HIRLAM strategy 2016-2020
Draft 20150930

Management summary

The purpose of the HIRLAM scientific cooperation is to provide the member institutes with a state-of-the-art short-range deterministic and probabilistic numerical weather analysis and prediction (NWP) system based on the convection-permitting model Harmonie, as the best possible means of support for their operational activities. This system should generally outperform other available forecast models on the HIRLAM member domains, and be versatile and flexible enough to cater to the changing needs of its users and stakeholders. With this, the HIRLAM member institutes aim to remain at the forefront of operational meteorology and NWP expertise in Europe.

To achieve these aims, the HIRLAM consortium has chosen the following strategic approach:

- In the development of Harmonie, HIRLAM has engaged in a strategic collaboration within the IFS code framework with the ALADIN consortium. This collaboration will be further intensified, with the aim that HIRLAM and ALADIN will form a new joint consortium by 2020.
- Highest scientific priority in the coming years is given to the development of a high-resolution (1-2.5km) short-range ensemble forecasting system in which the ensemble generation, the data assimilation system and the forecast model are closely integrated. The forecast skill of this system should be optimized with a particular view to the very short range (3-24h) and to the accurate prediction of high-impact weather phenomena.
- A second goal is to continue a sustained effort to demonstrably improve the meteorological performance of the Harmonie analysis and forecasting system through detecting and addressing systematic model weaknesses.
- Thirdly, but at relatively lower priority, the model should be developed towards use at higher (sub-km) resolutions and in the nowcasting (0-6h) range.
- Within human resource constraints, it is aimed to continue to gradually develop the model towards a more complete earth system model, with a focus in the coming years on sea surface and ocean aspects.
- The HIRLAM programme will continue its consortium-wide operational and pre-operational cooperation activities (e.g. the operation of a European-scale short-range ensemble system).

This document outlines the strategy for the HIRLAM Programme to achieve these objectives for the period 2016-2020. Please note that the present text is still preliminary in the sense that, while the basic goals and strategic objectives for the coming years have been defined by the consortium as described in section 2, the scientific plans for the coming years still need to be finalized in the first half of 2016 by the HIRLAM-C management group in coordination with the ALADIN consortium. At that time, this document will be updated accordingly.

1. Introduction

HIRLAM's prime long-term goal is to continue to provide the HIRLAM member states with a state-of-the-art operational short and very short range numerical weather prediction (NWP) system. The main application of this NWP system, called Harmonie, is the production of general weather forecasts, with particular emphasis on the detection and forecasting of severe weather. It should be the best possible means of support for the operational activities of HIRLAM members, generally outperforming other available forecast models on their domains, and be versatile and flexible enough to cater to the changing needs of its users and stakeholders. The Harmonie system also forms the basis of a wide range of national operational applications, such as aviation meteorology, road condition predictions, marine and storm surge forecasting, hydrological forecasts, predictions for the energy sector, urban meteorology and air quality modelling. The applications of Harmonie which are of critical importance to all HIRLAM members are severe weather warnings, aviation meteorological forecasts, and services in the context of public safety. The programme should assess the user needs for these applications, and take them into account in the setting of research priorities. Important non-operational applications include regional climate modelling and use of the model as a tool in atmospheric chemistry research studies.

The HIRLAM collaboration is primarily focussed on research, aiming to effectively provide a pool of manpower and expertise to maintain and develop a short-range NWP modelling capability according to the HIRLAM services' needs. As the scope of the research required for the model is ever widening and the available NWP staff within the Hirlam services is limited, a strategic choice has been made for close cooperation with other research teams, such as with ALADIN and the other partners in the IFS/Arpege framework, and with the Surfex community. A joining with Aladin in a new consortium is foreseen around the end of Hirlam-C. Mutually beneficial contacts with the regional climate modelling and atmospheric chemistry modelling communities have also been strengthening gradually. Within this larger R&D community, the HIRLAM consortium intends nevertheless to maintain an identity of its own in the coming years by concentrating on its strengths, e.g. its expertise on data assimilation. In this way, the consortium aims to retain a prominent position and acknowledged role in the field of both operational modelling and NWP expertise in Europe.

The HIRLAM consortium aims to build its research activities on a consistent long-term vision on NWP developments in Europe. This document describes the HIRLAM strategy for the period 2016-2020.

2. HIRLAM goals and strategy

The main **ambitions** of the HIRLAM consortium members are to optimally serve the changing operational needs of their various user communities, and to remain at the forefront of short-and very short range NWP expertise in Europe. In order to fulfil these ambitions, HIRLAM has set itself the following **goals** for the period 2016-2020:

- Further intensify the strategic collaboration with the ALADIN consortium, with the aim to form a new joint consortium by 2020.
- Highest priority in the coming years is given to the development of a high-resolution (1-2.5km) short-range ensemble forecasting system in which the ensemble generation, the data assimilation system and the forecast model are closely integrated. The forecast skill of this system should be optimized with a particular view to the very short range (3-24h) and to the accurate prediction of high-impact weather phenomena.
- Continue a sustained effort to demonstrably improve the meteorological performance of the Harmonie analysis and forecasting system at present operational resolutions, through detecting and addressing systematic model weaknesses.
- At a somewhat lower priority, prepare the model for operational use at increased resolution (~100 layers, 0.5-1.3km), and explore model behaviour at hectometric scales and in the nowcasting range.
- At relatively low priority, continue to develop the model gradually towards a more complete earth system model, with a focus in the coming years on sea and sea surface aspects.
- Continue to carry out joint actions which allow the member institutes to achieve a greater efficiency in their operational and/or pre-operational activities.

The **strategy adopted to achieve these goals** entails the pursuit of the following objectives:

0. Make preparations for the formation of a new joint consortium with Aladin in 2020 through targeted actions on the policy, organizational and code maintenance levels (see section 4).
1. Develop the Harmonie system towards a high-resolution (~1-2.5km) HarmonEPS probabilistic forecasting system in which ensemble generation, flow-dependent data assimilation techniques and the model formulation of stochastic processes are closely integrated, suitable for the accurate detection and forecasting of high-impact weather. Introduce local or regional operational HarmonEPS suites.
2. Identify and address the causes of systematic forecast weaknesses in both the model and the analysis system, particular concerning the description of convection, low clouds, boundary layer evolution and surface fluxes.
3. Continue optimizing the use and impact of existing, and introduction of new, types of high-resolution observations, in combination with advanced flow-dependent assimilation techniques.
4. Enhance the quality of the model surface description through the introduction and testing of more sophisticated surface component models, in combination with the assimilation of a wider range of satellite surface observations using more advanced data assimilation techniques. Achieve a better understanding of the interaction between the surface and the boundary layer through dedicated validation studies.
5. At somewhat lower priority than objectives 1-4, prepare the upper air and surface model for operational use at higher vertical (~100 layers) and horizontal (0.5-1.5) resolution and optimize the model configuration for use in the nowcasting (0-6h) range. On a longer time scale, develop the model formulation towards use at hectometric scales.
6. Extend the range of techniques and observations used for the validation and routine monitoring of the meteorological performance of Harmonie (e.g. through employing a wider range of spatial verification techniques, validation against Cloudnet supersites and a wider range of remote sensing observations, and the use of LES models).
7. Contribute to enhancing the computational efficiency, flexibility and scalability of the model in close collaboration with ECMWF, Météo-France and Aladin, mainly in the context of ECMWF's Scalability Programme.
8. Explore the potential of coupling the atmospheric model with the ocean surface. At a later stage, consider the benefits and costs of coupling with a 3D ocean model.
9. Continue the consortium-wide operational and pre-operational cooperation activities started during the HIRLAM-B period (2011-2015): the joint production of a European-scale ensemble system; the sharing of activities, software and expertise in observation pre-processing; monitoring and analysis of operational model performance; and mutual aid in the preparation of new model versions or benchmarking activities for the acquisition of new HPC systems.

The aim is that Harmonie will replace all existing deterministic operational HIRLAM systems in the coming years, and eventually the GLAMEPS short-range ensemble system as well. At some point, the HIRLAM model will be phased out also for non-operational applications, such as regional climate and chemistry transport modelling.

3. Scientific aspects

This section describes scientific aspects relevant for the objectives 1-9 listed in section 2. It should be noted that Hirlam shares many of these objectives with its Aladin partners, but not all. A joint strategy meeting in spring 2016 should clarify which scientific activities are foreseen, which ones will be included in the common work plan, and which ones will be Hirlam-specific. Based on this outcome, the Hirlam-C management and ALADIN CSSI will formulate a scientific strategy for the next five years for the shared objectives, and the ideas expressed below may be adapted and/or made more specific accordingly.

3.1 Towards an integrated Harmonie ensemble forecasting system

The aim is to develop the Harmonie system towards a high-resolution (~1-2.5km) HarmonEPS probabilistic forecasting system in which ensemble generation, flow-dependent data assimilation techniques and the model formulation of stochastic processes are closely integrated, and which is suitable for the accurate detection and forecasting of high-impact weather.

On global and regional scales, ensemble assimilation methods have shown great potential to let data assimilation and ensemble systems mutually benefit from each other. During Hirlam-B, experience has been gained with techniques like hybrid 3D-Var/ETKF and 3- and 4D-EnsVar in the Hirlam model, showing the benefits of these methods for LAM models as well. A key objective for the integration of the ensemble generation and analysis systems will therefore be the introduction of ensemble assimilation techniques into Harmonie. The aim is to move stepwise towards a Harmonie 4DEnsVar system: initially introduce a 3D-Var/(L)ETKF system for HarmonEPS, and later develop this into a full 3DEnsVar system for use in both the analysis and ensemble generation.

In parallel, the existing 4D-Var system should be further tested, developed and optimized, particularly from the view of computational efficiency. This 4D-Var method can then later be integrated into a 4DEnsVar system.

Unfortunately, given the high urgency of creating a powerful HarmonEPS system and the relatively slow progress of OOPS, the hybrid 3D-Var/ETKF development will presumably need to be undertaken in the existing Fortran framework. Although as much use as possible will be made in it of ongoing OOPS developments such as the observation operator refactoring which started in 2015, it will be necessary to recode the hybrid assimilation scheme to the OOPS structure, once the OOPS framework has been adapted to incorporate it.

In addition to perturbations in initial conditions a km-scale HarmonEPS system will also need to take into account uncertainties and stochasticity in the upper air forecast model, boundaries and surface conditions. At the end of 2015, model perturbations have been introduced in HarmonEPS through a multi-model approach and through perturbations in a selected number of parameters and processes. Stochastic physics is being implemented. Several ways of generating boundary perturbations are available. The relative value of these various perturbation approaches still needs to be assessed. Work on introducing perturbations in the surface analysis and model has only just started and should be intensified and diversified as a matter of high priority. It is aimed to evolve from a multi-model, multi-physics, multi-parameter approach and from stochastic perturbations of all tendencies towards perturbations of specific individual processes. Several new process-based perturbations are under development now, and these efforts should be widened.

A serious effort will be required for the calibration and post-processing of the ensemble. The present calibration techniques have limitations in areas of great inhomogeneity (steep orography, land-sea transitions). More powerful calibration methods need to be developed, at affordable costs.

For the routine verification of basic ensemble products, the HARP verification system will be used. Ensemble output generation should however be broadened beyond this direct output to include a wider range of probabilistic information on weather-related risks (e.g. by using upscaling techniques). Ensemble verification techniques may need to be diversified accordingly.

Relevant warning products should be developed in communication with duty forecasters and partners in the emergency services. It will need to be considered how to inform the forecasters and other users on convection-permitting ensemble quality and products, and train them in the best ways to interpret and deploy the ensemble output.

3.2 Identify and address systematic model weaknesses

To fulfil the ambition for Harmonie to be one of the best convection-permitting NWP models will require rigorous attention to assessment of the model’s strengths and weaknesses, and addressing the latter in a focused manner. A sustained effort to identify and reduce systematic errors in the deterministic model will also be essential to guarantee a high quality of the convection-permitting ensemble forecast system.

In sections 3.3 and 3.4, respectively, possible ways to systematically enhance the quality of the model analysis and the description of the model surface are described in more detail. Systematic forecast model weaknesses which have been identified and which are already being addressed are e.g. the over-prediction of clouds, in particular low clouds and fog; the poor screen level temperatures under very stable conditions; the positive bias in 10m wind; a significant bias in the downward radiative flux; the over-prediction of extreme precipitation. Other known weaknesses which still need to be tackled more rigorously, are e.g. the over-prediction of strong winds over sea; and problems with too great soil evaporation under summer conditions.

It is quite a challenge to alleviate these problems in a robust, well-validated process-oriented approach rather than by mere tuning (and risking the introduction of compensating errors in the model). The most important aspect of the forecast model to study in great detail in this respect is the description and evolution of clouds. There are highly complex interactions in the model between e.g. aerosol, radiation and clouds, as well as between turbulence, convection, clouds and microphysics, and these should be considered carefully. Certain systematic weaknesses are likely related to the fact that the various processes of clouds, microphysics, and radiation, and their mutual interactions, are not treated in an entirely consistent manner in the model. The radiation team has started work on studying and removing some of these inconsistencies, and this should be continued at high priority. The introduction of the new physics-dynamics interface should help making a cleaner split between the various processes described in the model.

One road towards improved model quality is to enhance the realism of specific model formulations. Areas which will receive specific attention in this respect are the representation of radiation-clouds-aerosol interactions, the introduction and testing of more realistic (incl. second moment) microphysics schemes, and the stable boundary layer.

Relevant research activities on the radiation-clouds-aerosol interaction would be e.g. the introduction of aerosol parametrizations in the new physics-dynamics interface, parametrization and assessment of indirect aerosol effects, the initialization of aerosols and surface emissions, a review of the cloud microphysics parameters, and studying the evolution of aerosols with a 2-moment microphysics scheme.

The accurate description of very stable boundary layer conditions remains a very big challenge, and studies on this need to be continued at high priority. Past research efforts have attempted to improve the boundary layer description (with partial or little success) through a better surface representation (esp. snow), and alternative turbulence schemes. To this work should be added an effort to study the impact of adopting a significantly higher vertical resolution in the PBL.

Due to limited available manpower, relatively little attention within Hirlam has been paid in recent years to the soil surface and its interaction with the boundary layer. This deserves to be studied in greater depth (see section 3.4).

The detection and analysis of the root causes of systematic errors in complex phenomena like clouds requires the use of validation and verification techniques that go well beyond the present routine verification tools. For a proper assessment of the complex interactions involved, a wide variety of validation methods should be employed (see also section 3.6): making use of well-observed international case studies; detailed comparison of the model against supersites with non-standard observations; 1D and 3D model comparisons against LES models and against other NWP models; and validation of the model in "climate mode" runs. This is an area where Harmonie research can clearly benefit from a close cooperation and interaction between the NWP and regional climate modelling communities using the model.

3.3 Enhanced use of high-resolution observations in a more sophisticated model analysis

During Hirlam-B, much effort has been spent on implementing several new types of high-resolution observations (radar, GNSS, Mode-S, ASCAT) into the Harmonie 3D-Var upper air and surface analysis. This work is not finished yet. Activities in the coming years should among others be focused on:

- First priority has the development and introduction of more advanced, flow-dependent assimilation techniques that can get the best impact out of complex data types like radar (initially 4DVar and hybrid 3DVar/ETKF, to be integrated later into a 4DEnVar framework; see also 3.1).
- making a better use of existing and already assimilated data types through e.g. enhanced quality control and more intelligent data selection (radar), enhancing the availability of relevant observation types (e.g. increasing the amount of Mode-S and radar winds data in Europe, do local processing of MSG AMV's to reduce latency and permit their use in the very short range) and better tuning of assimilation settings (e.g. relative weight of observations).
- increased use of existing but not yet assimilated remote sensing data such as satellite cloud products and especially surface data (soil moisture and vegetation, snow, sea ice, lakes; see 3.4). The use of Copernicus analyses should be considered for the initialization of aerosols.
- exploration of new observation types of interest, such as polarimetric radars, new MTG products such as geostationary hyperspectral sounder data, and ADM/Aeolus.
- restructuring of the data assimilation and observation handling code into a more modular, efficient and transparent system via participation in the OOPS and COPE projects.
- At lower priority, study of data assimilation setups which are optimal for use in the nowcasting range. Assimilation on these time scales requires the processing of very frequently available data sources (like radar or GNSS) with very fast, and hence relatively simple, data assimilation algorithms. The usefulness for nowcasting of non-variational initialization techniques such as field alignment should be considered, both stand-alone and integrated within 3D-Var.

3.4 Surface analysis and modelling

In fine-scale models like Harmonie, an accurate representation of the surface is of critical importance. Attempts will be made to strengthen the human resources devoted to this work.
A key objective of Hirlam-C should be to improve the surface description by means of a more intensive use of relevant remote sensing data in the surface analysis. Increasing the volume of satellite data used in the surface assimilation is partly dependent on the introduction of more sophisticated surface analysis algorithms than the present OI/Canari system. A new framework for this, called SODA (Surfex Offline Data Assimilation), is under construction, consisting of a set of Extended Kalman Filter assimilation systems for various surface types. It is of high priority to implement and test the components of this more advanced data assimilation system as soon as possible, and then to feed them with appropriate satellite data from both operational and research satellites (e.g. LandSAF products on soil moisture, albedo and vegetation; sea ice mask and thickness information; snow extent, density and water equivalent products; MODIS/MERIS data on lakes).

The latest Surfex-v8 package contains many surface schemes of varying degrees of realism and complexity, generally several schemes per surface type. It needs to be considered which level of complexity in these schemes is both affordable and still able to offer advantages in NWP applications. In this context, comparisons should be made e.g. between the present force-restore and the new diffusion soil scheme, and between the various sea ice or snow schemes. This clearly is an area where collaboration between weather and climate modellers is likely to be fruitful.

A better understanding is needed of the interaction between surface and boundary layer. To assess this, the behaviour of the surface fluxes should be studied in more detail, with a variety of validation/verification approaches (see 3.2). Also, it should be examined how this behaviour will be affected by an increased vertical resolution in the boundary layer.

3.5 Prepare the model for use at higher resolution

It has been generally agreed that precedence should be given to the introduction of HarmonEPS ensemble forecasting systems at present operational resolutions. In view of the associated increase in computational resources that this will demand, it will likely be practically infeasible to increase the operational horizontal resolution of the deterministic model as well in the short term. However, experiments should be initiated right from the start of Hirlam-C, to assess the impact of increasing operational model resolution, first in the vertical, then in the horizontal. The arguments for starting such experiments with an increase in vertical rather than horizontal resolution are that (1) an increase in the number of model levels is more affordable computationally, and hence will sooner be a realistic option for the operational model; and (2) from the point of view of improving model performance under stable boundary layer conditions and of obtaining a more realistic interaction between atmosphere and surface, there are already good reasons for wishing to test the impact of more model levels in the boundary layer. Use can be made of the experiences by Meteo-France in determining optimal settings for pre-operational suites with ~90 vertical layers and ~1km grid size.

Going down to hectometric scales implies moving into a “grey zone” where shallow convection and turbulence processes are neither fully resolved by the model, nor can be fully parametrized. Experiences by Meteo-France have indicated that possibly no major adaptations are required in the model formulations for shallow convection and turbulence at horizontal resolutions down to ~500m. On the longer term, however, preparations need to be made for model formulations involving explicit shallow convection and a more truly 3D description of turbulence (and possibly radiation).

It is a generic problem for all very high resolution models that numerical stability on these scales can be problematic due to e.g. increasingly steep slopes in model orography. Adaptations in the dynamics schemes may be needed to deal with this. On the longer term, far deeper changes in the Harmonie dynamics (presently spectral, semi-Lagrangian and semi-implicit) might be necessary to achieve the required computational efficiency on very fine scales. New methods for this are under consideration e.g. in the context of ECMWF’s scalability programme.

At present operational resolutions, the orographic and physiographic databases used in Harmonie have a resolution of 250m and 1km, respectively. For use of the model at hectometric scales, more detailed orographic and physiographic datasets (such as ASTER) should be introduced and inspected for gross errors. Within the programme, efforts on this should focus on generally available high-quality global or European datasets, rather than on national databases.

For the validation of Harmonie at sub-km resolutions, the study of, and comparisons against, LES simulations on these scales are indispensable. Hectometric model runs can also be compared against the downscaling of a ~1km Harmonie model with an LES. Local (point or 1D) validation may be done against observations from supersites, or from relatively densely observed areas such as the vicinity of airports. Additionally, it would be very valuable if Hirlam could engage in (international) field experiments with dense and non-standard local observations.

3.6 Post-processing, validation and verification

Considerable challenges exist in the interpretation of km-scale models. The continued development and routine use of a wider range of appropriate validation and verification techniques will be a high priority task within the programme. To quantify the real advantages which the more detailed features of the mesoscale model has to offer, scale-sensitive verification techniques and measures, such as SAL and upscaling, should be implemented in the HARP verification system and made available Hirlam-wide. To objectively assess the Harmonie performance with respect to that of other mesoscale models, a comparative verification should be done in both 1D (e.g against supersite data) and 3D. At sub-km scales LES models form an invaluable tool. Much can be learned from validation of the model against well-defined case studies, and from longer model runs in "climate mode". A wider range of (remote sensing) observations should be employed in the validation and verification of clouds and surface. Experience has been gained with all these techniques during Hirlam-B, and they should be exploited more fully during Hirlam-C.

Although duty forecasters remain primary users of the model, more and more often model output is directly supplied to end users. Consequently, the output needs to be both highly accurate and easily interpretable by end users. Actions aiming to improve model accuracy are described in section 3.2. To allow for easier interpretation of model output, more attention needs to be paid to extending model post-processing, and the quality assessment of these new post-processed products.

The coming of age of the convection-permitting Harmonie ensemble forecasting system implies that increasingly interpretations will be required in terms of probabilities for certain weather phenomena to happen. A major challenge will be to provide reliable probabilities for exceeding warning criteria for (relatively rarely occurring) high-impact weather; to achieve this, significant efforts should be devoted to the post-processing, calibration, and product generation for ensemble forecasts with a focus on severe weather. Also, it should be considered how to train forecasters and others in the use and interpretation of these products.

3.7 Enhancing computational efficiency, scalability and flexibility

The continued move towards higher resolution, the development of an integrated Harmonie ensemble forecast system, and the gradual transition towards a more complex earth system model are all developments which imply a strong future increase in required computational resources. To ensure that Harmonie can remain state-of-the-art, highly computer- and energy-efficient, flexible and scalable on future massively parallel architectures, a comprehensive effort is required to:

- adapt numerical algorithms to greater efficiency and scalability on massively parallel systems;
- introduce technical adaptations which permit to run the code more effectively on massively parallel architectures, involving e.g. parallelization by means of MPI and OpenMP, and making preparations for, and assessing mixed CPU-GPU architectures;
- adapt the code design to achieve a greater flexibility and transparency of the code, with the aim to permit the efficient development and incorporation of new scientific concepts.

Hirlam efforts in these areas have been relatively limited and fragmented, due to lack of human resources and technical expertise. In order to meet the future challenges to Harmonie's computational performance, on the one hand Hirlam will have to carefully align its efforts with those of a larger partnership; on the other, it will be essential to seek extra staff with the required expertise, initially perhaps via externally funded projects, but on the longer term via strategic human resource investments within the Hirlam services themselves.

As the Harmonie code is situated within the IFS code framework, the most obvious partners in code efficiency developments are ECMWF, Meteo-France and Aladin. Other relevant partnerships to develop are with the academia and with HPC providers. These latter efforts need strengthening.

Within the Aladin-Hirlam cooperation, the development of a new physics-dynamics interface, permitting a more modular setup of the model physics, is an activity which Hirlam should continue to support and contribute to. But Hirlam efforts on computational efficiency, flexibility and scalability should be viewed particularly in the light of ECMWF's Scalability Programme. This programme consists of several projects aiming at optimizing the observation preprocessing within the IFS (COPE), its data assimilation system (OOPS), numerical methods (PolyMitos), and data processing (Hermes), with support activities on IFS code adaptation (OAFS) and computer architecture benchmarking and migration (CAS), plus several projects funded externally by the Horizon 2020 programme. Hirlam and Aladin are already participating in several of these projects, and this involvement should increase in the future. In particular, Hirlam should consider its role in the Polymitos activities (alternative dynamics and physics approaches) and the Hermes project (more sophisticated treatment of I/O), and in any proposal for external funding submitted by the Scalability Programme.

3.8 Exploration of coupling with the sea and sea surface

One obvious way to further extend the model towards a more complete earth system model is by making the interaction between atmosphere and sea more realistic through coupling of the atmosphere with an ocean or sea surface model. The time appears ripe to begin exploring this. A good starting point would be to couple the model to a model representing the sea surface, like the wave model WAM, rather than to a more involved (and computationally expensive) 3D ocean model. The WAM model is well known in the Hirlam services. Preliminary studies of coupling Harmonie with WAM have indicated possible benefits for the description of surface drag and winds over sea. This work should be followed up with more extensive studies, discussions with the Surfex community, and considerations of how best to treat the coupling with the sea surface in the Harmonie Reference setup. At a later stage, coupling with a multi-layer ocean model can be considered.

3.9 Operationally oriented activities

In the period 2011-2015, HIRLAM has developed several community-wide operationally or pre-operationally oriented activities. The following joint activities will continue to be carried out within the HIRLAM-C programme:

- Routine operation, technical monitoring and troubleshooting of a European-scale short-range ensemble system (presently GLAMEPS), and dissemination of its products.
- Activities aiming at achieving efficiency gains in observation pre-processing through a better sharing of systems, software and expertise.
- Joint monitoring and evaluation of the Reference System and operational suites. Identification of structural weaknesses of the model and regular reporting on this.
- Coordinated pre-operational testing of new model versions over all domains and related troubleshooting.
- Cooperation in the preparation and evaluation of benchmarks for new HPC systems.
- A regular consultation of users (forecasters and representatives of end users) in member institute visits, and incorporation of their needs in the research plans.

Duty forecasters have expressed a wish for a forum for exchange of experiences and training in the use of the model, in both deterministic and ensemble mode. Ways should be considered how to best organize such an exchange of experiences and best practices, and possible training activities.

The past few years have seen an increased momentum for operational NWP cooperation between Hirlam member services. Arrangements for this have been and are being made on the basis of multi- or bilateral agreements. The consequences of this evolution for the Hirlam programme are not quite clear yet. The Hirlam management should keep in close touch with these operational developments to see whether and how they may affect the programme.

4. Collaboration aspects

4.1 ALADIN

A major step for Hirlam has been the decision in 2005 to commit to the development of a new mesoscale model, Harmonie, in close cooperation with the Aladin consortium and in the code context of the IFS/Arpege system. The strategic motivation for this move was the advantage expected both from the joining of forces with a wider community of NWP developers, and from the availability of a modelling system which can be used seamlessly from global to local scales.

During the past years, the research cooperation between Hirlam and Aladin has grown increasingly close, leading to joint scientific planning and activities in most areas of model

development. First steps have also been taken to achieve a stronger coordination on strategic issues at the level of the steering bodies of the two consortia. In December 2014, the HIRLAM Council and ALADIN General Assembly jointly declared their intention to form a single new consortium by 2020. This will necessitate a number of actions aimed at achieving more common policies, code maintenance procedures, and management practices. Policy issues which have been identified as deserving special attention are: code ownership (software IPR) and data policy; members' contributions to the various types of activity; identification of common (core) and group-specific (additional) activities; and branding. Several actions have already been identified and/or initiated to achieve a more uniform approach for code maintenance and evolution: the definition of canonical model configurations, the introduction of code architects, several meetings on the use of the Harmonie system within Aladin, and the introduction of a coordination group to define the common code. These activities will need to be pursued further. On the research side, one action is to formulate a joint scientific strategy in the first half of 2016. The practice of working together in joint research teams should be stimulated where this is not already the case.
In addition to these policy, code maintenance and working practice aspects, ways to homogenize the administrative and reporting procedures need to be explored, and preparations need to be made for the steering processes and financial procedures of the new joint consortium after 2020.

4.2 Code coordination in the IFS/Arpege code framework

The common code environment both enables and necessitates very close ties between Hirlam, Aladin, Meteo-France and ECMWF, in terms of research and of code developments. The use of a common code framework greatly facilitates stronger scientific cooperation and exchange between global and mesoscale NWP modellers. A sustained investment will be required from all parties involved in maintaining the code environment and making it more computationally efficient, flexible and capable of meeting future needs. In this context, the extensive code redesign and overhaul within ECMWF's Scalability Programme plays a critical role. Its successful completion will require a strong cooperation and coordination between ECMWF and its partners in the IFS/Arpege code framework, both on long-term code design and on ensuring a smooth, reliable process of introducing relevant changes in the code. This aspect will require much attention in the coming period.

4.3 Other partnerships

In addition to the IFS/Arpege partners, HIRLAM strives to cooperate fruitfully with various other research teams. The most relevant of these contacts occur in the context of the EUMETNET/C-SRNWP programme. Given the Hirlam focus on data assimilation and use of observation aspects, close interactions are also sought with the observation programmes of Eumetnet and with Eumetsat.

In the context of the trend towards more complete earth system models, two partnerships which are worth to develop further are with the regional climate modelling (RCM) and the atmospheric chemistry modelling (ACM) communities.

A growing number of RCM groups that are presently using the Hirlam model, or components thereof, have expressed interest in using the non-hydrostatic Harmonie system as their future framework for high-resolution climate projections. Development and maintenance of such a km-scale climate modelling capability is seen as primarily the responsibility of the RCM community, but it may be supported by the Hirlam programme. A first climate branch of Harmonie, HCLIM, has been set up by SMHI. This presumably needs to be developed further both in a technical sense (to facilitate typical climate experimentation) and by adapting existing, or introducing new, model descriptions to better suit RCM applications. Mutually beneficial interactions between NWP and RCM modellers are already taking place in forecast model validation and development. The potential of a stronger collaboration between the NWP and RCM communities is generally acknowledged to be very great, and it may be highly worthwhile to keep NWP and RCM model formulations very close.

But both the way to organize this collaboration and the ambitions of the RCM community are not yet quite clear. This still needs to be established more precisely.

Several meetings have been held between Hirlam-Aladin and the EuMetChem atmospheric chemistry community on establishing a framework in Arome/Harmonie for aerosol/chemistry experimentation, as a fine-scale extension of the C-IFS/MACC activities. From NWP perspective, the interest is to develop simple in-line aerosol parametrizations in order to describe, and assess the impact of, parametrizing aerosol direct and indirect effects on radiative fluxes, cloud development and cloud-radiation interactions. The development of active chemistry is beyond the scope of the Hirlam programme, but most of the above activities are already of great interest to the ACM community, and mutually beneficial interactions on these topics appear likely. Computational resources have been requested at ECMWF for experimentation with in-line coupling with aerosols and to some extent chemistry. To ensure sufficient staff for the relevant research activities, the options for joint NWP-ACM preparation of proposals for external (H2020) funding should be considered.