REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: Netherlands

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Other researchers: ~80 researchers from the HIRLAM countries.

Project Title: HIRLAM-C phase 2 special project (2019-2020)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ___________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2019	
Would you accept support for 1 year only, if necessary?	YES X☐	NO ☐

Computer resources required for 2019-2021: (To make changes to an existing project please submit an amended version of the original form.)		**2019**	**2020**	**2021**
High Performance Computing Facility	(SBU)	32 MSBU	32 MSBU	
Accumulated data storage (total archive volume)[2]	(GB)	20.000	20.000	

***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): 18/6/2018

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.

[2] If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year.

Principal Investigator: Jeanette Onvlee

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Extended abstract

The HIRLAM-C research programme, which has started in January 2016 and will 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 forecasting 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 0.5-2.5km. The Harmonie system is being developed within the IFS code framework in close cooperation with the Aladin consortium.

Following the past Hirlam practice, a Harmonie Reference system is being maintained on the ECMWF HPC platform. 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 requested HIRLAM-C Special Project at ECMWF will be primarily on experimentation, evaluation and testing of the Harmonie Reference System, and its ensemble configuration HarmonEPS. The computational resources from the Special Project will be used mainly to experiment with newly developed model, assimilation and ensemble generation components and to evaluate their meteorological and technical performance in beta-releases, before releasing them as Reference. In-depth validation and intensive (pre-)operational testing of these developments will be carried out both in the member institutes and at ECMWF.

In the past years, the HIRLAM-C phase 1 (2016-1028) project (spsehlam) concerned experimentation and testing of the deterministic Harmonie system only, while studies of the HarmonEPS ensemble configurations was carried out in the special project spnogeps. The present request is for a Special Project for the second half of the HIRLAM-C period, for 2019-2020, which will encompass both the deterministic and ensemble model configurations)hereby essentially merging the previous spsehlam and spnogeps projects into a single project for the period 2019-2020). Below, the main foreseen research activities on data assimilation, the forecast model, surface analysis and modelling, probabilistic forecasting and code efficiency and scalability (undertaken jointly with Aladin partners) from early 2019 until the end of 2020 are outlined.

A) Data assimilation developments:

The following activities are foreseen:

<u>A1: Enhanced use of high-density observations:</u>

At the beginning of the HIRLAM-C period, the Harmonie Reference system used as default a 3D-Var assimilation system, which routinely assimilates conventional data and radiances from AMSU-A, AMSU-B and MHS. During the years 2016-2018 several types of spatially and temporally dense observations have been added to the assimilation system either operationally or optionally: radar radial wind and reflectivity volume data, GNSS ZTD and slant delays, IASI radiances, SEVIRI, geostationanry and polar atmospheric motion vectors, Mode-S EHS observations and scatterometer winds. In addition, much work has been done to optimize the impact of these high-resolution data through e.g. improved data quality control, more intelligent thinning and super-obbing strategies, bias correction, and the introduction of more appropriate (fine-scale) structure functions.

In 2019 and 2020 the focus will shift to adding, and optimizing the use of, new sources of information: all-sky radiances; new satellite platforms and instruments such as ADM/Aeolus and MTG; new aircraft observations; polarimetric radars; boundary layer lidars and ceilometers; and crowd-sourced observations from e.g. road networks, amateur weather stations and smart phones. Efforts will be made to incorporate these new data types into the Harmonie analysis and assess their impact.

In the past years, the Harmonie 3D-Var system has been increasingly used for national re-analyses (e.g. Gleeson et al. 2017). Re-analysis activities will continue in the years 2019 and 2020, e.g. for the Arctic region (the CARRA project).

A2: Development and optimization of flow-dependent assimilation methods: Introduction of 4D-Var, development of LETKF and hybrid 3/4DEnVar

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. 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. 4D-Var can now technically be run with multiple outer loops and is very close to being able to be run together with the full range of observations that is used in the operational Harmonie 3D-Var suites. In the coming years, the 4D-Var system will be prepared for operational use, with impact and optimization studies for the full range of available observations, and with a view to further improve its computational performance.

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 build and implement a flexible algorithmic framework for 3- and 4D ensemble variational assimilation (3/4DEnVar) for Harmonie, suitable for both assimilation and ensemble forecasting purposes. In the past years, a hybrid 3D-EnVar prototype has been constructed, as well as an LETKF system. Sensitivity studies on the performance and optimal settings for both these systems have started, and this experimentation will continue in the years 2019 and 2020. Additionally, the EnVar and LETKF prototypes will be recoded in order to adhere to the new OOPS structure of the data assimilation code.

A3. Development of data assimilation suitable for the nowcasting range

For nowcasting purposes, experiments have started with the 3D-Var system in rapid update cycling mode, 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 have been 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. These experiments will be continued, with a focus on deriving assimilation setups which minimize spinup and which enable a more efficient use of the most recent observations (e.g. the overlapping windows technique developed by Yang et al, 2017).

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 in the model as compared to satellite and radar imagery. Variational assimilation methods are not well versed in handling such non-additive errors. For this reason, a so-called field alignment (FA) technique has been developed. The FA technique is used to identify and correct for displacement errors of the model first guess field relative to a radar wind or reflectivity field, after which a "normal" 3D-Var analysis is performed). FA (Geijo, 2012) has been demonstrated to be succesful in the nowcasting range, but its beneficial impact is often lost after 3-6 hours. It is believed that this is mainly due to imbalance problems. Experiments have therefore begun with different initialization techniques with the aim of improving balance. Also, a cloud initialization technique has been introduced using MSG satellite imagery, initially using only cloud top level information. It has been shown that the original cloud initialization algorithm, which generally resulted in a too moist model atmosphere, can be improved by using a wider range of cloud information at various levels in the atmosphere. A more sophisticated use of e.g. the NWC SAF cloud type information and cloud mask has been shown to result in a more realistic initialization of moisture profiles, and thereby better performance in the nowcasting range (Gregow, 2017).

B) Atmospheric Forecast model

The following activities are foreseen:

<u>B1: Studies to eliminate systematic model errors for cloud and boundary layer behaviour.</u>

Several studies are ongoing with the aim to eliminate systematic model biases under winter-time stable boundary layer conditions, (low) clouds and visibility, severe convection, 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 stable winter conditions, through e.g. assessment of the influence of increasing model vertical resolution, alternative turbulence formulations, and experimentation with the choice of lowest model level height.

Improvements are also sought through a more realistic, internally consistent treatment of the microphysics and the cloud-radiation-surface-aerosol interactions within the model. Detailed cloud and microphysics observations from e.g. Cloudnet supersites, CAMS products and international experiments like GABLS-4 will be used to evaluate alternative formulations of the turbulence and radiation schemes, to make an in-depth comparison between the first moment ICE3 cloud microphysics and the new second moment LIMA scheme, and to assess the radiation – cloud - aerosol interaction. Systematic studies to assess the practical importance of parametrizing direct and indirect aerosol effects on radiation fluxes, cloud development and cloud-radiation interactions will be continued. Several types of aerosols (sea salt, sand, sulphate) have been introduced in the physics parametrizations, which can be initialized from CAMS or regional atmospheric composition models. The number of types of aerosols will be extended with dust and black carbon, and the sensitivity of atmospheric evolution to their presence will be studied further. It will be studied how to port the new IFS radiation scheme ECRAD to Harmonie and then intercompare it with the existing default Harmonie radiation scheme and the ACRANEB2 scheme developed by LACE.

Orographic parametrizations of the effects of slopes and vegetation are being included in the radiation scheme, and will be assessed in detail. An orographic sub-grid scale parametrization is also under development.

B2: Preparations for increased vertical and horizontal resolution

At present, the Harmonie forecast system is typically run operationally at 2.5km horizontal resolution and with 65 layers in the vertical. In the past few years, work has started to prepare the model for use at higher vertical (~90 levels) and horizontal resolution (~250m-1km), and this will be intensified in the years 2019 and 2020. Many local Harmonie setups have been made which can be run at 500 or 750m horizontal resolution, on domains with very diverse characteristics (regions of steep orography and/or complex land-sea transitions, island domains dominated by sea, areas around airports or urban environments (e.g. Yang, 2018)). On these test domains, aspects of numerical stability will be considered and the dynamics and horizontal diffusion settings will 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, the need for applying alternative dynamical schemes in conditions of steep orography, and the tuning of the semi-Lagrangian horizontal diffusion (SLHD) 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. At grid scales of 500m and less, investigations will aim to find appropriate descriptions for the treatment of shallow convection, boundary layer clouds and turbulence. Model performance will be compared with that of LES models, field studies and high-resolution observation networks. In the urban areas, various existing but yet unexplored options of the urban TEB (town energy budget) surface module will be studied. Where available, appropriate (local) high-resolution physiographic information will be introduced for an accurate description of the surface at hectometric resolutions.

Furthermore the aim is to develop data assimilation and ensemble setups suitable for these high resolutions. It will therefore be investigated which (nowcasting) data assimilation setups and which observation types are most suitable to initialize the frequently run hectometric-scale models. For high-resolution ensembles, the so-called overlapping window technique developed by Yang et al. (2017) will be explored. In all of these studies, it will be considered what will be the optimal way to spend available computational resources, seeking the best balance between horizontal and vertical resolution, domain size, ensemble size and model complexity.

C) Surface analysis and modelling

The following activities are foreseen:

C1: Enhanced use of satellite surface observations in combination with more advanced surface assimilation algorithms

For the surface analysis, the Harmonie Reference System presently uses a simple OI approach 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. In the past few years, a new Surfex Offline Data Assimilation (SODA) surface assimilation framework has been constructed which will allow the assimilation of widely different in-situ and remote sensing observations with a set of Simplified Extended Kalman Filters (SEKFs) for soil, snow, lake and sea ice assimilation. The primary goal for the coming few years will be to implement this set of SEKF’s operationally, and then 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 satellite products for sea ice and snow cover and depth. Experiments to assess the potential of these satellite surface observations are ongoing, and will be continued at greater intensity in the coming two years.

C2: Introduction of more advanced surface model descriptions

For surface modelling, activities in the past years have focussed on improving the description of Northern, Arctic and Antarctic conditions in Harmonie. Key issues were the handling of snow, ice, forest, lakes and sea ice. This has led to the development of a multiple energy balance approach for vegetation- and snow-covered surfaces, of initially a simple and later a more sophisticated sea ice scheme, of extensions to the Flake lake model with lake and snow-on-ice parametrizations, and an improved lake database and lake climatology. Recently, in the Surfex-v8 package also a more sophisticated diffusion soil scheme and more realistic snow schemes have become available. All of these new modules have individually shown to be beneficial. Now they need to be tested in combination with each other, and also in relation to the new SEKF surface data assimilation schemes.

Operational experiences have shown that the quality of the physiographic databases used in the surface modelling is of critical importance to model performance. A sustained effort is therefore necessary to study potential deficiencies in existing databases and evaluate new (more detailed and hopefully more accurate) ones, such as ECOCLIMAP-Second Generation.

C3: 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 and Wavewatch wave models. Results so far indicate that the impact of two-way coupling, using an OASIS coupler, can be quite beneficient. In the coming years, the experimentation with atmosphere – wave coupling will continue. Also, the options, pro's and con's for coupling with 3-dimensional ocean models will be assessed.

D) Probabilistic forecasting

The ensemble configuration of the convection-permitting Harmonie system, HarmonEPS, is a flexible system with a range of possibilities to describe uncertainties in different parts of the NWP system. More than half the HIRLAM institutes presently run operational or pre-operational versions of HarmonEPS.

To account for the uncertainties in the initial conditions there is a close cooperation with the data assimilation research staff on developing ensemble DA methods (see section A2 above), which will continue for the duration of this project. In addition to what is mentioned in A2, EDA (ensemble data assimilation) has been introduced and will be further tuned. In HarmonEPS EDA is used to account for initial uncertainty by perturbing the observations and running separate assimilation cycles for all members.

For a limited area ensemble prediction system like HarmonEPS, perturbations at the lateral boundaries are important. Recently the impact on the performance of HarmonEPS by nesting and perturbing the LBCs using IFS ENS or SLAF was tested. SLAF (Scaled Lagged Average Forecasting) is a method where the lateral boundary perturbations are computed as scaled differences between previous forecasts from ECMWF high resolution forecasts valid at the forecast time. This study showed that the two methods are comparable, but that using IFS ENS gives better consistency of spread and skill for HarmonEPS. When nesting HarmonEPS in ENS, which typically has 10-15 members, while IFS ENS has 50, there is a question how to best choose the IFS ENS members to nest in. Clustering of IFS ENS members has been tried, and this gives somewhat better scores for HarmonEPS. In 2019 and 2020 different clustering techniques will be tested, where both the method itself and what parameters, forecast times and levels to cluster for, will be investigated. In the years 2019-2020 also the surface analysis perturbation scheme (Bouttier et al, 2015) will be developed further, especially with a focus on getting more realistic structures for SST, ice and snow perturbations.

For the representation of model error, the SPPT scheme (Buizza et al, 1999) is being optimized for HarmonEPS. A parameter perturbation approach is under development, where sensitive parameters in micro-physics, radiation, dynamics and turbulence, and possible also surface, are identified and perturbed. For this purpose, the SPP framework from Ollinaho et al. (2017) is being implemented in HarmonEPS. As the schemes, parameters, and spatial and temporal scales from HarmonEPS are quite different from IFS ENS, extensive testing will be needed. This work will continue in 2019 and 2020, including more parameters in the scheme, and testing spatial and temporal scales and stochastic pattern generators.
In addition to testing perturbation techniques as described above, there are structural changes that also needs testing, such as the balance between the number of ensemble members, the horizontal and vertical resolution, and the size of the area. These are important questions to answer to get the most out of the available operational computer resources in the members states.

E) Code efficiency and scalability

An important task to achieve is the optimization of code efficiency and scalability, with a view to use the model effectively on very massively parallel hardware platforms. Efforts on this will be intensified in the coming years.

Already ongoing activities within HIRLAM and our ALADIN partners to adapt scientific algorithms towards greater computational efficiency and/or scalability will be continued. Examples of these are e.g. the development of ensemble data assimilation techniques (EnVar techniques having been demonstrated to be both faster and more scalable than 3- or 4D-Var); the development of the Gaussian quadrature method to avoid the use of poorly scalable multiple outer loops in 4D-Var; the studies on the use of cubic, quadratic or "super-linear" spectral grids as alternative to the default linear grid; the trend to avoid computations in spectral space as much as possible; a dynamic setting of the time stepping scheme, allowing an efficient combination of the strengths of the SETTLS (cheap but sometimes not stable) and the predictor-corrector (more stable but twice as expensive) schemes; and the study of alternative (non-spectral) Helmholtz solvers and multi-grid approaches in the model dynamics. The overhaul of the data assimilation and observation preprocessing code in the context of the OOPS and COPE programmes will be used as an opportunity to make the code more transparent and more efficient. Also the Harmonie script system is being revisited to enhance its transparency and modularity.

A promising new development is the recently introduced option of running the model, and components thereof, in single, rather than double, or hybrid precision. This feature, which may have quite a significant impact on time- and energy-to-solution, will be tested and assessed thoroughly in terms of both computational and meteorological performance.

In terms of parallellization, several existing and potential bottlenecks can be identified. One of the weak points in the model used to be the relatively poor parallelization of the surface model and surface assimilation, and although this has been improved, further optimization in this area probably remains needed. Parts of the physics code are presumably also still sub-optimally parallellized; e.g. a recent relatively small change to optimize loop executions in the microphysics resulted in a 6% reduction of the forecast model run time.

Throughout the Harmonie system, a mix of MPI and OpenMP parallellization is used. OpenMP thread parallellization has been introduced in many parts of the Harmonie model code. However, this has not been done everywhere, and its original implementation has been relatively simple, which may be underutilizing the potential of the present generation of many-thread processors. The OpenMP implementation will therefore need to be reconsidered.

Collaboration with external partners such as the Barcelona Supercomputing Center is sought in order to achieve a comprehensive profiling and analysis of the code efficiency on a variety of computer architectures, including e.g. mixed CPU/GPU platforms.

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 last two years (1-1-2019 unil 31-12-2020) of the programme.

For testing and tuning of the deterministic Harmonie system at ECMWF at 2.5km horizontal resolution and 90 vertical levels over the DMI domain, runtime costs amount to ~18000 HPCF units 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 million 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.

To test HarmonEPS, an ensemble of 10 members is run over the MetCoop domain with one forecast per day running to +36h, and three +6 forecasts per day to keep the cycling. This costs ~100 000 HPCF units per day. Typically, updates are tested for 3 weeks in summer and 3 weeks in winter, so 42 days per update. With 2 tests for each perturbation type per year (initial, LBCs, surface, model and structural) we end up with:
100 000 HPCF units * 42 days * 10 experiments = 42 million HPCF units per year.

In total therefore, the testing of the Harmine and HarmonEPS configurations require ~ 74 million HPCF units per year. 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 HPCF quotas. For the Hirlam-C phase 2 special project, we apply for 2019 and 2020 for 32 million HPCF units (the sum of the resources granted for the previous spsehlam and spnogeps projects for the past year), and a data storage of 20,000 GB, most of latter on temporal storage (ECTMP).

References:

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