REQUEST FOR A SPECIAL PROJECT 2013–2015

MEMBER STATE: Denmark…………….…………………………………………...…

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Project Title: Enviro-HIRLAM/HARMONIE: development and test of an NWP model system accounting for aerosol-meteorology interactions

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPDKBAKL** ________________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2012	
Would you accept support for 1 year only, if necessary?	YES X ☐	NO ☐

Computer resources required for 2013-2015: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2015.)	**2013**	**2014**	**2015**
High Performance Computing Facility (units)	4000 kSBU	4000 kSBU	
Data storage capacity (total archive volume) (gigabytes)	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): 30/04/2012……………………………

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: Prof., Dr. Alexander Baklanov ....

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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 prediction and simulation of the coupled evolution of atmospheric transport and chemistry will remain one of the most challenging tasks in environmental modelling over the next decades. Many of the current environmental challenges in weather, climate, and air quality involve strongly coupled systems (see overview in Zhang, 2008; Baklanov et al., 2008; Alapaty et al., 2011). It is well accepted that weather is of decisive importance for air quality, or for the aerial transport of hazardous materials. It is also recognized that chemical species will influence the weather by changing the atmospheric radiation budget as well as through cloud and precipitation formation. Until recently however, because of the complexity and the lack of appropriate computer power, air chemistry and weather forecasts have developed as separate disciplines, leading to the development of separate modelling systems that are only loosely coupled (offline). In Numerical Weather Prediction (NWP), the dramatic increase in computer power enables us to use higher resolution to explicitly resolve fronts, convective systems, local wind systems, and clouds, or to increase the complexity of the numerical models. Additionally we can now 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 gone to an Earth System Modelling approach that includes atmospheric chemistry and oceans, NWP centres as well as entities responsible for Air Quality (AQ) forecasting are only beginning to discuss whether an online approach is important enough to justify the extra cost (IFS, 2006; Grell, 2008; Baklanov et al, 2008; Grell and Baklanov, 2011). NWP and AQ forecasting centres may have to invest in additional computer power as well as additional man power, since additional expertise may be required. We are in favour of integrating weather and chemistry together, for both NWP and air quality and chemical composition forecasting.

For NWP centres, an additional attractiveness of the online 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 modelling, air quality forecasting, and Earth system modelling. Potential impacts of aerosol feedbacks include (Jacobson et al., 2007; Zhang, 2008; Baklanov et al., 2008; Baklanov, 2010; Grell and Baklanov, 2011; Zhang et al., 2010a, b):

- a reduction of downward solar radiation (direct effect);
- changes in surface temperature, wind speed, relative humidity, and atmospheric stability (semi-direct effect);
- a decrease in cloud drop size and an increase in drop number by serving as cloud condensation nuclei (first indirect effect);
- an 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 and Fraser, 1997; Rosenfeld, 1999; Rosenfeld and Woodley, 1999; Givati and Rosenfeld, 2004; Grell et al., 2005; Lau and Kim, 2006; Rosenfeld et al., 2007, 2008).

Enviro-HIRLAM System Description

Enviro-HIRLAM is developing as an online coupled NWP and Atmospheric Chemical Transport (ACT) model for research and forecasting of joint meteorological, chemical and biological weather. The integrated modeling system is developed by DMI and other collaborators (Chenevez et al., 2004; Baklanov et al., 2004, 2008a; Korsholm et al., 2008, 2009, Korsholm, 2009) and included by the HIRLAM consortium as the baseline system in the HIRLAM Chemical Branch (www.hirlam.org/chemical), it is used in several countries. The model development was initiated at DMI more that 10 years ago and it was the first meso-scale online coupled model in Europe considering two-way feedbacks between meteorology and chemistry/aerosols.

The first version of Enviro-HIRLAM was based on the DMI-HIRLAM NWP model with fully online integrated pollutant transport and dispersion (Chenevez et al., 2004), chemistry, deposition and indirect effects (Korsholm, 2009) and aerosol dynamics (Gross and Baklanov, 2004). To make the model suitable for chemical weather forecasting (CWF) in urban areas, where most of the European population is concentrated, the meteorological part was improved by implementation of urban sublayer parameterizations (Baklanov et al., 2008b).

The current version of Enviro-HIRLAM is based on reference HIRLAM version 7.2 with a more sophisticated and effective chemistry scheme, multi-compound modal approach aerosol dynamics modules, aerosol feedbacks on radiation (direct and semi-direct effects) and on cloud microphysics (first and second indirect effects). This version is still under development and needs further validation within this proposed project.

Following the main development strategy of the HIRLAM community (HIRLAM-B project) the Enviro-HIRLAM further developments will be moving step by step towards the new HARMONIE NWP platform by incorporation of the Enviro-HIRLAM chemistry modules and aerosol-radiation-cloud interactions into the future Enviro-HARMONIE integrated system.

Scientific Developments

The overall objectives of the special project will be to analyse the importance of the meteorology-chemistry interactions and to provide a way for the development of accurate yet efficient techniques for the coupling of NWP and air quality via process-oriented parameterizations and feedback algorithms, which will improve both the numerical weather prediction and chemical weather forecasts.

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

- The radiative effects of chemical species such as ozone and aerosols in the atmosphere via absorption and scattering (direct effects);
- The effects of aerosols and clouds on photolysis rates via modifying actinic fluxes and temperature (semi-direct effects);
- The effect of aerosols on boundary layer meteorology via changing meteorological variables and atmospheric stability (semi-direct effects);
- The effect of aerosols on cloud formation and reflectance via aerosol activation, droplet and ice core nucleation, autoconversion, and collection (first and second indirect effects);
- The effect of aerosols on precipitation by affecting clouds and water vapour (indirect effects).

Those processes and interactions are essential if one wants to study air quality and climate jointly. For example, a recent study showed that aerosols can reduce incoming solar radiation by up to 16%, near surface temperatures by up to 0.37 °C, and planetary boundary layer (PBL) height by up to 24% under summer conditions over continental U.S., indicating a more stable atmospheric stratification that can further exacerbate air pollution over areas where air pollution is already severe (Zhang et al., 2010a; Korsholm et al., 2010). They are also important to correctly forecast air quality and weather. For example, neglecting the radiative effects of aerosols on air quality may lead to large errors in estimating the number of occasions when ozone critical values are exceeded (Grell and Baklanov, 2011).

There are various ways to treat those interactions because of the complexity of the processes involved and different levels of details may be used in an integrated model. For example, the activation of aerosol particles is a function of the chemical composition and size, as well as the updraft velocity and maximum supersaturation. The radiative effects of aerosols are not only a function of their size distribution and bulk chemical composition but also depend on whether particles are treated as internal or external mixtures. Therefore, the treatment of a size- and chemically-distributed aerosol population in the integrated model is a key component of the meteorology/chemistry interactions. The formulation of the radiative transfer in the model is particularly important because it directly affects the heat budget and the chemistry via photolytic reactions.

Overview of projects that benefits from the special project

The suggested Special project is realised in close relation with several European and national research projects, including the following:

HIRLAM-B: One of the main realisations of the specific tasks: 'Coupling with atmospheric chemistry' and 'Cloud microphysics, radiation and aerosols' within the HIRLAM community plans is development of the online NWP and ACT Enviro-HIRLAM (and further HARMONIE) modelling system (realised by DMI and other members of the HIRLAM chemical branch).

EuMetChem: DMI leads the new COST Action ES1004: 'European framework for online integrated air quality and meteorology modelling (EuMetChem)', which is focusing on a new generation of online integrated ACP and Meteorology (NWP and Climate) modelling with two-way interactions between different atmospheric processes including chemistry, clouds, radiation, boundary layer, emissions, meteorology and climate (see: http://eumetchem.info).

MEGAPOLI: DMI coordinates the EC FP7 project 'Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation', where Enviro-HIRLAM is considering one of the main integrated modelling system to study the interactions of meteorology, air pollution and climate change for large urban agglomerations (see: http://megapoli.info).

MACC: DMI participates in the MACC project with downscaling of the global ECMWF-MACC IFS/MOZART and regional MACC-ensemble CWF to meso- and city-scale CWF. The current MACC regional ensemble, linked with the global IFS-MOZART, includes only off-line ACT models. Within the next MACC-II project ECMWF will test a next generation online integrated C-IFS global model including aerosol/chemistry feedbacks, so it is important also to downscale at least one online integrated regional model with the global C-IFS. The online integrated Enviro-HIRLAM will be tested with the boundary conditions from off-line MOZART and further from online C-IFS for integrated forecast of regional physical and chemical weather.

PEGASOS: DMI together with the University of Copenhagen participates in the FP7 PEGASOS project with online integrated Enviro-HIRLAM model simulations. The Pan-European Gas-AeroSOls-climate interaction Study (PEGASOS), a large scale EC FP7 project, addresses the call on atmospheric chemistry and climate change interactions (see: http://pegasos.iceht.forth.gr). DMI is involved into further development/improvement/evaluation of the Enviro-HIRLAM model for long-term simulations and studies of aerosol feedback mechanisms on meteorological events and climate.

ENSCLIM: Nordic project EnsClim: 'Robustness of predictions of climate change impact on dispersion and effects of airborne pollutants in northern Europe' is considering studies of two-way interactions between pollutants and meteorological/climate processes for the Nordic countries / European Arctic (DMI team responsibility).

TRANSPHORM: DMI participates in the TRANSPHORM and responsible for WP2.4 on Regional and city-scale atmospheric chemical transport modelling. The FP7 project TRANSPHORM aims to improve the knowledge of transport related airborne particulate matter (PM) and its impact on human health and to develop and implement assessment tools for scales ranging from city to Europe (see: transphorm.eu).

CEEH: CEEH is the Danish strategic research Center for Energy, Environment and Health with the mission to develop a system to support planning of future energy systems in Denmark. The main DMI task in the center is integrated modeling of meteorology and atmospheric pollution within the CEEH integrated 'Energy-Environment-Health-Cost' modelling framework system (see: http://ceeh.dk).

AQMEII: Air Quality Model International Initiative phase 2 exercise focusing on evaluation and intercomparison of online integrated meteorology-chemistry models (see: http://aqmeii.jrc.ec.europa.eu).

Work Plan

Two main **application areas** of the integrated modelling are expected to be considered:

(i) improved numerical weather prediction with short-term feedbacks of aerosols and chemistry on meteorological variables, and

(ii) improved chemical weather forecasting with online 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 the Enviro-HIRLAM Special Project at ECMWF is primarily on the evaluation and testing of the online integrated Enviro-HIRLAM/HARMONIE System and sensitivity analyses the feedback mechanisms for CWF and NWP.

Expected simulations:

(i) for short term episodes and chemical and physical weather forecasting for study of sensitivity of the aerosol feedback effects on meteorology and air quality;

(ii) for long term simulations for testing the model for long-term effects and climate scenarios;

(iii) for testing boundary conditions and chemical data assimilation in Enviro-HIRLAM within the MACC-II framework.

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

The **evaluation methodology** will follow the recommendations/guidelines for the evaluation methodology and protocol for online integrated meteorology-chemistry modelling systems, recently developing by the COST Action ES1004: European framework for online integrated air quality and meteorology modelling (EuMetChem, 2010) and by the AQMEII Phase2 Initiative (Galmarini et al., 2011).

The **duration** of the requested special project is to be from 1 January 2012 until 31 December 2014. The computational costs of these Enviro-HIRLAM and further Enviro-HARMONIE experimentation and validation activities will likely extend well 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

Based on the above description the following processes, which are of importance in NWP and chemical weather prediction, will be implemented and tested during the special project:

- Implementation of simplified aerosol scheme for use in NWP models
- Direct aerosol-radiation interactions including both short and long wave radiation
- Semi-direct aerosol-radiation interactions
- Aerosol-cloud interactions with respect to precipitation and radiation
- Implementation of cold-phase microphysics into the STRACO cloud scheme and coupling to the aerosol scheme

Workplan for the second year (2013):

Within the special project the following specific activities will be performed:
0-2013: Set-up of a new mass conserving semi-lagrangian version of Enviro-HIRLAM system on the ECMWF HPC system
1-2013: Test and first evaluation of the Enviro-HIRLAM model for long-term simulations (PEGASOS, EuMetChem)
2-2013: Test and evaluation of a new aerosol model for usage in online model systems (PEGASOS)
3-2013: Sensitivity runs/studies of aerosol feedback mechanisms on meteorological events and climate (PEGASOS, TRANSPHORM)
4-2013: Running of HARMONIE system with improved aerosol-radiation interaction on the ECMWF HPC system (HIRLAM-B)

List of deliverables for 2013:

D0: 28-02-2013 Semi-lagrangian mass conserving version of Enviro-HIRLAM Set-up on ECMWF HPC system
D1: 31-12-2013 Results of test and first evaluation of the Enviro-HIRLAM model for long-term simulations
D2: 31-07-2013 Results of new aerosol model evaluation for usage in online model systems
D3: 01-12-2013 HARMONIE system with improved aerosol-radiation interaction on the ECMWF HPC

Estimated resource requirements:

The initial phase of the proposed special project will focus on setting up system and perform various technical evaluation, sensitivity experiments and configuration studies, based on the HIRLAM chemical branch as implemented at ECMWF platform. In accordance with the research plan in HIRLAM-B programme, pilot study will be initiated at the later stage of HIRLAM-B for development of the HARMONIE chemistry branch.

Currently, for a typical Enviro-HIRLAM simulation with gas phases and simpler chemistry, the runtime costs is at the order of 10000 SBU per experiment day, with significant variations depending on resolution and domain size, sophistication of chemistry scheme. A rough estimate of a one-year worth of simulation experiments would then arrive to 3.6 million SBU. In anticipation of some contribution from the Danish national SBU allocation, we wish to receive an annual allocation of 4 million SBU in form of special project for a three year period.

References:

Alapaty, K., R. Mathur, J. Pleim, Ch. Hogrefe, S. T. Rao, V. Ramaswamy, S. Galmarini, M. Schaap, R. Vautard, P. Makar, A. Baklanov, G. Kallos, B. Vogel, R. Sokhi (2011) "New Directions: Understanding Interactions of Air Quality and Climate Change at Regional Scales". *Atmospheric Environment*. doi:10.1016/j.atmosenv.2011.12.016

Baklanov, A., 2010: Chemical weather forecasting: A new concept of integrated modelling. *Advances in Science and Research*, 4: 23-27. www.adv-sci-res.net/4/23/2010/

Baklanov, A., A. Gross and J.H. Sørensen, 2004: Modeling and Forecasting of Regional and Urban Air Quality and Microclimate, *J. Computational Technologies*. 9(2), 82-97.

Baklanov, A., Korsholm, U., Mahura, A., Petersen, C., and Gross, A., 2008a: ENVIRO-HIRLAM: on-line coupled modelling of urban meteorology and air pollution, *Advances in Science and Research*, 2, 41-46.

Baklanov, A., P. Mestayer, A. Clappier, S. Zilitinkevich, S. Joffre, A. Mahura, N.W. Nielsen, 2008b: Towards improving the simulation of meteorological fields in urban areas through updated/advanced surface fluxes description. *Atmospheric Chemistry and Physics*, 8, 523-543.

Baklanov, A., A. Mahura, R. Sokhi (eds), 2010: *Integrated systems of meso-meteorological and chemical transport models*, 186 pp. Springer, ISBN: 978-3-642-13979-6

Chenevez, J., A. Baklanov and J. H. Sørensen, 2004: Pollutant Transport Schemes Integrated in a Numerical Weather Prediction Model: Model Description and Verification Results. *Meteorological Applications.* 11, 265-275.

EuMetChem, 2010: Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action ES1004: *European framework for online integrated air quality and meteorology modelling*, Brussels, Dec. 2010, http://eumetchem.info/images/es1004-e.pdf

Galmarini, S., Rao, S.T., 2011: The AQMEII Two-Continent Regional Air Quality Model Evaluation Study: Fueling Ideas with Unprecedented Data. *Atm. Environ.* 45(14), 2464.

Givati, A., Rosenfeld, D., 2004: Quantifying Precipitation Suppression Due to Air Pollution. *Journal of Applied Meteorology* 43, 1038–1056.

Grell, G.A., 2008: Coupled Weather Chemistry Modeling. Large-Scale Disasters: Prediction, Control, Mitigation, Mohamed Gad-el-Hak, Cambridge University Press. Book Chapter.

Grell, G. A., S. E. Peckham, R. Schmitz, and S. A. McKeen, G. Frost, W. C. Skamarock, and B. Eder, 2005: Fully coupled "online" chemistry within the WRF model, *Atmos. Environ*., 39, 6957-6975.

Grell, G. and A. Baklanov, 2011: Integrated Modeling for Forecasting Weather and Air Quality: A Call for Fully Coupled Approaches. *Atmospheric Environment*, doi:10.1016/j.atmosenv.2011.01.017.

Gross, A. and A. Baklanov, 2004: Modelling the influence of dimethyl sulphid on the aerosol production in the marine boundary layer, *International Journal of Environment and Pollution*. 22, 51-71

Hollingsworth, A., R.J. Engelen, C. Textor, A. Benedetti, O. Boucher, F. Chevallier, A. Dethof, H. Elbern, H. Eskes, J. Flemming, C. Granier, J.W. Kaiser, J. J. Morcrette, P. Rayner, V-.H Peuch, L. Rouil, M. Schultz, A. Simmons and the GEMS consortium, 2008: Toward a monitoring and forecasting system for atmospheric composition. The GEMS Project. *Bull. of the American Meteor. Soc*., 89, 1147-1164.

Jacobson, M.Z., Kaufmann, Y.J., Rudich, Y., 2007: Examining feedbacks of aerosols to urban climate with a model that treats 3-D clouds with aerosol inclusions. *Journal of Geophysical Research* 112, D24205, doi:10.1029/2007JD008922.

IFS, 2006: *Integrated Forecasting System, Documentation*. Cy31r1, Physical Processes. ECMWF, http://www.ecmwf.int/research/ifsdocs/.

Kaufman, Y.J., R.S. Fraser, 1997: The effect of smoke particles on clouds and climate forcing. *Science*, Washington, DC, 277(5332), 1636-1638.

Lau, K.-M., Kim, K.-M., 2006: Observational relationships between aerosol and Asian monsoon rainfall, and circulation. *Geophysical Research Letter* 33, L21810, doi:10.1029/2006GL027546.

Korsholm, U., 2009: *Integrated modeling of aerosol indirect effects – development and application of a chemical weather model*, PhD thesis. University of Copenhagen, Niels Bohr Institute and Danish Meteorological Institute, http://www.dmi.dk/dmi/sr09-01.pdf.

Korsholm, U.S., Baklanov, A., Gross, A., Mahura, A., Sass, B.H., and Kaas, E., 2008: Online coupled chemical weather forecasting based on HIRLAM – overview and prospective of Enviro-HIRLAM. *HIRLAM Newsletter*, 54: 1-17, 2008.

Korsholm, U., A. Baklanov, A. Gross, J.H. Sørensen, 2009: Influence of offline coupling interval on meso-scale representations. *Atmospheric Environment*, 43 (31), 4805-4810.

Korsholm, U., Mahura, A., Baklanov, A., 2010: Monthly averaged changes in surface temperature due to aerosol indirect effects of primary aerosol emissions in Western Europe. *Atmos. Environ*. (in review), available from: http://megapoli.dmi.dk/publ/MEGAPOLI_sr10-10.pdf

Rosenfeld, D., 1999. TRMM Observed First Direct Evidence of Smoke from Forest Fires Inhibiting Rainfall. *Geophysical Research Letter* 26 (20), 3105-3108.

Rosenfeld, D., Dai, J., Yu, X., Yao, Z., Xu, X., Yang, X., Du, C., 2007. Inverse relations between amounts of air pollution and orographic precipitation. *Science* 315.

Rosenfeld, D., Woodley, W. L., Axisa, D., Freud, E., Hudson, J. G., Givati, A., 2008. Aircraft measurements of the impacts of pollution aerosols on clouds and precipitation over the Sierra Nevada. *Journal of Geophysical Research* 113, D15203, doi:10.1029/2007JD009544.

Rosenfeld, D., Woodley, W.L., 1999. Satellite-inferred impact of aerosols on the microstructure of Thai convective clouds. Proceedings, Seven WMO Scientific Conference on Weather Modification, Chiang Mai, Thailand, 17-22 February 1999, 17-20.

Zhang, Y., 2008: Online-coupled meteorology and chemistry models: history, current status, and outlook, *Atmos. Chem. Phys*., 8, 2895-2932.

Zhang, Y., X.-Y. Wen, Y. Pan, and C. J. Jang, 2010a, Simulating Climate-Chemistry-Aerosol-Cloud-Radiation Feedbacks in Continental U.S. using Online-Coupled WRF/Chem, *Atmos. Environ*., 44(29), 3568-3582.

Zhang, Y., Y. Pan., K. Wang, J. D., Fast, and G. A. Grell, 2010b: Incorporation of MADRID into WRF/Chem and Initial Application to the TexAQS-2000 Episode, *J. Geophys. Res*., 115, D18202, doi:10.1029/2009JD013443.