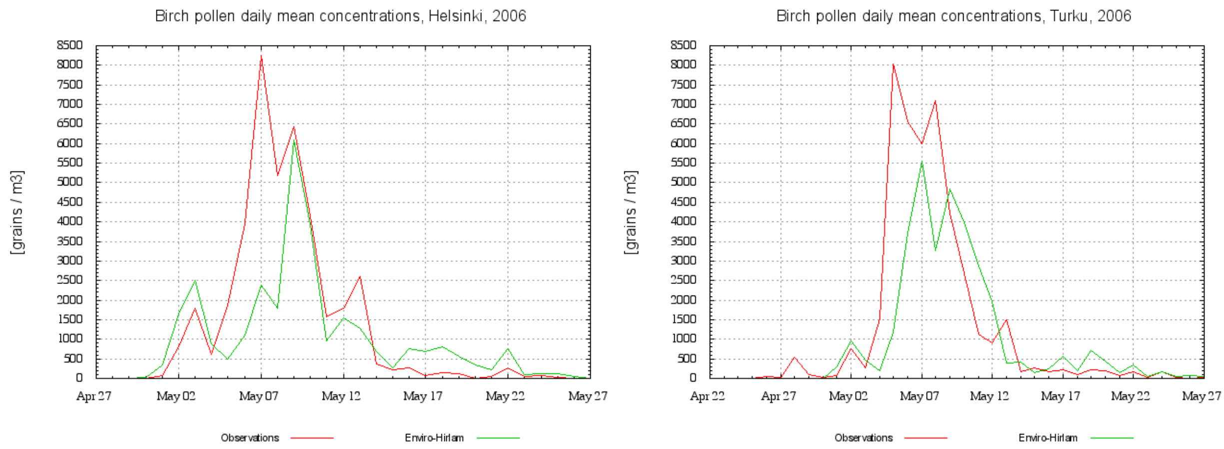
For birch pollen studies, the Enviro-HIRLAM-POLLEN model runs were performed to simulate birch pollen concentrations for Northern European domain (118 x 118 grid horizontal points; 40 vertical hybrid levels) at 0.135° horizontal resolution. Birch pollen module is an integral part of the Enviro-HIRLAM modelling system, and the module consists of spatial birch forest habitat map, emissions from local pollen sources, atmospheric transport, diffusion, gravitational settling and scavenging of particles in the atmosphere. Birch pollen emission parameterization is meteorology-dependent and based on correcting dimensionless functions (*Sofiev et al., 2012*). The main meteorological parameters influencing the birch pollen emission are air temperature at 2 meter, relative humidity at 2 meter, wind speed at 10 meter and accumulated precipitation.
TSI (Skjøth *et al.*, 2008) is represented by 39 types of tree species (birch, oak, alder, etc.), and it is based on national forest inventories and national statistics. Birch forest fraction within broadleaved forest layer with 50 km horizontal resolution was used for the analysis (Fig. 13a). Several layers such as land-mask, forest, vegetation, urban territory (from GLC), broadleaved forest (from EFI) and birch forest fraction in broadleaved forest (from TSI) have been extracted from these databases, recalculated for the domain as a weighted mean and combined for correct assessment of birch forest fraction in each grid cell. The calculated spatial birch forest distribution map is shown in Fig. 13b.



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

Figure 13: *(a): Spatial distribution of birch forest fraction within broadleaved forest (Tree Species Inventory); (b) birch forest fraction calculated for the modelling domain.*

The model results for pollen episode in 2006 were compared with observations for two Northern European sites in Finland: Helsinki and Turku (see in Fig. 14). Preliminary evaluation for both modelled and observed birch pollen concentrations showed extremely high values (daily averages more than 1000 grains/m^3), and especially during 5-12 May 2006 episode for the Northern European stations. This phenomenon can be explained by high number of birch male catkins, favourable meteorological conditions for local birch pollen emissions as well as long-range transport of birch pollen particles from remote regions during the spring period of 2006. Although the modelled results reflected the overall general shape of changes in pollen concentration during the episode studied, some underestimation of modelled concentrations is visible, especially for the occurrence of maximum concentration.



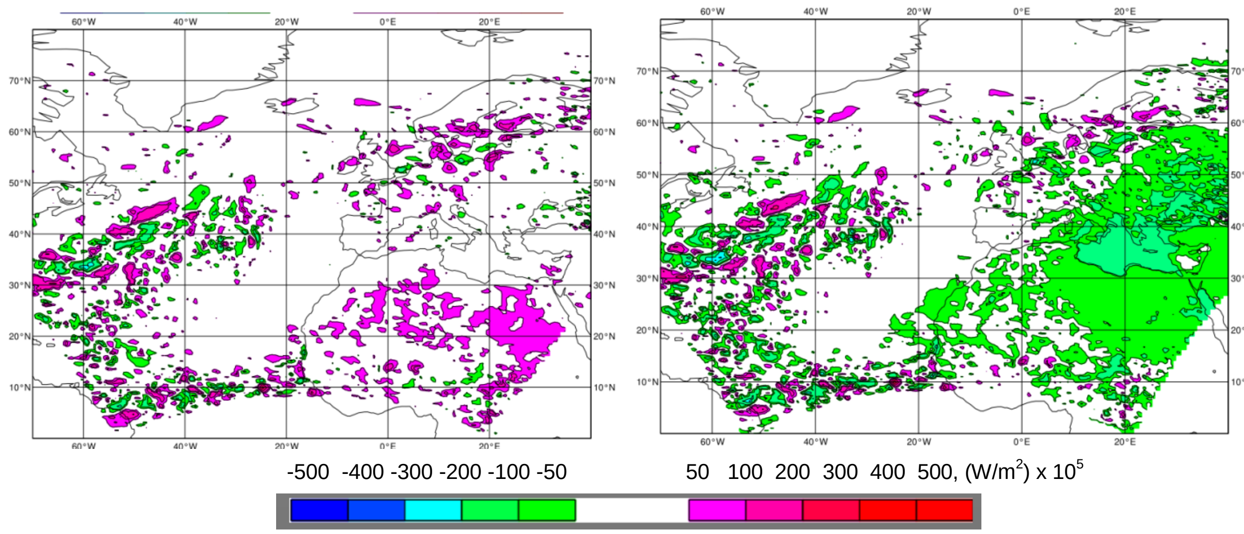
(a) ***(b)***

Figure 14: *Birch pollen concentrations observed (red) vs. modelled (green) at two Finnish sites: (a) Helsinki (60°10‘ N and 24°54‘ E), (b) Turku (60°32‘ N and 22°28‘ E).*

HARMONIE: The focus was at high-resolution simulations of meso-scale synoptic patterns accompanied by cloud systems and moderate precipitation over a domain, where the radar data will be available. For these studies, the radar reflectivity measurements (accumulated during the BaltRad experiment) allowed investigating pre-conditions, developing and life-cycle of cloud and precipitation systems in interaction with chemical environment and associated radiation/energy transformations. Additionally, the development of a part of the code and associated scripts for successive assimilation of aerosols from the MACC monitoring system (https://www.gmes-atmosphere.eu/) were continued.

The role of aerosols in atmospheric processes was investigated by comparing fields of meteorological parameters from different experiments. Results showed that including aerosols can lead to changes in most of physical atmospheric fields, such as air temperature, relative humidity, vertical velocity, cloud cover, precipitation, short-wave and long-wave radiation fluxes through the low and middle atmosphere. A complex influence of aerosols on a whole troposphere and seen cross-chains of links between various characteristics was studied. In particular, at first, aerosols can change radiation fluxes both short- and long-wave, which in turn alter the vertical profile of air temperature and humidity, then modify vertical velocity and stratification and finally influence cloudiness. On the other hand, aerosols are accumulating water and hence, shifting a precipitation phase. Also, changes in water content in the atmosphere affect radiation fluxes closing the chain. So far, model simulations with/without aerosols showed their role as a trigger-link, which generates the above chain of interactions between physical atmospheric variables.

A feature of the aerosol impact on physical fields is observed in a form of intermitting meso-scale deviations with opposite signs. This occurs despite of a homogeneous or smoothly changing cover of aerosols over the domain and they are similar to the Bernard cells. The short-wave radiation is increased at the top of the atmosphere by extra ~100 W/m2, while it is decreased near the surface by extra ~200 W/m2 (see Fig. 15), while the long-wave radiation is less sensitive to aerosols at a clear sky conditions. However, this becomes tentative at a front lines/zones and cloudy areas. The changes in radiation fluxes prevail over the land surfaces, while over the ocean surface it mostly relates to areas of interactions between mid-latitude and tropical air masses having different thermal characteristics. For example, a large area of decreasing short-wave radiation near the surface over the Sahara desert points to strong influence of dust particles by its scattering and absorption of solar radiation.



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

Figure 15: *Example of difference fields (climate aerosols – no aerosols) of short-wave radiation fluxes simulated by the HARMONIE model (a) at the top of the atmosphere and (b) near the surface.*

Summary of Results (Jul 2014 – Dec 2014)

Enviro-HIRLAM: The model runs showed that the atmospheric aerosols can substantially influence formation and development of meteorological fields on region-to-urban scales. Future expansion of urban areas in Europe will cause more emissions of anthropogenic aerosols. As a result, the absolute precipitation frequency will decrease, while the precipitation during heavy rains will likely to increase its amount. The atmospheric aerosols scavenging will decrease, because it rather depends on the precipitation frequency than on its amount. Results showed, that birch pollen (as biological aerosol) can be predicted at some degree of accuracy with a general shape of observed changes in concentration and with underestimation of predicted concentrations (and especially for the occurrence of maximum concentration).

HARMONIE: The model experiments (with aerosol module) have shown that aerosols can influence most of meteorological variables. The impact occurs through a complex chain of interactions between the radiation, air temperature, humidity, stratification, vertical motions, cloudiness, and precipitation. Aerosols play in that chain a role of a "trigger". However, they work in a different manner depending on a type of aerosol and a synoptical pattern. Major changes occur in the boundary layer and along the frontal zones with high gradients at all vertical levels. The perturbations appear in a form of meso-scale cells growing with a time, while domain averaged deviations are oscillating around zero. Concerning precipitation, the aerosols affect mainly weak rates by changing their life-time. Note, a proper accounting of aerosols for precipitation forecasting requires accurate information about their concentration, distribution, and evolution. Further investigation of aerosol contributions/impact is needed, and especially, at a short time step to study detailed evolution of the life-time of a single precipitation cell.

List of projects that benefited from the Special Project

This Special Project also contributed to the following EU and national research projects:

- HIRLAM-B (http://hirlam.org);
- COST Action EuMetChem ES1004 "*European framework for online integrated air quality and meteorology modelling*" (http://eumetchem.info);
- FP7 EU MEGAPOLI "*Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation*" (http://megapoli.info);
- FP7 EU MACC "*Monitoring of Atmospheric Composition and Climate*" (https://www.gmes-atmosphere.eu);

- FP7 EU PEGASOS "*Pan-European Gas-AeroSOls-climate interaction Study*" (http://pegasos.iceht.forth.gr);
- FP7 EU TRANSPHORM "*Transport related Air Pollution and Health impacts - Integrated Methodologies for Assessing Particulate Matter*" (http://www.transphorm.eu);
- CEEH "*Danish strategic research Center for Energy, Environment and Health*" (http://ceeh.dk);
- AQMEII "*Air Quality Model International Initiative*" Phase 2 (http://aqmeii.jrc.ec.europa.eu).

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Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

A new proposal is in preparation for the Special Project "**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*" (to be coordinated by DMI) is to be realised in a close relation with several European and national research projects as well as in a close collaboration with Universities (*UoC - University of Copenhagen, Denmark; UoT - University of Tartu, Estonia; ITU - Istanbul Technical University, Turkey; OSEU - Odessa State Environmental University, Ukraine; UHMI – Ukrainian Hydrometeorological Institute, Ukraine; UoM - University of Malta, Malta; RSHU - Russian State Hydrometeorological University, Russia; ICMMG – Institute Computational Mathematics and Mathematical Geophysics, Russia*) involved into Enviro-HIRLAM/ HARMONIE research and development tasks/activities.