REQUEST FOR A SPECIAL PROJECT 2016–2018

MEMBER STATE: The Netherlands……………………….………………………

Principal Investigator[1]: Jeanette Onvlee, Hirlam-B programme manager ………………..……

Affiliation: KNMI…………………………………………………………..……

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Other researchers:
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Project Title: Hirlam-C project first phase (2016-2018)*
(*: The HIRLAM-C programme itself lasts from 1-1-2016 until 31-12-2020. The present request is for a special project for the first three years of the HIRLAM-C programme. This will likely be followed up with a follow-on project for the final two years, 2019-2020, with updated scientific goals).

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.)	2016	
Would you accept support for 1 year only, if necessary?	YES ☐	NO X☐

Computer resources required for 2016-2018: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2018.)		**2016**	**2017**	**2018**
High Performance Computing Facility	(units)	10000000	11000000	12000000
Data storage capacity (total archive volume)	(gigabytes)	20000	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):
…16/6/2015……………………………

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: J. Onvlee……………………………………………………

Project Title: Project HIRLAM-C first phase (2016-2018)
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Extended abstract

The HIRLAM-C research Programme, which will start in January 2016 and end in December 2020, is a continuation of the research cooperation of the previous HIRLAM projects. The members of HIRLAM-C 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-C, research efforts are focussed on the development, implementation and further improvement of the mesoscale analysis and forecast system Harmonie, and its associated ensemble prediction system HarmonEPS, in particular to enhance their quality for the accurate prediction of severe weather at a target horizontal resolution of 0.5-1km. The Harmonie system is being developed within the IFS framework in close cooperation with the Aladin consortium.

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-C Special Project at ECMWF is primarily on experimentation, evaluation and testing of the Harmonie Reference System. 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 (undertaken jointly with Aladin partners) foreseen until the end of 2018 are outlined. In-depth validation and intensive (pre-)operational testing of these developments will be carried out both in the member institutes and at ECMWF. In addition to the deterministic model, research is also done on ensemble forecasting at scales of ~1-5km horizontal resolution, and on coupled atmospheric – chemistry modelling with the Hirlam and Harmonie atmospheric models. For these two activities, separate special project resources have been requested, and they will not be described here.

<u>Data assimilation:</u>
The following activities are foreseen:

1. Enhanced use of high-density observations in 3D- and 4D-Var:

At present Harmonie uses as default a 3D-Var assimilation system, which routinely assimilates conventional data and radiances from AMSU-A, AMSU-B and MHS. Additionally, several types of spatially and temporally dense observations can be assimilated optionally: radar radial wind and reflectivity volume data, GNSS ZTD, IASI cloud-free and cloudy radiances, Mode-S observations and ASCAT winds. Work to optimize the impact of these high-resolution data through e.g. improved data quality control, intelligent thinning or super-obbing strategies, bias correction, and the introduction of more appropriate (fine-scale) structure functions will be continued in the HIRLAM-C period. Additionally, in the coming years several new sources of high-resolution remote sensing observations will become available, such as ADM/Aeolus and MTG, and also the availability of observations from e.g. new aircraft observations, polarimetric radars or boundary lidars/ceilometers is likely to increase. Preparations will need to be made to incorporate these new data into the Harmonie analysis and assess their impact.

2. Development and optimization of flow-dependent assimilation methods: Introduction of 4D-Var and 3D-Var/ETKF

Until now, the impact of new high-resolution observations in the Harmonie 3D-Var configurations has generally been positive but limited in both size and duration. In particular when using combinations of different types of high resolution observations, e.g. radar winds together with reflectivities, it can regularly be seen that the combined data are less beneficial to the analysis than the individual data sources. There are many indications that this is at least partly due to inherent limitations of the 3D-Var method. On the algorithmic side, the main aim therefore is the introduction of more sophisticated flow-dependent data assimilation methods. A Harmonie 4D-Var system has been developed which has shown good potential to enhance the quality of the model analysis over that of 3D-Var, particularly also in critical weather situations. In the coming years, work on 4D-Var will be continued with a view to improve its computational performance and test its suitability for large model domain (order 1000x1000 grid points). However, for both global NWP models and for LAM models such as Hirlam, it has been shown that ultimately a more promising way forward is to combine the strengths of ensemble and variational approaches, to the mutual benefit of the model analysis and its probabilistic forecasting ability. For the next few years, the primary aim in data assimilation algorithmic development therefore is to design and build a flexible algorithmic framework for 4D ensemble variational assimilation (4DEnVar) for Harmonie, suitable for both assimilation and ensemble forecasting purposes. The starting point for this will be the construction of a hybrid 3D-Var/ETKF scheme. An LETKF scheme has already been set up and experimentation with it has started.

3. Development of data assimilation suitable for the nowcasting range

For nowcasting purposes, experiments have been made with the 3D-Var system in rapid update cycling mode. Such experiments will be continued at update frequencies of 1h and less, using observations such as radar, GNSS and locally processed AMV's with very short cutoff times. Spin-up effects will be studied, as well as the impact of these rapidly updating systems with the respect to less frequent updating with a more sophisticated technique such as 3-hourly 4D-Var.

4. Enhanced use of satellite surface observations in combination with more advanced surface assimilation algorithms

For the surface analysis, a simple OI approach is being used at present to assimilate conventional surface and screen level observations. The use of a much wider range of relevant remote sensing surface observations, however, requires application of more advanced assimilation methods. A new Surfex Offline Data Assimilation (SODA) surface assimilation framework is under construction which will allow the assimilation of widely different in-situ and remote sensing observations with a set of Extended Kalman Filters (EKFs) for soil, snow, lake and sea ice data. The primary goal for the coming few years will be to implement and use this set of EKF's to start exploiting a much 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

5. Integration of non-variational initialization methods into the variational assimilation system

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, a so-called field alignment technique (by which displacement errors are first identified and corrected for, after which a "normal" 3D-Var analysis is performed) has been developed which is of potentially great interest for application in the nowcasting time range, using radar observations. Also, a cloud initialization technique has been introduced using MSG observations, which was shown to be of significant benefit for forecasts of clouds and precipitation. The aim is to extend the cloud initialization technique to a wider range of satellite cloud products, and to integrate the field alignment and cloud initialization methods into the variation assimilation framework.

<u>Forecast model</u>

The following activities are foreseen:

1. Preparations for increased vertical and horizontal resolution

At present, the Harmonie forecast system is operationally run at 2.5km horizontal resolution and with 65 layers in the vertical. In the coming years, the model will be prepared for operational use first at higher vertical (~90 levels), then at higher horizontal resolution (~1km). In particular the vertical resolution upgrade is likely to require substantial re-tuning of the model physics. Use will be made of the experience already gained by Meteo-France at these resolutions. Aspects of numerical stability will need to be considered and the dynamics and horizontal diffusion settings will need to be optimized for these resolutions. In this context, among others the impact of the use of a cubic rather than a linear grid, the impact of upper boundary nesting, and the need for tuning of the semi-Lagrangian horizontal diffusion scheme will be investigated. In regions with steep orography, the impact of use of sub-grid orographic parametrizations for radiation and momentum at increased spatial resolution will be assessed.

2. Experimentation with modelling at hectometric resolutions

A start will be made with the development of appropriate schemes for the treatment of shallow convection and turbulence on those scales. Experiments are being set up for relevant areas (environments of airports, urban areas). Model performance will be compared with that of LES models. Appropriate (local) high-resolution physiographic information will need to be introduced for an accurate description of the surface at hectometric resolutions. Apply spatial verification techniques, experiment with the use of available local observation networks. In addition to stochastic physics, new approaches like cellular automata are being tried to assess the impact of introducing stochasticity and memory at various stages of development of the boundary layer, turbulence and convection.

3. Studies to eliminate systematic model errors for clouds and boundary layer behaviour.

Several studies are ongoing with the aim to eliminate systematic model biases under winter-time stable boundary layer conditions, in (low) clouds and visibility, and in surface fluxes. These studies will be continued in the coming years. It is being attempted to improve model stable boundary layer behaviour, in particular for low-wind winter conditions, through e.g. assessment of the influence of increasing model vertical resolution, alternative turbulence formulations, testing of the near-surface sublevel approach in the canopy scheme of SURFEX, and experimentation with the choice of lowest model level height.
The fog and low cloud and surface flux studies involve alternative formulations of the turbulence and radiation schemes, the cloud microphysics (first and second moment schemes), and a more realistic and consistent treatment of the radiation – cloud - aerosol interaction.

The present spectrally detailed radiation scheme is not run at every time step, due to its cost. A comprehensive radiation inter-comparison study is ongoing against several alternative schemes from Hirlam and Alaro which are less spectrally detailed but cheaper and run more frequently; this is believed to be important for a realistic description of the cloud-radiation interaction and cloud evolution. Improvements are also sought through a more realistic, internally consistent treatment of cloud-radiation-surface-aerosol interactions within the model. Orographic parametrizations 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 radiation fluxes, cloud development and cloud-radiation interactions. The use of MACC regional analyses for the initialization of aerosol will be explored.

Several avenues are being explored to improve, or provide competitive alternatives for, the ICE3 microphysics parametrizations. It is aimed to compare them to a more advanced second-moment microphysics scheme, LIMA (developed by Meteo-France),which treats the number concentration of cloud condensation nuclei in a prognostic manner.

For the validation of all these developments, extensive use will be made of the recently developed KNMI testbed and the Cloudnet supersite monitoring facilities, as well as participation in international studies such as GABLS4.

4. Dynamics developments

The main emphasis in the dynamics research is on increasing the accuracy and computational efficiency of the dynamics code, with a view to prepare the model for future use at hectometric resolutions and on massively parallel computer systems. Issues which are being considered in this context in the coming years are the development of a vertical finite element (VFE) discretization, introduction and testing of a cubic grid, assessing the physics-dynamics interaction on km- and sub-km scales, and alternative methods of boundary condition treatment and nesting.
On a longer time scale, an important issue is what should be the necessary changes to the current Harmonie dynamics (spectral, 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 and linear vs. higher-order grids
- Compare semi-implicit vs. explicit treatment of gravity and acoustic waves in the horizontal.

5. Physics-dynamics interaction

A new physics-dynamics interface will be introduced throughout the model with the aim to permit making a split between Arome and Alaro physics parametrizations at the process level. The effect which increasing model spatial resolution into the grey zone for shallow convection and turbulence will have on the physics-dynamics interaction and the treatment of horizontal diffusion will need to be assessed.

6. Surface modelling

For surface modelling, the main focus is 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. Activities of the past few years have included the development of a multiple energy balance approach for vegetation- and snow-covered surfaces, of a simple and a more sophisticated sea ice scheme, extensions to the Flake lake model with lake and snow-on-ice parametrizations, and an improved lake database and lake climatology. These developments have now become available for operational use, and need to be tested in combination with each other, and also in relation to surface data assimilation. In the new Surfex-v8 package, additionally also a more sophisticated diffusion soil scheme and more realistic snow schemes have become available, and these will be experimented with and assessed.

7. Coupled atmosphere – sea surface modelling

First experiments have been carried out with coupling Harmonie with the sea surface through one- and two-way coupling with the WAM wave model. The indications were that the impact of two-way coupling was quite beneficient. More extensive experimentation on this topic will be carried out, and the options for how best to implement this coupling operationally will be considered. On a longer time, the options, pro's and con's for coupling with 3-dimensional ocean models will be assessed.

Code efficiency and scalability

An important task to achieve is the optimization of code efficiency and scalability, with a view to use on very massively parallel hardware platforms. 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. 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. Plans to assess the impact of more efficient and "localized" dynamics options together with the IFS/AAAH partners were already mentioned above. In the context of the semi-implicit (SI) semi-Lagrangian (SL) Harmonie dynamics, communications are presently 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 aim is that I/O and as many computations as possible will take place in grid point space, thus reducing the need for spectral transforms.

In terms of parallelization, several existing and potential bottlenecks can be identified. One of the weakest points in the model was the relatively poor parallelization of the surface model and surface assimilation, and although this has been improved, further optimization in this area remains needed. From the point of view of scalability, the 4D-Var code (with its multiple outer loops) is one of the potentially most troublesome issues. This was an important motivation for the planned move to a more inherently parallellizable 3- and 4DEnVar system. Another option which is being studied is the Gaussian quadrature approach for 4D-Var, which would eliminate the need for (poorly scalable) multiple outer loops. The refactoring of the data assimilation code will be used to realize opportunities for making the code both more transparent and scalable. A similar restructuring of the full forecast model code is presently beyond reach, but at least the main physics steering routines and time step organization will be refactored with a view to enhanced transparency and performance.

Comprehensive profiling of the code at the introduction of every new cycle is necessary to clearly establish which parts of the code are the most limiting factors in terms of efficiency and scalability. The Harmonie model is regularly being benchmarked on as massively parallel machines as are available to the consortium. Studies to assess how best to optimize code performance on mixed CPU/GPGPU computer architectures are being undertaken both in the context of externally funded projects (e.g. ESCAPE) and in cooperation with hardware providers like Bull.

Duration of the project and estimated resource requirements:

The duration of the HIRLAM-C programme is from 1-1-2016 until 31-12-2020. The present request is for special project resources in the first three years (2016-2018) of the programme. A follow-on project will likely be submitted for the final two years of the programme, 2019-2020, 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 and 90 vertical levels, runtime costs amount to ~18000 SBU per experiment day.
The estimated needs for the testing of the deterministic Reference system are:

- pre-release technical tests: 12 months in total
- parallel validation: 12 months total
- 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 * 18000 units = 32 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 partly through explicit contributions from member states to a dedicated Hirlam SBU pool supplementing the special project resources, partly through direct billing to the member state SBU quotas. For the Hirlam-C phase 1 special project, we apply for 2016 for 10 million HPCF units, and a data storage of 20,000 GB, the most of latter on temporal storage (ECTMP).