LATE REQUEST FOR A SPECIAL PROJECT 2015–2017

MEMBER STATE: ……………………DENMARK……………..…………………...…

Principal Investigator[1]: …… Bent Hansen Sass ………...………………………….……

Affiliation: …… Danish Meteorological Institute (DMI) …………………….……

Address: …… Lyngbyvej 100, Copenhagen, DK-2100, Denmark …..….…

E-mail: …… bhs@dmi.dk ..……………………………………….……

Other researchers:
Alexander Mahura DMI [ama@dmi.dk]
Kristian Pagh Nielsen DMI [kpn@dmi.dk]
Roman Nuterman UoC [nuterman@nbi.ku.dk]
Eigil Kaas UoC kaas@nbi.ku.dk]
Alexander Kurganskiy UoC/RSHU [alexkurg@nbi.ku.dk]
Velle Toll UoT [velle.toll@ut.ee]
Svitlana Krakovska UHMI [KraSvit@ua.fm]
Serguei Ivanov OSEU [svvivo@te.net.ua]
Alexey Penenko ICMMG [a.penenko@gmail.com]
Suleiman Mostamandy RSHU [suleiman.mostamandy@gmail.com]
Noel Aquilina UoM [noel.aquilina@um.edu.mt]
Huseyin Toros ITU [huseyintoros@yahoo.com]

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 …

Would you accept support for 1 year only, if necessary?	YES ☐	NO ☐

Computer resources required for 2015-2017: (The project duration is limited to a maximum of 3 years, agreed at the beginning of the project. For late requests the project will start in the current year.)		**2015**	**2016**	**2017**
High Performance Computing Facility	(units)	4000 kSBU	4000 kSBU	4000 kSBU
Data storage capacity (total archive volume)	(gigabytes)	8500	9000	9500

An electronic copy of this form ***must be sent*** *via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date):

…………………………………………

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

Principal Investigator: ……………… Bent Hansen Sass …………………………………

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* …………….………………………………………………………..

Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

Introduction

The simulation of the coupled evolution of atmospheric transport and chemical composition remain one of the most challenging tasks in environmental modelling. Many of the current environmental challenges in weather, climate, and air quality modelling involve strongly coupled systems (*Zhang, 2008; Baklanov et al., 2008a, 2010; Alapaty et al., 2011*). It is well accepted that weather is element of key importance for air quality for daily life as well as accidental/emergency situations. It is also recognized that chemical species and aerosols can influence weather by changing the atmospheric radiation budget as well as through cloud and precipitation formation. However, until recently (because complexity and lack of computer power) air pollution and weather forecasts have developed as separate disciplines, leading to development of separate modelling systems which are only loosely coupled (off-line). In Numerical Weather Prediction (NWP), a substantial increase in computer power and capabilities enables to run NWP models at higher horizontal (down to 1+ km) as well as vertical (more model levels within the atmospheric boundary layer) resolutions to explicitly resolve small-scale circulation features, fronts, clouds, or to increase the complexity of the numerical models.

As of now, it is possible directly couple air quality forecast models with numerical weather prediction models to produce a unified modelling system – online – that allows two-way interactions. While climate modelling centres have directed towards an Earth System Modelling (ESM) approach that includes also atmospheric chemistry and ocean-sea-ice interactions, the NWP and Air Quality (AQ) forecasting centers/ organizations have started discussions whether an on-line approach is important enough to justify the extra-cost (*IFS, 2006; Grell, 2008; Baklanov et al, 2008a; Grell & Baklanov, 2011*). NWP and AQ forecasting centres may have to invest in additional computer power as well as additional man-power, because additional expertise may be required. DMI is in favour of integrating weather and chemistry together, for improvement of weather prediction skills as well as for air quality and chemical composition forecasting. For NWP centres, an additional attractiveness of the on-line approach is its possible usefulness for meteorological data assimilation (*Hollingsworth et al., 2008*), where the retrieval of satellite data and direct assimilation of radiances will likely improve – assuming that the modelling system can beat climatology when forecasting concentrations of aerosols and radiatively active gases.

The focus on integrated systems is timely, since recent research has shown that meteorology/climate and chemistry feedbacks are important in the context of many research areas and applications, including NWP, climate, and air quality forecasting, and Earth system modelling. Potential impacts of aerosol feedbacks include (*Jacobson et al., 2007; Zhang, 2008; Baklanov et al., 2008a; Baklanov, 2010; Grell & Baklanov, 2011; Zhang et al., 2010ab*): reduction of downward solar radiation (direct effect); changes in surface temperature, wind speed, relative humidity, and atmospheric stability (semi-direct effect); decrease in cloud drop size and an increase in drop number by serving as cloud condensation nuclei (first indirect effect); increase in liquid water content, cloud cover, and lifetime of low level clouds, and suppression or enhancement of precipitation (second indirect effect).

Traditionally, aerosol feedbacks have been neglected in NWP and air quality modelling mostly due to an historical separation between the meteorological and air quality communities as well as a limited understanding of the underlying interaction mechanisms. Such mechanisms may, however, be important on a wide range of temporal and spatial scales, from days to decades and from global to local. Field experiments and satellite measurements have shown that chemistry-meteorology feedbacks exist among the Earth systems including the atmosphere (*e.g., Kaufman & Fraser, 1997; Rosenfeld, 1999; Rosenfeld & Woodley, 1999; Givati & Rosenfeld, 2004; Grell et al., 2005; Lau & Kim, 2006; Rosenfeld et al., 2007, 2008*).

Enviro-HIRLAM/ HARMONIE modelling system

The **Enviro-HIRLAM** (***Environment – HIgh Resolution Limited Area Model***) was developing as an on-line coupled Numerical Weather Prediction (NWP) and Atmospheric Chemical Transport (ACT) integrated modelling system for research purposes and for joint forecasting of meteorological, chemical, and biological (including pollen) weather. The integrated modeling system was started more than 10 years ago to be developed by DMI (*Chenevez et al., 2004; Baklanov et al., 2004, 2008ab; Korsholm, 2009; Korsholm et al., 2008, 2009, 2010*) and further in a close collaboration with the Universities, and it was used by the HIRLAM consortium as a baseline system for the HIRLAM Chemical Branch (http://www.hirlam.org/chemical). The Enviro-HIRLAM model was the first meso-scale on-line coupled model in Europe, which considered two-way feedbacks between meteorology and chemistry/ aerosols.

As of now, the Enviro-HIRLAM is a fully online-coupled NWP-ACT modeling system for regional-, meso- and urban scale different environmental applications. The NWP part developed by the HIRLAM consortium (*Unden et al, 2002*) is used for operational weather forecasting. The Enviro-components were mainly developed by DMI with partners from European Universities. It consists of gas-phase chemistry CBMZ (*Zaveri & Peters, 1999*) and aerosol microphysics M7 (*Vignati et al., 2004*), which includes sulfate, mineral dust, sea-salt, black and organic carbon (*Nuterman et al. 2013*). There are modules of urbanization for land surface scheme, natural and anthropogenic emissions, nucleation, coagulation, condensation, dry and wet deposition, and sedimentation of aerosols. The Savijarvi radiation scheme (*Savijaervi, 1990; Wyser, 1999*) has been improved to account explicitly for aerosol radiation interactions for 10 aerosol subtypes. The aerosol activation scheme (*Abdul-Razzak & Ghan, 2000*) was also implemented in STRACO condensation-convection scheme. The nucleation is dependent on aerosol properties and the ice-phase processes are reformulated in terms of classical nucleation theory. Emission inventories include: anthropogenic - TNO-MEGAPOLI, MACC; biomass burning - IS4FIRES; natural - interactive sea-salt (*Zakey et al., 2008*) and mineral dust (*Zakey et al., 2006)* emission modules.

Following the main development strategy of the HIRLAM community (HIRLAM-B,-C projects) the Enviro-HIRLAM further developments are moving step-by-step towards the new NWP **HARMONIE** (***HIRLAM-ALADIN Research for Meso-scale Operational NWP In Europe***) model platform by incorporating (of the Enviro-part of the Enviro-HIRLAM modelling system - chemistry and aerosol-radiation-cloud interactions modules), testing and further development of the **Enviro-HARMONIE** integrated modelling system. It is also possible to consider enhancement of the HARMONIE framework by coupling NWP and ACT models in order to provide on-line weather information needed for modelling atmospheric composition and air quality. Note that the NWP HARMONIE system combines elements from the global IFS/Arpege model (*Déqué et al., 1994*) with the ALADIN non-hydrostatic dynamics (*Bénard et al., 2010*). At high horizontal resolutions (<2.5 km), the forecast model and analysis system are basically linked with AROME model from Météo-France (*Seity et al., 2011; Brousseau et al., 2011*). Physical parametrizations from ALARO, HIRLAM (*Undén et al., 2002*) and ECMWF are applicable in this framework.

Scientific developments

The overall objectives of the special project will be 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.

The developing on-line integrated meteorology-chemistry/aerosols modelling system Enviro-HIRLAM/ HARMONIE is expected to be able to handle the following major processes and interactions (*Jacobson et al., 2007; Zhang, 2008*):

- direct effect - radiative effect of chemical species such as ozone and aerosols in the atmosphere via absorption and scattering;
- semi-direct effect - effect of aerosols and clouds on photolysis rates via modifying actinic fluxes and temperature;
- semi-direct effect - effect of aerosols on boundary layer meteorology via changing meteorological variables and atmospheric stability;

• 1st and 2nd indirect effects - effect of aerosols on cloud formation and reflectance via aerosol activation, droplet and ice core nucleation, autoconversion, and collection;
• indirect effects - effect of aerosols on precipitation by affecting clouds and water vapour.

These processes and interactions are essential in studies for weather, climate and air quality. Aerosol particles, as an integral part of the atmosphere, play important role in the environmental conditions behavior and have impact on human health, in particular. Depending on aerosols' origin, chemical composition, lifetime, size, shape and optical properties they can cause multiple complex effects in the atmosphere at various temporal and spatial scales (*Kulmala et al., 2009; Sesartic et al., 2013; Lohmann & Feichter, 2005; Calvoa et al., 2012*). *Zhang et al. (2010a)* showed that aerosols can reduce incoming solar radiation by up to 16%, near surface temperatures - 0.4°C, and height of the atmospheric boundary layer - 24% under summer conditions. *Grell & Baklanov (2011)* noted that neglecting radiative effects of aerosols on air quality may lead to large errors in estimating the number of situation with exceeded ozone critical levels.

According to evaluation of the recently completed COST Action EuMetChem (European framework for online integrated air quality and meteorology modelling; http://eumetchem.info), among main important couplings for numerical weather prediction there are the following when changes in aerosols affect: precipitation (initiation and intensity of precipitation); radiation (short-wave scattering/ absorption and long-wave absorption); cloud droplet or crystal number density (cloud optical depth); haze (hydroscopic growth of aerosols interrelated with relative humidity); cloud morphology (reflectance); and others. Among main important couplings for chemical weather forecasting there are the following when changes: in wind speed affect dust and sea-salt emissions; in precipitation affect atmospheric composition; in temperature and radiation affect chemical reaction rates and photolysis; in liquid water affect wet scavenging and atmospheric composition; and others. EuMetChem case studies showed that improvement due to aerosol feedbacks depends on geographical region and season; during extreme episodes such as dust-storms and forest-fires the improvement can be larger; and indirect effects can be larger (or similar) to direct effects of aerosols. Approach on implementation of the indirect effect have a large impact on model results, and hence this should be a focus for future studies as well as complete analysis will require simulations at high resolution and aerosol representations in the model. Model based forecasts are usually done with insufficient or approximate input data like initial and boundary conditions, approximate emission source estimates and model coefficients. These uncertainties can be potentially reduced with assimilation of available measurement data covering a relatively small number of model parameters. Numerical experiments should be performed to evaluate performance of data assimilation algorithms in the context of integrated models on realistic inverse modelling scenarios.

Overview of projects that benefits from the special project

The previous Special Project "***EnviroChemistry on ECMWF****: Enviro-HIRLAM/HARMONIE development and test of an NWP model system accounting for aerosol-meteorology interactions*" (PI – Prof. Alexander Baklanov) substantially 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).

The suggested new 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*" 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, including the following:

HIRLAM-B (C): the HIRLAM-B Programme (and further HIRLAM–C; 2016-2020) plans include realisations of specific tasks on coupling with atmospheric chemistry and cloud microphysics, radiation and aerosols within the HIRLAM community for development of on-line integrated NWP and ACT modelling system (e.g. from Enviro-HIRLAM to further Enviro-HARMONIE) to be realised by DMI, other members of the HIRLAM consortium in collaboration with mentioned Universities.

CarboNord: Nordic project "*Impact of black carbon on air quality and climate in Northern Europe and Arctic*" is assessing robustness of model predictions of long-range black carbon distribution and its relation to climate change and forcing over the Northern Europe and Arctic. DMI team is focused on short-term/episode (winter vs. summer) sensitivity studies on interactions between black carbon and meteorological processes as well as mechanisms of Arctic haze formation.

MarcoPolo: FP7 EU project "*Monitoring and Assessment of Regional air quality in China using space Observations, Project Of Long-term sino-european co-Operation*" is focused on improving air quality monitoring, modelling and forecasting using satellite and ground-based data and new emission inventories (see more details at: http://www.marcopolo-panda.eu). DMI team is leading WP5 on "Air Quality Assessment and Forecasting" and focused on modelling of weather and atmospheric composition from sub-regional to urban/city-scale for selected metropolitan areas and study relationship between air pollution and meteorology/ climate and aerosol-cloud-radiation interactions.

FAAS: Nordic project "*The Future Arctic - Assessment and Scenarios*" is aiming at assessing feedbacks and interlinks between future environment and societies in the Arctic and to link changes to global context; and in particular, to provide scientific understanding of drivers for development in the Arctic land – atmosphere – ocean – social systems; and to identify and quantify the most critical feedbacks of their interaction dynamics. The DMI team will focus on regional scale on-line integrated meteorology-chemistry/aerosols (with Enviro-HIRLAM/HARMONIE +SURFEX) modelling/ analysis and downscaling for Arctic and boreal regions; and evaluation of impact on shipping in Arctic in a changing climate conditions.

H2020-MSCA-GC-PEEX-ETN: Horizon-2020 EU project "*The Grand Challenges in the Pan-Eurasian Experiment (PEEX) domain*" is focused on the following main research themes: climate feedbacks and comprehensive measurements, climate forcing and global modelling, climate-air quality interactions, anthropogenic emission inventories and scenarios, land-atmosphere interactions, air quality and regional modelling, biogeochemical cycles, ecosystem functioning and biogenic emissions, greenhouse gas exchange, carbon sink and source estimation. The DMI team is focused on studies with modelling for urban areas in changing land cover and climate conditions as well as on regional integrated modelling of meteorology-chemistry/ aerosol feedbacks and interactions through further development and employing Enviro-HIRLAM/HARMONIE modelling system.

Workplan

Two main **application areas** of the on-line integrated modelling are expected to be 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.

Following the past HIRLAM practice, the system is being maintained on the ECMWF HPC platform. The **emphasis** in this Special Project at ECMWF is primarily on the evaluation and testing of the online integrated Enviro-HIRLAM/ HARMONIE modelling system and sensitivity analyses the feedback mechanisms for weather and atmospheric composition modelling.

The **simulations** are expected for:
(i) short-term/episodes studies with physical and chemical weather forecasting (downscaling from regional/meso to urban/city) in order to evaluate sensitivity of aerosol feedback effects on meteorology and atmospheric composition;
(ii) long-term simulations for weather, climate and air quality applications to evaluate possible long-term effects;
(iii) testing meteorological and chemical initial and boundary conditions, and chemical data assimilation.

The Special Project computational resources will be used mainly to experiment with newly developed components of the modelling system and evaluate their performance and sensitivity to feedbacks. In-depth validation and intensive testing of all of these developments will be carried out at DMI, Universities and ECMWF environments.

The **evaluation methodology** will follow the recommendations/guidelines for the evaluation methodology and protocol for online integrated meteorology-chemistry modelling systems, recently developed by the COST Action EuMetChem ES1004 (*EuMetChem, 2010*; http://eumetchem.info) and by the AQMEII Phase2 Initiative (*Galmarini et al., 2011*).

The **duration** of the requested Special Project is expected to be from 1 July 2015 till 31 December 2017. The computational costs of these simulations and validation activities might likely extend beyond the requested project resources (see the specification below). The allocated computational resources at ECMWF for DMI will be used to supplement the Special Project resources.

New developments towards Enviro-HARMONIE

Based on recent Enviro-HIRLAM/ HARMONIE scientific developments and working plan the following topics, which are important for operational numerical weather prediction and atmospheric composition forecasting, will be investigated during the Special Project (through collaboration of DMI with the listed above Universities):

- 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*);
- Implement new Secondary Organic Aerosol (SOA) module in Enviro-HARMONIE model by building interface to provide boundary conditions from RegCM4 regional climate model (*UoM*);
- Evaluate performance of new SOA-to-radiation interaction module by comparing outputs of the Enviro-HARMONIE vs. RegCM4 models through analysis of atmospheric transport from Mediterranean region towards Northern Europe (*UoM*);
- 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*);
- Implement and test chemical data assimilation for Enviro-HIRLAM/HARMONIE for European and Nordic countries domain (*ICMMG, UoC*);
- 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*).

Workplan tasks for the first year (2015)

Within the Special Project the following specific activities will be performed:
T1-2015: Setup of Enviro-HIRLAM/ HARMONIE modelling system on the ECMWF HPC
T2-2015: Implementation and tests of microphysics for both aerosols and clouds interactions
T3-2015: Test and first evaluation of the modelling system for case studies/episodes simulations
T4-2015: Sensitivity runs/studies of aerosol feedback mechanisms on meteorological and air pollution events

List of deliverables for the first year (2015)

D1: 30-09-2015: Enviro-HIRLAM/ HARMONIE modelling system setup on the ECMWF HPC
D2: 31-10-2015: Results of tests and preliminary evaluation of implemented microphysics for aerosols and clouds interactions
D3: 30-11-2015: Preliminary results of evaluation for selected case studies/episodes
D4: 31-12-2015: Results of sensitivity runs/studies of aerosol feedback mechanisms on meteorological and air pollution events

Estimated resource requirements

The initial phase of the proposed Special Project will focus on setting up the system and performing various technical evaluations, sensitivity experiments and configuration studies, based on the Enviro-HIRLAM/HARMONIE modelling system implemented at the ECMWF platform.
Currently, for a typical Enviro-HIRLAM (note, that Enviro-HARMONIE – more expensive due to non-hydrostatic approach and more expensive dynamical core) simulation with a gas-phase (simple) chemistry, the runtime costs is at the order of 10000 SBU per experiment day. Note that significant variations depend on horizontal/vertical resolutions and overall size of model domain, sophistication of chemistry and aerosol schemes. A rough estimate of a half-year worth of simulation experiments would arrive at 1.8 million SBU. In anticipation of some contribution from the Danish national SBU allocation, we would like to receive annually allocation of 2 million SBU in form of Special Project.

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