REQUEST FOR A SPECIAL PROJECT 2014–2016

MEMBER STATE: The Netherlands ....

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Project Title: Hirlam-B project second phase (2014-2015)*
(*: The HIRLAM-B programme itself lasts from 1-1-2011 until 31-12-2015. For the years 2011-2013, special project resources have been requested for a previous special project (project account spsehlam). The present request is for a follow-on project for the final two years, 2014-2015, with updated scientific goals.).
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If this is a continuation of an existing project, please state the computer project account assigned previously.	SP ______________	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)		
Would you accept support for 1 year only, if necessary?	YES ☐	NO X☐

Computer resources required for 2014-2016: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2016.)		**2014**	**2015**	**2016**
High Performance Computing Facility	(units)	6000000	6500000	
Data storage capacity (total archive volume)	(gigabytes)	20000	20000	

*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):

.........17/6/2013..........................

[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: Jeanette Onvlee..

Project Title: HIRLAM-B project second phase (2014-2015)

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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.

The HIRLAM-B research Programme, which has started in January 2011 and will end in December 2015, is a continuation of the research cooperation of the previous HIRLAM projects. The members of HIRLAM-B are the national meteorological institutes of Denmark, Estonia, Finland, Iceland, Ireland, Lithuania, Netherlands, Norway, Spain and Sweden, with Meteo-France as associated member.

Within HIRLAM-B, research efforts are focussed on the development, implementation and further improvement of the non-hydrostatic mesoscale analysis and forecast system Harmonie, and of short-range 10km-scale and mesoscale ensemble prediction systems (called GLAMEPS and HarmonEPS, respectively) suitable for severe weather. The Harmonie system is being developed in a code cooperation with the Aladin consortium. The hydrostatic Hirlam model still is maintained and used (e.g. for ensemble forecasting purposes and coupling with chemistry), but is gradually being replaced by Harmonie.

Following the past Hirlam practice, a Reference system is being maintained on the ECMWF HPC platform for the Harmonie model. This Reference System includes not just the code, scripts and tools for the deterministic model, but also those for the Harmonie-based convection-permitting ensemble forecasting system HarmonEPS. The emphasis in the HIRLAM-B Special Project at ECMWF is primarily on experimentation, and evaluation and testing of the Harmonie Reference System. The quality of the Reference System is of paramount importance to all Hirlam members. The Special Project computational resources will be used mainly to experiment with newly developed model components and evaluate their meteorological and technical performance in beta-releases, before releasing them as Reference.

Below, the main research activities planned for the coming two years are outlined. In-depth validation and intensive (pre-)operational testing of all of these developments will be carried out both in the member institutes and at ECMWF. In addition to the development of the deterministic model, research is also done on ensemble forecasting at scales of ~10km horizontal resolution down to convection-permitting ensembles. For these activities, separate special project resources have been requested, and they will not be described here.

<u>Data assimilation:</u>

At present Harmonie uses as default a 3D-Var assimilation system. A first priority for upper-air data assimilation is to refine this present system with respect to applications at horizontal resolutions of 1-5 km. These refinements focus on tuning of present observation usage, and exploitation of new types of spatially and temporally dense observations: radar radial wind and reflectivity volume data, GNSS ZTD, IASI cloud-free and cloudy radiances, Mode-S observations and ASCAT winds. Considerable resources are being devoted to the pre-processing, quality control, tuning and impact assessment of these data types. For ATOVS, IASI and GNSS, a variational bias control algorithm has been included and has been or is being tested. For radar data, a common quality control procedure, based on the Baltrad QC algorithms, has been introduced in local suites, and impact studies including both local and non-local radar reflectivity and wind data are ongoing. For IASI, the channel selection procedure is being revisited to study effects of surface- or cloud-contamination. Software for the quality control and pre-processing of Mode-S wind and temperature observations has been developed, and negotiations are ongoing with several air traffic control centers to make these data available for meteorological applications on an operational basis. Preparations are being made for the assimilation of ASCAT winds (including the new high-resolution coastal product) and soil moisture. Observation impact and rapid update cycling studies (hourly and 3-hourly) are being carried out for all of the above-mentioned observation types individually. An integrated observation experiment involving radar reflectivity and radial winds, GNSS ZTD and IASI observations, on top of a baseline of conventional and ATOVS data, has started late 2012. These assimilation impact experiments and further optimization of the assimilation procedures for high-resolution data will continue throughout 2013 and 2014.

Cloud initialization based on cloud mask, top and base information derived from MSG is under investigation. The simple method initially employed for this is being extended to assimilation of more advanced MSG cloud products, and it is being considered how to best integrate such a cloud initialization in a 3D-Var framework.

Furthermore, it is aimed to improve the use of observations types that already are routinely used: conventional observations (e.g. improved AMDAR bias correction) and measurements from satellite-based instruments (AMSU, MHS, AMV). Work is ongoing to tune and further optimize the handling of these data with regard to quality control, thinning, bias correction and error characteristics.

On the algorithmic side, the main aim is the development of more flow-dependent data assimilation methods. Experiments are being carried out with hybrid ensemble data assimilation systems based on Hirlam 3- and 4D-Var. Extensions to the basic Harmonie 4D-Var system which are presently being assessed, are weak constraint large scale filtering and digital filter initialisation, and the application of multiple outer loops. In addition, several 3D-Var hybrid ensemble assimilation techniques are undergoing testing: introduction of flow dependent background error covariances by a hybrid 3D-Var/ETKF system (Lorenc, 2003), ensemble data assimilation (Berre et al., 2007). For the next few years, the aim ultimately is to design and build a flexible algorithmic framework for 4D ensemble variational assimilation (4DEnsVar) for Harmonie, suitable for both assimilation and ensemble forecasting purposes. In Hirlam, the 4DEnsVar approach has already been implemented and shown to be superior to 4D-Var.

At high resolutions, it becomes increasingly important for the analysis system to be able to correct for position and phase errors of fine-scale atmospheric features. Present assimilation methods are not well versed in handling such non-additive errors. For this reason, so-called image warping or field displacement techniques (by which displacement errors are first identified and corrected for, after which a "normal" 3D-Var analysis is performed) are of potentially great interest. These methods have shown quite promising initial results; they will be pursued further and different ways of integrating them into the variation assimilation framework are under consideration.

For use of 3D-Var in rapid update cycling mode, model spin-up is a challenge that needs to be assessed and addressed. Optimisation of initialisation methods as well as of cycling procedures for moist parameters is being studied to improve the model description of (low) clouds and precipitation.

A complete overhaul of the data assimilation and use of observations code is planned in the projects OOPS and COPE, respectively, which have been initiated by ECMWF for the global IFS, but which will also be carried through for the LAM IFS parts like Harmonie in the coming years. For OOPS, a 4DEnsVar framework (incorporating all 3- and 4D-Var normal and hybrid ensemble assimilation setups of interest) has been developed using the Hirlam model, as a "toy system" to aid the design and testing of a modular and flexible Harmonie assimilation code environment.

Surface data assimilation has clearly shown to be beneficial for Harmonie. The analysis of <u>all</u> surface aspects relevant to NWP specifically requires the use of remote sensing surface observations, and optimal use of these observations in turn requires application of more advanced assimilation methods than the presently available OI. For soil data assimilation, an EKF has been developed, and this approach is being extended also to assimilation of snow, lake and sea ice observations. Research on surface observation usage mainly focuses on exploiting a greater variety of remote sensing observations, such as ASCAT and SMOS products for soil moisture, MODIS data for lake water temperature and ice fraction assimilation, and several different satellite products for sea ice and snow cover and depth.

<u>Dynamics</u>

The main emphasis in the dynamics research is on increasing the accuracy and efficiency of the dynamics code, also with a view to prepare the model for future use at very high resolutions and on massively parallel computer systems. Issues which are being considered in this context are the development of a vertical finite element (VFE) discretization, the physics-dynamics interaction on km-scales, and boundary condition treatment, domain size and nesting considerations.

In the past years, two formulations of a vertical finite element discretization have been developed by an ALADIN and a HIRLAM/ECMWF team, respectively. The ALADIN formulation turned out to be stable in 2- and 3D tests, and has been selected for further development and implementation.

The semi-implicit semi-Lagrangian scheme in the present Harmonie dynamics offers the possibility of using long time steps, but its efficiency is seriously hampered by the need to use, in some circumstances, a predictor-corrector scheme for stability reasons. It is aimed to make the dynamics more stable through the introduction of a higher order physics –dynamics coupling, thus hopefully allowing to dispense with the need for a predictor-corrector scheme. A second disadvantage of the semi-Lagrangian technique is that it is not designed to conserve neither the mass of dry air nor the proportion of any other component of the atmosphere. Improvements of the semi-Lagrangian method to better conserve mass for a wide range of resolutions are being sought which do not involve a large increase of the expense of the model. Presently a method proposed by Wedi, which has led to improved conservation of dry air mass in the global IFS, is under investigation. Additionally, it is being considered to enhance mass conservation for individual atmospheric components in the semi-Lagrangian treatment of the mixing ratio equations.

An aspect deserving further study is the influence of domain size on the forecast quality of high-resolution models. Past experience indicates that the use of small model domains may prevent or hinder a good representation of mesoscale features by the model, but this needs to be examined more thoroughly. Likewise, the influence of the choice of the model top, upper boundary treatment, and width of the relaxation zone on model performance should be carefully checked.

An important issue is what should be the necessary changes to the current Harmonie dynamics (spectral and VFE, semi-Lagrangian, semi-implicit) in order to sustain good performance at sub-km resolutions on future HPCs, in terms of a good balance between accuracy, stability and scalability. For the model dynamics, this entails introducing and testing alternative options in a stepwise and modular manner:

- Compare Semi-Lagrangian and Eulerian advection at high (sub-km) resolution
- Keep spectral solver but compare spectral technique for the computation of derivatives against local methods (finite elements, finite volume, finite differencing at high order)
- Compare spectral and grid-point Helmholtz solvers
- Compare staggered versus non-staggered grids
- Compare semi-implicit vs. explicit treatment of gravity and acoustic waves in the horizontal

Testing of these options has started at RMI.

Physics parametrizations:

Harmonie contains two branches of upper air parametrizations: AROME physics with explicit deep convection, and ALARO with partially parametrized convection. Physics developments will principally focus on improving the package most suitable for use at high resolutions, AROME, applying HIRLAM and ALARO experiences where relevant.

A major challenge in physics developments is posed by one of the present weaknesses of the forecast model, namely the description of low clouds and of fog over sea. Research on this focuses on the one hand on cloud initialization, and on the other on targeted improvements in the turbulence, cloud, microphysics and convection schemes. A number of ways of achieving this is under investigation. Several avenues are being explored to improve, or provide competitive alternatives for, the ICE3 microphysics parametrizations (e.g. introduction of the Liu-Penner ice microphysics, and an updated version of STRACO with a prognostic cloud droplet distribution, its resulting effective cloud droplet radius, and an ice nucleation scheme). These adapted or alternative schemes are being introduced and assessed. An alternative to be studied is the development of a more advanced, second-moment microphysics scheme, which treats the number concentration of cloud condensation nuclei in a prognostic manner. A second-moment scheme would permit a physically realistic way of taking into account indirect aerosol effects. Meteo-France is presently experimenting with two second-moment schemes.

The present spectrally detailed radiation scheme is not run at every time step, due to its cost. A comprehensive radiation inter-comparison study against several alternative schemes from Hirlam and Alaro which are less spectrally detailed but cheaper and run more frequently, has started. These studies have shown weaknesses in the short-wave radiation description of the model, and alternative improved formulations have been proposed for implementation. Improvements are also sought through a more realistic, internally consistent treatment of cloud-radiation-surface interactions within the model. Orographic parametrization of the effects of slopes and vegetation are being included in the radiation scheme. Systematic studies are being undertaken to assess the practical importance of parametrizing direct and indirect aerosol effects on cloud development, radiation fluxes and cloud-radiation interactions. Experiments have started with the introduction of a direct aerosol effect parametrization in the radiation scheme. At a later stage, parametrizations for indirect aerosol effects will be included as well.

A second major challenge for the forecast model is to increase model accuracy for (very) stable boundary layer conditions, especially at northern latitudes, where cold winter temperatures and development of low clouds and fog frequently present problems. In a workshop in December 2012, plans have been formulated for improving the description of the stable boundary layer by an interdisciplinary team, paying attention to the following aspects:

- Turbulence parametrizations of, and interactions between waves and turbulence in, the (long-living) stable boundary layer. For this purpose, the so-called turbulence energy and flux budget (EFB) scheme by Zilitinkevitch is being implemented and tested.
- The decoupling between upper air and near-surface layer in the model as compared to reality (influence of model vertical resolution, the near-surface sublevel approach in the canopy scheme of SURFEX, and the optimal definition of the lowest model level height).
- Description and initialization of clouds: Cloud microphysics and radiation interactions, treatment of the long-wave radiation near the surface. Cooling at the surface and at the top of fog/stratus.
- Influence of surface properties and their initialization - snow, ice, vegetation. Operational implementation of a multiple energy balance formulation for snow-forest-soil, and testing of an enhanced description of ice, and snow on ice, on lakes.

Validation studies for these various aspects will focus on the GABLS-4 experiment for Antarctica, which is presently being prepared by an international team with strong involvement from several Hirlam experts.

For surface modelling, the main focus remains on improving the description of Northern, Arctic and Antarctic conditions in Harmonie. Key issues are the handling of snow, ice, forest, lakes and sea ice. A multiple energy balance approach has been developed for vegetation- and snow-covered surfaces. Extensions of the FLake lake model with an ice and snow on ice parametrization, are being tested, as well as several parametrizations of different complexity for sea ice. Offline validation of the urban energy balance model (TEB scheme) for urban areas at sub-km resolutions has demonstrated the capability of TEB to provide realistic descriptions of urban effects upon the atmosphere.

For the mesh sizes presently used in Harmonie (~2.5km), several processes which need to be parameterized at coarser scales can be assumed to be at least largely resolved, and thus can be described explicitly, such as deep convection and orographic gravity waves. At resolutions of ~1km or less, also shallow convection and turbulence become partially resolved. Hirlam participates in international "grey zone" experiments in which model behaviour for convection and turbulence is compared against LES results for a range of resolutions down to several 100m.

Various Harmonie setups are presently being tested at sub-km resolutions.In these sub-km scale models, highly detailed orographic and physiographic information is required for the description of constant or slowly evolving surface properties, both in parametrizations and the surface assimilation. The databases presently used in Harmonie, GTOPO30 and ECOCLIMAP, are probably of insufficient resolution and quality for such use. The potential to augment or replace them by newer, more detailed satellite-based orographic and physiographic datasets is under investigation.

Future models of such high spatial detail are likely to require 3-dimensional parametrizations of unresolved processes as well as the introduction of some form of stochasticity in the physics. A 3D physics-dynamics interface will have to be developed to allow these developments. Investigations are being done on the use of 1+2D and 3D parametrizations for turbulence and radiation, respectively. The relation between the horizontal diffusion applied by the model dynamics (Semi-Lagrangian or conventional horizontal diffusion) and the parametrized vertical diffusion will be studied under different flow conditions. Moisture-conserving turbulence parametrizations in two and three dimensions are being developed based on the present TKE-scheme of AROME. Tilted array modelling of surface radiation will be applied to study the importance of transient and local cloud shadow effects for surface radiation fluxes, and the possible impact of a 3-dimensional treatment of the radiation parametrization. In addition to stochastic physics, new approaches like cellular automata are being tried to assess the impact of introducing stochasticity at various stages of development of organized convection.

Code efficiency and scalability

An important aspect to consider in the coming years is the optimization of code efficiency and scalability, with a view to use on very massively parallel hardware platforms. Comprehensive profiling of the code at the introduction of every new cycle will be necessary to clearly establish which parts of the code are the most limiting factors in terms of efficiency and scalability.

The main bottleneck for scalability, in Harmonie as in most other forecast models, is the need for I/O to read initial data and to write out forecast fields at required intervals. Removal of the present use of intermediate formats and the introduction of an I/O server are developments aiming to reduce these problems. From the point of view of scalability, the 4D-Var code is one of the potentially most troublesome issues in the future. The planned move to a 4DEnsVar system is intended as a solution to this issue.

In terms of parallelization, several existing and potential bottlenecks can be identified. The greatest problem at the moment remains the relatively poor parallelization of the surface model and surface assimilation. Solutions for this are being sought. The best way to improve the parallelization of a computer code on the longer term is to restrict as much as possible the need for communications among processors. In the context of the semi-implicit (SI) semi-Lagrangian (SL) Harmonie code, communications are unavoidable for applying SL interpolations and to perform spectral transforms. The efficiency of the communications needed for the SL scheme can be improved with the use of "on demand" SL communications.

The Harmonie model is regularly being benchmarked on as massively parallel machines as are available to the consortium. These benchmarks should be done not only for the model as a whole, but also for the system with different "bricks" removed (e.g. physics, I/O, …). GPGPU's (General Purpose computing on Graphical Processing Units), which are much faster than normal CPU's but less flexible in terms of I/O requirements, can provide the model with a possible speedup, at the cost of some recoding. Speedups of a factor 3-4 have been shown for some parts of the code, but a more extensive refactoring will likely be needed in order to improve the inherent parallellizability of the code.

Duration of the project and estimated resource requirements:
The duration of the HIRLAM-B programme is from 1-1-2011 until 31-12-2015. For the first three years (2011-2013), special project resources have been requested and granted in a previous project. The present proposal is for a follow-on project for the final two years of the programme, 2014-2015, along similar lines (experimentation with the Harmonie Reference system) but with updated scientific and technical goals.

For testing and tuning of the deterministic Harmonie system at ECMWF at 2.5km horizontal resolution, runtime costs amount to ~12000 SBU per experiment day.
The estimated needs for the testing of the deterministic Reference system are:

- pre-release technical tests: 12 months in total (4 "alpha" and "beta" software releases, each with approximately two weeks technical testing and debugging)
- parallel validation: 12 months total (6 month-long tests per major release for approximately 2 release versions)
- pre-operational impact and sensitivity tests evaluating individual components: 12 months
- debugging, problem detection and fixing activities: 12 months
- real time trunk suite, 12 months in total

So in total roughly 60 months or 60 * 30 * 12000 units = 21 M HPCF units are estimated to be required per year for testing and experimentation with the deterministic Harmonie Reference System at ECMWF in the coming years. A considerable amount of these total requirements will be covered by utilizing allocated member service national resources, partly through explicit contributions from member states to a dedicated pool supplementing the special project resources, partly through direct billing to the member state SBU quotas. For the Hirlam-B special project, we apply for 2014 for 6 million HPCF units, and a data storage of 20,000 GB, the most of latter on temporal storage (ECTMP).