Subject:	A snapshot of the rolling plan in its current state.
Summary:	This is a first snapshot of the common HIRLAM-ALADIN rolling plan that will span the period of the two MoUs of the two consortia, i.e. until 2015. "Rolling" means that this plan will be adapted in the course of the coming 3 years; depending on the evolution in both consortia, the priorities of the activities may change. This approach to the planification process was approved by the General Assembly of 2011. This plan will then be used every year to fill in the man power. What will then be presented to the governance bodies of ALADIN should then be considered as snapshots of the current status of the ongoing planning process with the the two consortia. Given the tight calendar this year of the short period between the LTM meeting (on 9/10) and the GA, one can consider • the content of this version as quite settled, but • **there was no time for the 16 LTMs to fill up the man power commitments** and **one should not use the man power numbers in this document before the finalized version has been settled**. This will be finalized after the General Assembly meeting in Vienna of 13-14 November. PAC can then approve it by E-mail correspondence.
Action(s) required:	• Comment • Ask your LTM to provide man power number, if it has not been done so.

ALADIN-HIRLAM
Rolling Plan
2011-2015
V1. 27/08/2012

Contents:

1.   Introduction (ALADIN)

This is a first snapshot of the common HIRLAM-ALADIN rolling plan that will span the period of the two MoUs of the two consortia, i.e. until 2015. "Rolling" means that this plan will be adapted in the course of the coming 3 years; depending on the evolution in both consortia, the priorities of the activities may change. This approach to the planification process was approved by the General Assembly of 2011. This plan will then be used every year to fill in the man power. What will then be presented to the governance bodies of ALADIN should then be considered as snapshots of the current status of the ongoing planning process with the the two consortia. Given the tight calendar this year of the short period between the LTM meeting (on 9/10) and the GA, one can consider

- the content of this version as quite settled, but
- there was no time for the 16 LTMs to fill up the man power commitments

and one should not use the man power numbers in this document before the finalized version has been settled. This will be finalized after the General Assembly meeting in Vienna of 13-14 November. PAC can then approve it by E-mail correspondence.

2.   Strategic goals and priorities (ALADIN)

It was put forth that the models in the future will be at the convection permitting scales and increasingly probabilistic. This implies three main avenues of importance:

- mastering the model behavior in the gray zone and at the convection permitting scales, through better understanding of physics-dynamics interactions,
- the development of convection permitting EPS(s), and
- related to both, the potential for increased probabilistic predictability by relying on multi-physics and multi-model systems.

The necessary actions to tackle the critical issues:

- the installation of the SURFEX Steering Committee;
- the evaluation of the use of SURFEX in all applications (by the SURFEX SC);
- include the LAM community in the OOPS project;
- make an effort to extend the LACE data-assimilation coordinated efforts for having 3Dvar to more ALADIN countries, where, in the long term, the hybrid approach of HIRLAM seems to be an interesting avenue with several attractive features;
- start the work plan on the dynamics and incorporate it in the 2012 plan;
- set up of a HIRLAM-ALADIN task force on verification;
- endorse the research on physics-dynamics interaction (including physics-dynamics interfacing) and the development of new parameterizations aimed the high resolutions.

In the longer term radar data assimilation is the primary point of attention and will become more important. Additionally, as can be found in the strategy document extra efforts will be made to prepare our consortium for the future evolution of HPC. But these are longer term issues and, while one cannot expect any concrete deliverables in 2012 for all the ALADIN partners, some of the actions in the present are necessary to prepare for them.

It is also useful to mention here four of the five short-term actions that were presented to the GA in2011 to keep the ALADIN strategy on track, from the point of view of the management of the consortium (with some ordering according to urgency), taking from the report of the strategy meeting:

- **Invest (seriously) in code design/development/maintenance**. This needs to be an optimal mix in liberating and provision of manpower, and the (further) elaboration of the maintenance procedures and a strategy for planning research and implementation of it. As mentioned above we have been very good in capitalizing on new ideas, so in some sense up to now "science is coming before the maintenance". One

effort to anticipate the growing complexity was the development of an engineering to manage the biodiversity of ideas with one single code, leading to the two-stream approach as the outcome of convergence days in September 2008.

- One place where <u>less is more,</u> is clearly in **the replacement of the old ISBA scheme by SURFEX**. Since ISBA is, in principle, part of SURFEX, there is no reason to assure a maintenance service to the partners for both, provided all partners could agree to use it (both in performance and scientific work practice). The attempt in the past for the replacement, guaranteeing full reproducibility failed (lack of modularity?). The COSP action is currently an effort to provide sufficient scientific evidence that we can nevertheless all still switch to SURFEX, from the point of view of operational performance.

- **Collaboration**. How to avoid creating sub-optimal solutions, for instance avoiding double work. This a an important problem for the management of the consortium, but it is also problem for the scientists since, also the scientist may get a suboptimal pay-off in case of a lack of cooperation. At the code level we need to continue to insist on *flexibility, modularity and generality*, that are mentioned in the strategy document.

- Launch an effort to **"define"our users** and to coordinate a project on addressing the user requirements. This lies outside of my domain of expertise, and progress can only be obtained if it is addressed in a systematic manner. Nevertheless, this should be organized in close collaboration with HIRLAM. In fact, as recent, discussions (ALADIN workshop/HIRLAM ASM) the general opinion is that this should get a renewed impulse by the creation of a verification task force.

The content of the present plan covers all the above issues. The added manpower contributions are only to be interpreted as indications of what type of manpower is available and what could be provided and, as said above, will require some redirection in 2012.

3. Development of the analysis and forecast system

The NWP landscape in Europe is swiftly changing. Global models are continuously increasing in resolution and moving into the short-range. E.g. ECMWF plans to attain a horizontal resolution of ~10km by 2015. Correspondingly, the European LAM consortia are moving to (sub-)km-scales and the nowcasting range. There are many scientific challenges to be met in this field. For the coming years, highest priority will be given to optimize the performance of the LAMs for resolutions in the 1-5km range; in parallel, but at lower priority and with a longer time perspective, research will be done on adapting the model towards use at sub-km resolutions. In view of the limited predictability at these small scales, probabilistic forecasting with LAM EPS will become more and more important. The development of a convection-permitting ensemble therefore has high priority, but still requires many scientific and technical questions to be answered.

At the same time the Aladin and Harmonie systems are growing and it is necessary to keep a consistent software with the global IFS/Arpège code. Thus, over the coming years, specific care about code design/development/maintenance issues will be required. Additionally, on the longer term, we need to pay attention to the development of our dynamical core. The Aladin consortium will make an extra effort on verification and on validation.

The planned research activities for the period 2011-2015, and their rationale and relative priority, are described below for upper air data assimilation (section 3.1), dynamics (3.2), upper air physics (3.3), surface analysis and modelling (3.4), probabilistic forecasting (3.5), quality assessment and verification (3.6), and system development (3.7). Some issues transcend the traditional boundaries between these research areas; these transversal issues are dealt with in section 3.8.

3.1 Data assimilation algorithms and observation usage (upper air)

3.1.1 Scientific considerations

Data assimilation algorithms:

Both upper air and (especially) surface data assimilation have been proven to provide important added value to a mesoscale NWP system. The capabilities of 3D-Var for km-scale data assimilation have been demonstrated within the operational Arome-France model (Seity et al., 2011). With Harmonie and Hirlam at 3-5km horizontal resolution, a similar added value over downscaling has been shown.

Variational techniques have long been at the core of our assimilation strategy. However, for the convection-permitting scale there is no consensus on the most appropriate assimilation procedure to apply. At present a 3D-Var system is default, and a 4D-Var research system is available. 4D-Var has proven very successful on synoptic scales in introducing flow-dependency and in extracting information from complex observations types, both very important for km-scale data assimilation. However, there is great uncertainty concerning the ability of 4D-Var to handle highly non-linear processes on km-scales, and also its high computational costs and relatively poor scalability on massively parallel HPC platforms represent potentially serious limitations. Other existing methods deserve to be also considered as alternatives capable of introducing greater flow-dependency within the 3D-Var framework, such as the use of air-mass dependent masks (Montmerle and Berre, 2010) and hybrid ensemble assimilation techniques. More research is needed to determine whether the pro's or con's of 4D-Var versus these methods will prevail. The assimilation strategy for the convection-permitting scale therefore is to focus in the short term on optimizing 3D-Var and enhancing it towards greater flow-dependency, while keeping open the door to 4D-Var.

The first priority for upper-air data assimilation is to refine the present 3D-Var system for application at horizontal resolutions of 1-5 km. These refinements focus on tuning of observation and background error characteristics and observation usage, experimenting with higher cycling frequencies, and most of all exploitation of new observation types (radar!). Different ways to use large scale information from the host model in the analysis will be considered (focussing in 2013 on the performance of a large scale error constraint, and in 2014 on an improved treatment of the LBC constraint in the 4D-Var framework).

To make optimal use of high-frequency observations and adapt the analysis system towards use in nowcasting applications, one should aim for a rapid updating assimilation cycle (RUC). For a RUC system, radar, GPS, geostationary satellites and surface networks are relevant sources of input. Ways to reduce model spin-up and optimize cycling strategy for application in the nowcasting (~2-6h) range will be considered. Presently, 3D-Var with a 3h update cycle is the default configuration. More research is needed to exploit the potential of a 3D-Var RUC with 1h update cycle (in particular how to reduce dynamical spin-up).The need for initialisation, and the potential of the present DFI approach to handle this initialisation, will be addressed, taking into account existing experiences at Météo-France.

The optimal domain size is an issue to be investigated. Current experimentation shows that the impact from the lateral boundary conditions start to dominate after approximately 6 hours on a the domain of size 1000x1000 km. To allow more efficient use of observations in the future, an externally funded study is to be carried out on the optimal scale for superobbing, taking into account the effective model resolution (hopefully year 2013). Further work on the tuning of the utilization of observations (biases, representativeness errors, thinning strategy) will be postponed to 2014.Externally funded case studies should be initiated in order order to assess the quality of the analysis system and outline deficiencies under different weather regimes and in different orographic conditions.

Due to the uncertainty of how to handle the fundamental issue of balance in km-scale models, several approaches will be explored for further enhancing the upper-air assimilation system with regard to background error modelling, including dry and moist balances. Methods already available or with developments closely related to future plans for ensemble forecasting will be applied. These include introduction of flow-dependent background error covariances by applying ensemble data assimilation (Berre et al., 2007) or a hybrid 3D-Var/ETKF method (Bojarova et al. 2011), and air-mass dependent background error covariances (Montmerle and Berre, 2010) to distinguish between balances in rainy and dry areas. Other types of weather-situation dependent slicing of the B-matrix can be envisaged and experimented with (e.g. cloudy – non-cloudy or very stable or not). In addition, the potential of structure-based techniques and handling of model errors are relevant long-term areas of research.

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 errors. For this reason, so-called image warping or field alignment techniques (by which displacement errors are first identified and corrected for, after which a "normal" 3D-Var analysis is performed) are a longer-term research issue of potentially great interest. This will be carried out on somewhat lower priority, preferably using external funding or within a PhD framework. It will be a challenge to apply these techniques in a multivariate setup. Flow-dependent balances might be required in order to exploit the full potential of alignment/warping schemes. A related subject of study will be to evaluate feasibility of the assimilation of structures using locally weighted ensemble averages.

The potential of 4D-Var at the convection-permitting scale in terms of handling of balances and extraction of information from observations will be further assessed. Limitations due to the difficulties in representing non-linear processes will be examined at different model resolutions, as well as the optimal settings of the assimilation window with regard to obtaining a proper balance constraint and decay of predictability. Planned developments include the introduction of the ECMWF linearized physics package with its relatively advanced moist physics, tuning and evaluation of weak constraint digital filter initialisation, the application of multiple outer loops and adaptations needed for application together with the Surfex surface scheme.In an externally funded study the performance and feasibility will be evaluated of the Gaussian quadrature 4D-Var for full-dimentional NWP models. If the technique will prove to be successful, it may lead to a significant improvement of 4D-Var numerical performance (multiple outer loops can be avoided).

The Hirlam community will start with implementation of the hybrid variational data assimilation scheme using the EnsDA method for ensemble perturbations. At a later stage the square-root rescaling scheme is to be tried for ensemble generation. The 4D-Var Harmonie data assimilation scheme with ECMWF non-linear and simplified diabatic physics will be set up in the first instance as a "reference" scheme for the development of other flow-dependent data assimilation methods.

For the long term, it is aimed to achieve a framework enabling the implementation of any of the presently targeted configurations of ensemble and VAR methods (we call this framework "4DEnsVar"). The 4D-Var scheme, 3- and 4D-Var hybrid ensemble assimilation scheme and variations of 3DVAR using for instance a hybrid/masked B-matrix formulation, should appear as special configurations in this "4DEnsVar" framework. It is important to phase this envisaged further development of the core data assimilation algorithms into the evolution of the IFS code overhaul following the OOPS paradigm. In the long perspective, an extension of the "4DEnsVar" framework simulating a "non-perfect" model assumption would be developed. This extension of the 4DEnsVar framework will be studied first using the toy quasi-geostrophic model provided by the OOPS prototype, and later transferred to

IFS/Harmonie.

Observation usage:
For a realistic mesoscale analysis, first and foremost observations containing small scale information are required. For that reason, the emphasis will be on utilizing, and assessing the impact of, high-resolution data in the upper air and surface analysis. In particular, observations are needed which help constrain and guide the model in terms of the evolution of moisture, clouds and precipitation.

Given this, first priority in upper air analysis is given to assimilation of radar reflectivity and radial wind observations. At Météo-France, positive results have been obtained from assimilation of radar radial winds (Montmerle and Faccani, 2009) and reflectivities (Caumont et al., 2009). Outside of Météo-France, the work on radar assimilation is still in its initial phase. Considerable resources are being devoted to pre-processing, quality control and impact assessment of these data. Testing of available quality control procedures and integrated observation impact studies have started in 2012 and will be continued in 2013. Real-time data exchange across national borders is an important issue to arrange. Beyond 2014, the OPERA radar data hub will hopefully provide a solution to these access and quality control issues, but until then we will have to create our own solutions.

Secondly, other sources of spatially and temporally dense observations will be introduced: e.g. ground-based GNSS, SEVIRI, and Mode-S winds. Experiences with Arome-France (Fischer, priv. comm. 2012) and Hirlam (De Haan, 2012) have shown the relevance of these data types to capture fine-scale features. On the longer term, studies will be done with deriving, and assessing the impact of, hydrometeor information from radars in the Aladin/Hirlam countries with dual-polarimetric capability.

Thirdly, better use should be made of data types that already are available in the assimilation system: particularly AMDAR, surface measurements, and sounding observations. We need to further optimize the handling of these data with regard to quality control, thinning/super-obbing depending on the scales resolved in the model, bias correction and error characteristics. It will be studied how better to handle cloud-affected radiances and ground- contaminated channels, keeping track of relevant experiences elsewhere. In Hirlam, positive results were obtained by applying more realistic moist physics in the observation operator when assimilating cloud-affected SEVIRI radiances. A similar activity has been undertaken by Meteo-France with IASI cloudy radiances. More advanced data assimilation methods might be required for the efficient use of such observations.

An important research issue is how to make optimal use of observations related to clouds and moisture. The complicated coupling between the assimilation control variables (various dynamical variables and specific humidity) and clouds/ hydrometeors needs to be described. A related challenge for moisture assimilation is the short predictability time range of clouds and hydrometeors as compared to humidity and dry dynamical variables (Fabry and Sun, 2009). A simple cloud cover initialisation technique has been developed, in which temperature and humidity profiles are modified preserving buoyancy. This methodology has been tested with encouraging results both in Hirlam and Harmonie, and will be extended using more advanced MSG cloud products developed at DMI. The challenge will be how to integrate this cloud initialisation properly into the variational data assimilation framework.

On the longer term, the correct way to impose moisture balances needs further study; this is related to the 4D-Var and hybrid ensemble assimilation research mentioned above. In the meanwhile, Météo-France will continue assimilating cloud-affected radiances with the CO_2-slicing technique (where cloud top pressure estimates are derived from specific CO_2-channels). Another area of continuous research and implementation is that of surface-affected radiances (over land), where the use of maps of surface emissivity will be further studied in both infra-red and microwave spectra.

Coordinated observation system experiments involving upper-air and surface observations will be done to investigate the relative impact of different observation types on different scales. The results

of these impact studies should be used to perform the overall tuning of the observation network to optimize its performance (possibly from 2014 onwards).To exploit our expertise in this area, participation can be considered in network studies by EUCOS, in support of the design of a cost-effective European observation network suitable for operational km-scale NWP.

Three system-related aspects will impact on assimilation algorithm research plans. In the first place, the overhaul of the assimilation code through the OOPS project will last at least over 2012/2013. In this interval, OOPS-related code changes will overlap with developments on Jb, Jk, hybrid assimilation and extension of control vectors. Such new developments will enter the code only after having been made OOPS-compliant. Secondly, streamlining the observation pre-processing is an important system support activity for all data assimilation research. This is to be done in the context of the ECMWF COPE project, in which the LAM IFS partners will actively participate. Thirdly, there is the issue of scalability. A rapidly growing concern in data assimilation is the performance of algorithms on massively parallel architectures (several 100000's of PE's). In particular, 4D-Var has been questioned in this respect. Our data assimilation community will need to stay in close touch with system experts within our consortia and elsewhere, on the porting and evaluation of codes on massively parallel computers. All these issues will be described in more detail in section 3.7.

3.1.2 Summary of planned activities and priorities

Highest priority is given to the refinement of the present 3D-Var upper air analysis system through:
- Tuning of background and observation error statistics, and testing of alternative constraints and control variables (work package (WP) DA1 in the 2012 work plan)
- Assessment/sensitivity studies and experimentation with rapid update cycling (WP DA2).

In parallel, but with a longer time perspective, it is aimed to develop more flow-dependent data assimilation methods (WP DA3):
- Hybrid ensemble assimilation and slicing methods, and, at lower priority, 4D-Var and field displacement techniques.

In terms of observation usage in the upper air analysis, priorities are as follows:
- Highest priority is given to the assimilation of radar reflectivity and radial winds (WP DA4).
- Secondly, other new observations will be added (with a focus on moisture- and cloud-related parameters; WP DA5), specifically GNSS data. Also, it will be studied to what extent better use can be made of existing observations. For radiance data, it will be investigated how best to assimilate cloud- and rain-affected radiances, and radiances (IR and microwave) over land. There will be a continuous implementation and assessment of data from new satellites/instruments for already assimilated radiance types (this, in close coordination with IFS and Arpège activities)
- Comprehensive observation impact studies will be done for all of the above data sources, with a focus on radar and other moisture-and cloud-related remote sensing data (WP DA6). Participation in international OSE studies will be sought if these are in line with observation impact studies already planned within the programme.

All of this work is to be carried out in close collaboration between the Hirlam and Aladin teams.

3.1.3 Work packages in 2013

DA1: Development of the 3D-VAR assimilation system

- Climatic background error statistics: continue to investigate dependency of structure functions on boundary layer stability and cloudiness; simple parameterization of inter-annual variability;
- Improvement of the ensemble approach for estimation of background error statistics;
- Investigate influence of observation network, forecast length and ensemble size when ensemble techniques are used to compute the background statistics (high priority but delayed);
- Implement heterogeneous B-matrix in Harmonie (priority medium, "learning exercise")
- Treatment of the extension zone in the assimilation and estimation of structure functions: continue theoretical study of the effect of bi-periodization of spectra (priority medium); adapt algorithms for the treatment of the extension zone following developments in dynamics (priority high, but awaits implementation of the extension zone in dynamics) ;
- Perform comparison of the large-scale error constraint and spectral blending techniques for a proper accounting of large scales in LAM (priority high, in cooperation with MetCoOP)
- Towards cloud data assimilation: evaluate quality of 2D cloud products (CPP) from MSG and SEVIRI (priority high), initialize humidity fields from CPP products (priority high); investigate impact of the cloud initialisation on radiation and surface analysis (priority high); design integration of the cloud initialisation into the variational data assimilation scheme (priority medium); study weather regime dependent balances between hydrometeor model variables (cloud water, in first instance) and control state variables, possibly using ensemble techniques (priority medium).
- Carry out externally funded (related) study on superobbing techniques
- Adaptive background error statistics and online tuning;

  HIRLAM staff: Dahlgren*(2pm), Zhuang (3pm), Gustafsson (0.5pm), Nielsen (3pm), Lindskog (0.5pm), Landelius* (2pm), Ivanov*, van der Veen (3pm), Barkmeijer (1pm), Bojarova (0.5)

  ALADIN staff: Berre, Desroziers, Montmerle, Brousseau, Faure, El Ouaraini, Monteiro, Kovačić (1 pm), Horvath (1 pm)

  Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova / Fischer

DA2: Assessment and sensitivity studies and RUC experimentation

- Local implementations of 3D-Var: Continue installation and validation of real-time assimilation suites and sensitivity studies for different aspects of assimilation setup (frequency of data assimilation update, method for generation of the climatological forecast error covariance, accounting for large-scales in LAM, setup of digital filter initialisation; outline model deficiency and monitor usage of observations); (priority high);
- Assess available high-resolution high-frequency observation networks suitable for RUC setup (priority high); adjust the assumptions of the variational data assimilation scheme including VarBC to be consistent with the Harmonie setup (priority high)
- Investigate impact of assimilation frequency, length of observation time window and observation network configuration on spin-up properties (priority high); study validity of assumed structure functions for the particular set-up of the observation network (priority medium);

  HIRLAM staff: Perttula(1pm), Thorsteinsson(1pm),   Sanchez(1pm), Lindskog(1pm), Geijo(2pm), Schyberg/met.no*(1pm), Zhuang(1pm), de Haan*(1pm),   Ridal*(1pm) , Barkmeijer(1pm), Vignes*(1pm), Verkleij (1pm), Amstrup(1pm)

  ALADIN staff: Brousseau, Auger, Strajnar (2pm), Monteiro (1pm), Meier (2pm)

DA3: Development of flow-dependent assimilation methods
- Further develop and/or assess the "Jb of the day" based on global ensemble DA information: Arpège ensemble DA – AEARP – for Arome-France and EnsDA (ECMWF) option, perform comparison for Harmonie; start considering an Arome ensemble data assimilation prototype.
- Towards hybrid ensemble variational data assimilation in Harmonie: implement the EnsDA schemes in Harmonie (LBC perturbations + selected observation network perturbations + model error perturbations) (delayed, priority high); Implement the LETKF scheme in IFS/Harmonie (with assistance from ECMWF) and extend it to allow satellite data (priority medium); continue improvement and comparison of the different ensemble generation techniques (downscaling of regional EPS/LETKF/EnsDA) with regards to affordable ensemble size, lagging strategy for ensemble perturbations, the way to simulate "model error" simulation for sampling the error-of-the-day uncertainty (priority high);
- OOPS-related design of the data assimilation systems: extend quasi-geostrophic (QG) OOPS prototype to allow ensemble framework (EnsDA) and LAM specific framework (LBC treatment for 4D-Var and large-scale error constraint for LAM in general); implement the "centered" FGAT design in the OOPS layer; extend the QG 4D-Var scheme allowing ensemble propagation on the increment; implement hybrid ensemble 3D variational scheme into QG prototype and extend it into 4DEnsVar scheme with a constant ensemble control variable over the assimilation window (priority high)
- 4D-Var: implement the centered FGAT scheme in OOPS in a consistent way; set up in a way adjust the scripts system to be consistent with the design of the QG 4DEnsVar (priority high); implement non-linear and simplified diabatic ECMWF physics packages to be run with Surfex (priority medium); feasibility study of the QG-4DVAR approach;
- Treatment of non-additive errors: further develop phase error correction techniques (with emphasis on preservation of the flow-dependent balances) (priority medium) ;
- Finalize coding of LAM wavelets

    HIRLAM staff: Escriba(3pm), Landelius*(2pm), Lindskog*(6.5pm), Geijo(3pm), Gustafsson (4pm), Bojarova(3pm), Vignes(1pm), Johansson(2pm), Dahlgren (3pm), Barkmeijer (1pm)
    ALADIN staff: Berre, Montmerle, Ménétrier, Michel, Raynaud, Deckmyn, Monteiro, Randriamampianina
    Priority: medium
    Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova/Fischer

DA4: Assimilation of radar data
- Promote radar data exchange between different centres (waiting for OPERA); spread expertise and establish routines on use of CONRAD (ongoing, high priority).
- Common quality control algorithms: investigate performance of Baltrad QC Toolbox and outline strong and weak sides of the package (high priority), study consistency between the Baltrad QC algorithms and the IFS/AAAH radar data assimilation system (high priority);
- Continue implementation of radar data assimilation at the NMCs (priority high); move the emphasis from the technical implementation of radar data assimilation algorithms to the impact assessment on the quality of RUC forecasting systems (rely on severe thinning of observations as a simplistic approach to avoid cross-correlated observation errors)
- Experiment with a reflectivity operator in Alaro context (this might not require huge adaptations, only checks of consistency for microphysics between model and simulator)

- Radar DA in all LACE NMSs: analysis of the feasibility
  HIRLAM staff : Haase(3pm), Leijnse (1pm), Thorsteinsson(1pm), Dahlbom(1pm), Geijo(2pm), Zhuang(2pm), Ridal(2pm), Whelan(1pm), Tveter*(2pm), Verkleij(4pm), Xiaohua (0.5pm),Siebren(1pm), Serguei*(2pm), Schyberg/met.no(6pm)
  ALADIN staff: Wattrelot, Montmerle, Mahfouf, Randriamampianina , Stanešić (2.5 pm), Kovačić (3 pm), Monteiro (3pm), Yan (1pm)
  Priority: high
  Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova/Fischer

DA5.1: Other ground-based and space-borne upper air observations

- IASI radiances: introduce lower peaking channels over oceans, extend assimilation algorithms for water-vapour sensitive channels to allow cloud affected (CO2 slicing) and cloudy (hydrometeors in control variable or observation operator) radiances, improve the VarBC procedure to be better in handling heterogeneous data distributions;
- radiances from sounders: improve estimation of surface emissivity and skin surface temperature to allow use of these data over sea ice and land; investigate different approaches for emissivity products, dynamically estimated emissivity, "slack" control variables;
- Ground-based GNSS: Implement GNSS ZTD observations including white-listing of the stations (dependent on producing center, representativity error, orographic conditions) and station-dependent VarBC (off-set only initially) (high priority); perform impact assessment in Harmonie RUC suites (high priority); investigate possibilities for the refinement of the VarBC scheme by introducing of optimal set of predictors (priority medium)
- Mode-S and other aircraft data: Implement Mode-S observations, including optimal configuration of the VarBC scheme (off-set/ optimal set of predictors) and perform impact assessment (priority high); refine implementation of the AMDAR data assimilation (bias correction) and perform impact assessment (priority high)
- scatterometer surface winds (in particular the high resolution coastal product): perform further tuning of the assimilation setup (update frequency, domain size, structure functions) and assess impact on the forecast quality of meso-scale phenomena;
- Cloudy infra-red SEVIRI radiances: implement in 4D-Var using the simplified ECMWF physics package (in the observation operator) and perform impact assessment on the forecast quality of moist variables (refinement of structure functions might be required; priority high)
- Implement T2m and RH2m observations into the upper air assimilation, including refinement of observation operator, improved quality control procedure, careful white- or blacklisting of observations depending on model orography and station height, and perform impact assessment (priority high); promote exchange of local data between NMSs (priority medium)
- Radiosonde data: continue impact assessment of the higher spatial and temporal resolution of new BUFR format data, promote use of the high-frequency options
- At MF: Use of ASCAT scatterometer, SEVIRI and IASI over land, cloud-affected IASI; Preparations for new sensors: ATMS/CrIS on NPP, IASI/ATOVS/GRAS/ASCAT on MetOp-B, winds from various scatterometers, IRS on MTG (longer term), IASI-NG on EPS-SG (longer-term)
  HIRLAM staff: Perttula*(5pm), Thorsteinsson(3pm), Schyberg/met.no *(4pm),met.no/RF (4mm), Yang(0.5pm),Ridal(2pm, de Haan*(2pm), Sanchez(4pm), Whelan(1pm), Marseille

(4pm); Dahlbom (1pm), Geijo(1pm),Bojarova(1pm)
ALADIN staff: Guidard, Moll, Saint-Ramond, Payan, Guedj, Vincensini, Fourrié, Martinet, Sahlaoui, Hdiddou, Randriamapianina(1pm), Strajnar (4pm), Yan (1pm), Schneider (1pm)
Priority: medium
Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova/Fischer

DA5.2: Further development and improvement of pre-processing / monitoring software
- Participation to ECMWF's COPE Project (development of ODB-2 in C++, upgraded BUFR2ODB, extraction of model-independent screening code and recoding in C++). The first step is to extend BUFR inputs for "Bator", then join the COPE work with ECMWF.
- Upgrade the LACE centralized observation pre-processing system OPLACE; Build a backup system for OPLACE; Optimize OPLACE data formats.
- Extend, implement and maintain LACE observation monitoring and processing tools
- WMO stations list: implement and assess enhanced quality control and blacklisting;
- Maintenance and development of ODB software, basic extraction tools from the raw observations to ODB (oulan, bator), and related ancillary tools (mandaodb, odbviewer, ...).

HIRLAM staff: Whelan(6pm), Aspelien(1pm), Dahlbom(4pm), Amstrup(2pm)
ALADIN staff: Puech, Guillaume, Moll
Priority: medium
Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova/Fischer

DA6: Comprehensive observation impact and network design studies
- Perform high frequency observations impact studies (radar, GNSS ZTD, IASI, ASCAT against a baseline of ATOVS and conventional observations) (delayed, high priority);
- Design and implement diagnostic tools to account for the impact of various observing systems on different spectral scales (e.g. FSO, DFS; priority high).

HIRLAM staff: Thorsteinsson(1pm), Lindskog(2pm), Sanchez(2pm), Geijo(2pm), Verkleij(1pm), de Haan (1pm), Ridal (1pm), Schyberg/met.no (4pm), Marseille(1pm)
ALADIN staff: Randriamampianina(0.5pm)
Priority: medium
Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova / Fischer

3.2   Dynamics

3.2.1   Scientific considerations

The main emphasis in dynamics research is on increasing the accuracy and efficiency of the dynamics, both within the present algorithmic framework and with a view to its longer-term evolution towards use at very high resolutions and on massively parallel computer systems. Dynamics research basically covers three areas. In the first place, a number of activities aim at the further development of the non-hydrostatic dynamical core. Secondly, work will be done concerning the long-term evolution of the non-hydrostatic dynamic core and comparison to alternative cores, in terms of meteorological performance, numerical efficiency and stability. A third area of study is boundary conditions and nesting. The aspects of numerical efficiency and the physics-dynamics interaction on km-scales are regarded as transversal issues, and research plans for these topics will be described under section 3.8.

Improving the accuracy of the dynamics code:
Both at present (~2.5km) and future (sub-km) resolutions, it is important to use dynamics schemes of the highest order of spatial accuracy. Nowadays these are the spectral method in the horizontal, which is presently used, and the cubic finite elements in the vertical (VFE), which is still under development. It is aimed to maintain and further develop these methods at least for the coming years.

For the introduction of a VFE discretization, two different approaches continue to be pursued. For the height-based hybrid vertical coordinate formulation developed by Hirlam and ECMWF, stability problems still occur in numerical experiments using finite elements or higher than 4th order finite difference discretization of the vertical differential operator. A mass-based VFE formulation developed within Aladin appears to be stable in idealized cases and close to ready for application in real 3D cases.

Mass conservation is important in long integrations (relevant for regional climate modelling applications) and for atmospheric chemistry. One disadvantage of the present semi-Lagrangian (SL) technique is that it is not designed to conserve either the mass of dry air or the proportion of any other component of the atmosphere. Conserving SL schemes have been devised but these are prohibitively expensive; therefore, adaptations of the SL method are being sought which better conserve mass but do not involve a large increase in computational cost. Tests involving changes in the interpolations used for the continuity equation, have already been shown to lead to improved conservation of dry air mass, but not consistently for a range of resolutions. As a next step it will be considered to enhance mass conservation for individual atmospheric components in the SL treatment of the mixing ratio equations.

A semi-analytical scheme has been studied which was claimed to be free of the dispersion in the treatment of short linear gravity waves which is seen in the semi-implicit method. However, this did not live up to expectations and the semi-analytical approach has therefore been abandoned, although new ideas might revive this approach in the future.

Longer-term development of the dynamical core:
One issue to be considered is what should be the necessary changes to the current dynamics strategy (spectral and VFE, semi-Lagrangian, semi-implicit) in order to sustain good performance (in terms of accuracy, stability and efficiency) at sub-km resolutions on HPCs on the longer term.
Issues for which alternatives to the present dynamics are considered, are:
- Assess the adequacy of the spectral and semi-Lagrangian approaches at very high O(100m) resolution, test the limitations of the spectral model by running Harmonie in LES-mode, and compare SL and Eulerian advection for very fine mesh sizes (see section 3.8.1)
- 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 horizontal
- Compare a U-V versus divergence/vorticity formulation of the momentum equations
- Consider use of an acoustic-free formulation of the equations

These alternative options should be introduced and tested in a conservative, stepwise and modular way, keeping present solutions until alternatives have proven their value. A start will be made with testing alternatives for the present spectral approach. Also, comparisons of the efficiency and scalability of the adiabatic core with those of other models will be considered, e.g. in SRNWP context.

Boundary conditions and nesting:
All limited area models use the Davies-Kållberg relaxation towards the host model in the boundary

coupling zone. Attempts to use a more elegant approach (transparent boundary conditions) for operational purposes have so far been unsuccessful. It has been planned in the future to extend the work done for the shallow water equations to the Euler equations in simplified set ups. However, whether this work will start will highly depend on available manpower and other priorities in dynamics (e.g. the question of the new dynamical cores). Additionally, the idea was put forward in the past to use knowlegde of incoming and outgoing signals at the lateral boundaries to perturb lateral boundary conditions to estimate the propagation of the LBC errors. The work might be revived if manpower is found.

Instead it will be attempted to improve the Davies-Kållberg relaxation and make it computationally more efficient. Once Boyd's bi-periodization procedure has been implemented, the data flow in the Davies scheme can be modified to reduce calculations in the boundary and extension zones. A clear deficiency in the present boundary treatment is the truncation of semi-Lagrangian trajectories when they come from outside the C+I area. A halo of values around this area, coming from the host model, will be included to avoid the need for truncation. Thirdly, the implementation of some kind of relaxation of the upper boundary will be considered. A spectral nudging is already available, but this has been shown to be insufficient to avoid in some cases the occurrence of very strong winds at the highest model level which causes the model to crash. It will be investigated whether a stronger control of these winds by the nesting model can be achieved. This may also be related to the choice of the model vertical resolution close to the highest level, and the location of the model top.

Earlier nesting experiments have shown that a single-nested configuration can be of better forecast quality than a double-nested system involving an intermediate LAM model, even with a significant jump in resolution from the host model (ECMWF at 16km resolution) to the nested model (Harmonie at 2.5km and Hirlam at 3km). The MetOffice Unified Model employs a variable resolution in the boundary zone, which stepwise becomes coarser as its outer boundaries are approached. In principle this approach allows for an even greater contrast in resolution between host and nested model. It can be considered if such a solution may be desirable when going to sub-km mesh sizes.

An aspect deserving further study is the influence of domain size on forecast quality. The conventional wisdom is that the smaller the domain, the larger is the influence of the host model through the boundary conditions, and therefore the higher resolution of the nested model will be less beneficial. This needs to be tested thoroughly. Likewise, the influence of the width of the relaxation zone and the choice of model top and upper boundary treatment on model performance should be carefully checked.

3.2.2   Summary of planned activities and priorities
The main short-term focus is to further improve the accuracy (WP DY1) of the present dynamics schemes. Highest priority in this is given to the implementation of the NH VFE vertical discretization. Research on boundary conditions and nesting (WP DY3) is of relatively lower priority.
On the longer term, the possible need for major changes in the dynamical core will be assessed through evaluation of the present methods against alternative algorithms (WP DY2).

3.2.3   Work packages in 2013

DY1: Development of the dynamical core
- **DY1.1:** Investigation of a possible **vertical finite element (VFE) discretization** for the non-hydrostatic (NH) model following two different approaches. Related to one of them, the investigation of the option of using a hybrid vertical coordinate based on height instead of on

hydrostatic pressure. An off-line model developed and tested using this kind of vertical coordinate, gives stable forecasts using finite differences up to 4th order in the vertical. Higher order finite differences or finite element methods are so far unstable. The implementation into the IFS/Harmonie model is ongoing. The question of the physics-dynamics coupling (i.e. the projection of the physics on height levels in stead of pressure levels) and the Catry et al. (2007) interface needs to be addressed.

- **DY1.2 More accurate SL interpolators and improvement of conservation.** Test options for computation of trajectory and interpolation used at departure point for terms of the continuity equation for dry air, and later for other atmospheric components (water, ozone, chemical constituents). Alternative approaches have been tried (MetOffice ENDGAME approach, non-interpolating scheme), but with disappointing results. Some combinations of cubic and linear interpolation do appear to be beneficial, but this benefit is not consistent across a range of resolutions. Work will continue with trying other options for dry air and studying the conservation of different atmospheric components such as humidity or ozone.

- **DY1.3: Multi-phase aspects:** do a preliminary study of what is involved in the description of the model in terms of a multi-component fluid, and how its impact on the physics-dynamics interaction and interface can best be handled.

- **DY1.4: Inter-comparison of performance of present dynamics on different architectures and against alternative existing schemes:** Submissions of projects for accessing computer time on advanced machines on which the current code could be used without heavy modification. Experiments with removing "bricks" in order to better estimate the evolution of the relative efficiency of the purely adiabatic kernel, and other bricks (surface package, physics...); Experiments with adiabatic model options (including comparisons with Eulerian option). Actions to encourage comparisons with other dynamical cores built on different strategies (COSMO, UM, WRF,...). These would be compared on the same machines, and mainly in adiabatic mode, in order to compare the efficiency of dynamical cores only.

    HIRLAM staff resources: DY1.1: Hortal (2mm), Simarro(2mm), I Santos(6mm); DY1.2: Morales (6mm);
    ALADIN staff: DY1.1: Bénard (liaison with AEMET colleagues), Yessad (code aspects); DY1.2: Ricard; DY1.3: Brozkova, Degraauwe, Geleyn; DY1.4: Benard
    Priority: DY1.1 high; DY1.2 medium; DY1.3: low; DY1.4: medium;
    Responsible HIRLAM project leader/ALADIN CSSI member: Hortal / Benard

DY2: Longer-term evolution of the dynamics and testing of alternative schemes

- Separately explore the switch to grid-point methods for limited parts of the dynamical core (computation of derivatives, SI solver).
- Remaining in the current staggering (A-grid), implement and test a horizontal finite volume (or elements) method as alternative to the bi-Fourier spectral method for LAM derivatives. To remove only the "spectral" option while keeping the SI option, a 3D grid-point solver should be implemented and tested, all the rest being kept identical.
- Results should be analyzed from the scientific and computer points of view (scalability).
- Writing a literature review of alternative methods (e.g. unstructured grids)
    ALADIN staff: Caluwaerts, Degrauwe, Voitus, and supervision by Bénard and Termonia
    Priority: highest
    Responsible HIRLAM project leader/ALADIN CSSI member: Hortal / Benard

DY3: Boundary conditions and nesting

- Finalize implementation of Boyd's solution together with rationalization of extension zone.

15

- Application of boundary conditions together with Boyd's bi-periodization in spectral space, and test with Degrauwe's test. Compute inside configuration 927 (FULLPOS) all the fields from the nesting model needed for lateral boundary relaxation and biperiodization, keeping this information in spectral space. During the forecast, only points belonging to the inner and relaxation zones need to be computed. Once these are multiplied by the Davies relaxation factor, they go smoothly to zero at the boundaries which makes the biperiodization to become a mere padding with zeroes in the extension zone. Prepare documentation to easily implement Boyd's solution operationally
- Prepare an exportable script system for applying MCUF.
    HIRLAM staff: Hortal
    ALADIN staff: Voitus
    Priority: medium
    Responsible HIRLAM project leader/ ALADIN CSSI member: Hortal / Benard

3.3   Physics parametrizations (upper air)

3.3.1   Scientific considerations

Convection and turbulence
The LAM IFS code basically contains three branches of upper air parametrizations: Arome physics with explicit deep convection, the Aladin physics and Alaro with partially parametrized convection.

For Arome, the current model version is capable of producing accurate forecasts of e.g. extreme precipitation and gusts for severe deep convection events which are strongly forced and on the larger scale of the convective spectrum, such as MCS's, line convection etc. It is reassuring that the model can represent this type of high-impact weather. However, experience has shown that good forecasts of such events are only made when the model domain is sufficiently large, allowing convective systems to fully develop inside that area. Items that remain to be improved in Arome are the sometimes overactive convection in weakly forced situations, the occasional strong outflow from convective cells, and, most importantly, the representation of the stable boundary layer, low clouds and fog. Studies on the limitations of explicit convection treatment in Arome should be continued. In this context, participation in international idealized studies of clouds and convection is intended. One thing that could impact positively on small scale deep convection in the model is to impose a brake on vertical velocities, which may help to dampen over-enthusiastic deep convection in these situations. To improve the description of low clouds, several adaptations have been suggested to the mass flux scheme (detrainment/entrainment (Rio et al 2010, de Rooy 2012), equation reformulation (Honnert et al 2011) and the statistical cloud scheme (distinction thermals/environment). Also, the impact of vertical resolution increase on clouds and convective behaviour needs to be considered. A comprehensive, transversal approach to increase model performance under stable conditions in general is described in section 3.8.

For mesh sizes of ~1km or less, also shallow convection and turbulence become partially resolved. For such spatially detailed models, there is an increasing need to consider process descriptions from a more stochastic and inherently 3-dimensional point of view. Activities required for this are described in more detail in section 3.8.

The aim of the Alaro developments is to provide a set of physics parametrizations which provide a seamless transition from fully parametrized deep convection on synoptic scales to explicit deep

convection on km-scales. In the Alaro framework, the development of 3MT and TOUCANS by the Aladin community continues. The 3MT scheme has been introduced also into Arpege and is being tested on both regional and global scales. For the TOUCANS turbulence scheme a prognostic mixing length and prognostic convective cloudiness are under development. The complementary sub-grid updraft (CSU) scheme developed in Belgium has been shown to result in a more realistic transition from parametrized to explicit convection when going to higher resolution. In 2013, the highest priority for the Alaro team will be to integrate and validate all of these developments into the Alaro-1 package. The STRACO convection scheme includes a simple way to gradually switch off parametrized deep convection with increasing horizontal resolution. It can be tested how this compares to the Alaro approach.

The model treatment of wave-turbulence interactions should be considered: the handling of breaking orographic and non-orographic gravity waves in upper troposphere/stratosphere and boundary layer, the generation and dissipation of transient (convection-related) gravity waves etc. In this respect, the applicability of quasi-normal scale elimination theory (QNSE, Sukoriansky et al., 2005) will be studied.

Cloud microphysics, radiation and aerosols
Improvements in the parameterizations of cloud microphysics and hydrometeor interactions within the clouds are sought with the aim to enhance forecast accuracy for extreme precipitation events and the prediction of fog and low clouds.

Microscale parametrizations would benefit from the availability of new types of observational information in the atmospheric analysis, for example on atmospheric aerosol or cloud hydrometeor properties. For consistency, all microphysics variables calculated within the microphysics scheme, should be passed on for use by the radiation and convection parametrizations (presently this isn't done). They also should become part of the standard model output, for validation purposes and to serve as background for the assimilation of cloud and hydrometeor information from satellites and polarimetric radars. In this respect, the consistency and connections between the data assimilation and microphysical parametrizations needs attention. Related to this, the spin-up properties of various hydrometeors should be studied, in particular those involving relatively slow processes (snow).

Within Hirlam, it is aimed to update the STRACO microphysics in several ways and apply and test this within Arome at high resolution. A prognostic cloud droplet distribution, its resulting effective droplet radius, and an ice nucleation scheme are being introduced and tested within single-column HIRLAM during 2012. Further steps in 2013 include introduction of a new cloud droplet description, and implementation and testing within Hirlam. Following this, the updated version of STRACO will be ported to Arome/MUSC and tested there.

An alternative to seeking improvements on the present ICE3 scheme would be 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 more realistic way of taking into account indirect aerosol effects. Meteo-France has been experimenting with two second-moment schemes within Méso-NH. As a start, Météo-France plans to extend the present microphysics of Arome to including a diagnostically evolving cloud water droplet distribution (parameter Nc). It would be desirable if work on the two-moment schemes can start already in 2012.

The present radiation scheme in Arome is the spectrally detailed RRTM scheme. A comprehensive radiation inter-comparison study against several alternative schemes has started, in which several ways

are considered to further improve the radiation treatment:

●the impact of using a more advanced clear sky radiation transfer parametrization

●the handling of cloud-radiation interactions in the model. Presently, the radiation scheme does not make use of information on cloud microphysical parameters which is already available within the model or from observations; the impact of utilizing this information should be assessed.

●the treatment of radiation-surface interactions, in particular the effects of slopes and vegetation. In the derivation of surface radiative properties for radiation parametrizations (based on surface physiography, assimilation and/or climatology), a consistency of formulations between the atmospheric and surface modelling and data assimilation is required. Sloping surface parametrizations developed within Hirlam (Senkova et al. 2007) will be introduced and tested. Information on slopes will be prepared from high-resolution digital elevation maps. Tilted array modelling of radiation will be applied to study the importance of cloud shadow effects on surface radiative fluxes and the possible impact of a more 3-dimensional radiation treatment.

In recent years, much research has been done on aerosols, providing new possibilities for application in NWP. Aerosols can directly affect clear-sky radiation throughout the atmosphere. They influence cloud microphysics by providing condensation and freezing nuclei of different physical and chemical properties and size distributions. Systematic studies of aerosol effects will be done in order to assess the practical importance of parametrizing direct and indirect aerosol effects on cloud development, radiation fluxes and cloud-radiation interactions. Within Enviro-Hirlam, simple parametrizations for direct and indirect aerosol effects have been developed and tried. These will be transferred to and tested in Harmonie, starting with the introduction of the direct effect in the radiation scheme. Input information about atmospheric aerosol distribution and its optical and chemical properties can be derived from climatology data, MACC analyses or assimilation of (satellite-based) observations, or provided by coupling Harmonie with chemistry models, as is done in Enviro-Hirlam. Studies are needed to understand the requirements and availability of such input sources and to choose optimal methods for their introduction. Between 2006 and 2012, a desert dust model has been evaluated and implemented in Aladin (PhD work of Mohamed Mokhtari, Algeria). This work could serve to provide guidelines for other aerosol studies and developments in any of the NWP models in the AAAH framework.

Some transversal issues

Orography affects a number of upper air parametrizations. These orography-related parametrizations are considered a transversal research activity, plans for which are described in section 3.8.

Apart from the deterministic forecast model, parametrizations are also applied in a simplified or probabilistic way in data assimilation and ensemble prediction systems, respectively. Consistency, integration and coordination between these different worlds of parametrizations presents a challenge for model development. Plans for this transversal research activity are given in section 3.8.

Tools for learning, testing and diagnosis of the physical parametrizations

For model physics studies, diagnostic tools are needed which make it possible to analyse full model experiments and/or individual parametrizations in a less computationally demanding (1D) framework. Such utilities are useful in international inter-comparison studies, in collaborations with the academic community, and for training. The most important available, but still under-utilized, tools are:

● Surfex in stand-alone mode.
● MUSC, the single column model version of Harmonie.
● DDH, a 3D diagnostic tool for budget calculations and analysis of physical parametrizations.

18

When going to higher resolution, LES modelling is an essential utility to employ, and this is increasingly being done, by Meteo-France and in the KNMI parametrization testbed. For validation of moisture and cloud microphysics properties, satellite retrievals of cloud information are an important tool. Efforts will be made to make such retrievals available in real-time and for all of Europe.

3.3.2   Summary of planned activities and priorities

The primary objective of physics parametrizations research in the first half of the 2011-2015 period is to tackle existing model deficiencies at present resolutions (2-5km):

- For the upper air physics, an improved description of the stable boundary layer behaviour (WP TR4) has first priority, together with research aiming at an improved daily cycle of precipitation and convection under unstable circumstances (WP PH1).
- For Alaro, a complete overhaul has been achieved; the highest priority for the ALARO team in 2013 will be to integrate and test the various components of it (WP PH4).
- At somewhat lower priority it is aimed to improve the parametrizations of microphysics, radiation and aerosols (WP PH2); in this field activities will focus on:
  - Radiation intercomparison studies
  - The inclusion of direct and indirect aerosol effects in radiation and cloud schemes.
  - A more consistent use of cloud parameters information throughout the physics

  For the time being, the inclusion of active tracers through the coupling of the LAM models with atmospheric chemistry is not seen as a priority.
- In support of parametrization development, physics staff will participate in international boundary layer, clouds and convection studies (WP PH3).
- For the longer term, research will be done on modelling on sub-km scales (WP TR5)

3.3.3 Work packages in 2013

PH1: Convection and turbulence
- Arome: investigate shallow convection behaviour at sub-kilometric scale
- Arome and Arpège: validation of diurnal evolution of the PBL with respect to the BLLAST field campaign measurements.
- Alaro: continue development and evaluation of 3MT and CSU schemes.
- Alaro: Continue development, validation and testing of the TOUCANS scheme in 1D and 3D, considering also the connection between TOUCANS and Surfex. Preparation of scientific and technical documentation. Priority: high
- Shallow convection parametrization: Feasibility study on the ideas of Arakawa (2011) for a multiscale treatment of convection; investigate alternative ways to account for the increase of sub-plume and environmental turbulence due to convection. Priority: medium
- Study on a unified cloud scheme which can be used for consistent treatment of sub-gridscale clouds in convection, cloud and radiation schemes. Further development of the Rasch-Kristjansson scheme in Alaro-1. Priority: medium
- Preliminary study aiming to code and test the turbulence energy and flux budget (EFB) scheme by Zilitinkevitch et al. in the context of Arome and Alaro, initially in single column mode (MUSC) and without moisture. Priority: medium

  HIRLAM staff: de Rooij (mm), Bengtsson (mm), Ivarsson (mm), Fortelius (mm), Kadantsev (mm)

ALADIN staff: Honnert, Piriou, Bouteloup, Riette, Bazile, Seity, Couvreux, Szintai, Geleyn, Bastak, Gerard, Banciu, Brozkova, Wittmann (1pm), Pristov (1pm), Cedilnik (1pm)
Priority: high
Responsible HIRLAM project leader/ALADIN CSSI member: Rontu / Pristov

PH2: Cloud microphysics, radiation and aerosols

- Introduce and evaluate alternative descriptions of microphysics and condensation/ evaporation associated processes in Arome and Alaro:
  - Inclusion of ICE3 microphysics and of prognostic graupel in Alaro
  - Update STRACO cloud parametrization scheme for application at high resolution in Arome. Introduction of new cloud droplet description and testing with Hirlam; after that, porting and testing of the new scheme to Arome/MUSC.
- Improvement of statistical representation of sub-grid clouds, using a bi-Gaussian PDF
- Alaro: Continued development of ACRANEB radiation scheme. Evaluation of adaptations in radiative cloudiness and water content computations.
- Continued testing of a parametrization of aerosol direct effect in the hlradia radiation scheme.Implement this in Harmonie/Arome in the context of the radiation intercomparison study. Test the updated hlradia within Enviro-Hirlam. Introduce observation-based aerosol in Harmonie/hlradia for a case study on the Russian forest fires of summer 2010.
- Harmonie radiation intercomparison: Finish interfaces to call hlradia and ACRANEB from apl-arome. Study the relative importance of high spectral detail versus more realistic treatment of cloud-radiation and radiation surface interactions. Prepare observational data for validation, perform intercomparison experiments and report. Test also orographic radiation parametrizations within Harmonie over complex orography.
- Cloud microphysics – radiation interactions: continue development of algorithms for calculating cloud transmittance and absorptance based on two-stream theory, and test against the expressions currently used. Study possibility to introduce Hirlam Liu-Penner scheme in Arome/Alaro. Before introducing any of these Hirlam-based formulations in Harmonie, study the existing cloud-radiation interaction scheme to ensure consistent usage of cloud microphysical information throughout the model code.

HIRLAM staff: Korsholm (3pm), Sahyoun* (PhD student), Pagh Nielsen (mm), Khoreva* (mm), Gleeson (mm), Nuterman* (mm), Ivarsson (mm), Rontu (mm)
ALADIN staff: Riette, Lac, Seity?, Vanderberg; radiation: Masek, Brozkova; desert dust (expert on this field): Mokhtari
Priority: medium
Responsible project leader: Rontu / Vana
Main contacts from ACT community: Alexandr Baklanov, Mihail Sofiev, Tanya Ermakova

PH3: International boundary layer, clouds and convection studies

- Stable boundary layer study and participation in GABLS-4: see WP TR4
- Harmonie cloud study: In-depth evaluation of model cloud / convection behaviour with a variety of diagnostics tools (e.g. LES/CRM combined with MUSC, pseudo-satellite and pseudo-radar images, use of SAF cloud property information, SAL), to investigate aspects like "on-off behaviour" of clouds and precipitation, overprediction of convective precipitation and over/underprediction of fog over sea and land.
- Participation in ASTEX stratocumulus study, investigate impact of e.g. alternative top entrainment formulation in turbulence scheme on stratocumulus description.

- Participation in WGNE Grey Zone project, to study how well Harmonie is resolving and/or parameterizing convection at different resolutions.
- Maintenance, monitoring and training in MUSC single column model:
- Test Surfex - upper-air interactions in MUSC experiments and in preparation of MUSC input. Ensure possibility to use MUSC with Alaro physics.
- Continue and improve daily monitoring with MUSC (KNMI Testbed, Barajas airport)
- MUSC is the topic of NumLab 2013 at Helsinki University, to be used in real-time internet training sessions.

   HIRLAM staff: MUSC: Calvo, de Bruijn, Sokka, Rontu; output diagnostics: ?
   ALADIN staff: Voitus (DDH), Bazile, Sbii (MUSC)
   Priority: medium
   Responsible project leader: Rontu, Andrae / Vana

PH4: Integration and testing of ALARO-1
- 2012 (and extended to 2013): Establishing a baseline of the Alaro-0 version (as a reference) with two steps:
    ○ Repeat the exercise of retuning of Alaro-0 when increasing the horizontal and vertical resolution
    ○ test and tune the screen level diagnostics developed by Kullmann for the stable boundary layer (this is linked to the actions in WP TR4).
- First focus on the basic steps regarding code design:
    ○ 2012: tests of Degrauwe's physics-dynamics interface
    ○ 2012-2013: revisit of APLAR aimed at big blocks such as radiation, turbulence, microphysics.
- 2012-2013 Devise an assembling strategy for putting the development on TOUCANS, CSU and ACRANEB2 together.
- Readdress the interface with Surfex, such that the coupling of Surfex can be used consistent with the underlying hypotheses of TOUCANS
- 2013 - …: validation: invest in validation testbeds common with Arome and Arpege, facilitating cross testing of our paramaterizations.

   ALADIN staff: Pristov (1pm)

3.4 Surface analysis and modelling

3.4.1 Scientific considerations

Surface description:
For the initialization of constant or slowly evolving surface properties - orography, land use, vegetation – detailed physiographic information is required both by the parametrizations and the surface analysis. Recently, significant developments in high-resolution surface physiographic databases have taken place outside the NWP community. In Surfex, physiographic information on vegetation, land use, water bodies etc. is provided by the Ecoclimap database. The potential should be studied of additional sources of sub-km scale information (CORINE, local sources for land use and vegetation, urban data, lake depth data base). As this area of work is relevant (and undermanned) for all European LAM consortia, this is an obvious topic for cross-consortia cooperation in the SRNWP framework.

Surface observations and data assimilation:
There will be a strong emphasis on surface assimilation, as surface observations have been seen to have a relatively great impact on high-resolution models. At present the surface assimilation applied in Harmonie consists of a horizontal spatialization based on OI (CANARI), followed by an OI-based soil analysis for temperature and moisture. Given the importance of an accurate representation of the surface, it is highly relevant to extend surface data assimilation in the model to all surface aspects relevant to NWP. This 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 present OI scheme. This more sophisticated data assimilation setup is being developed in the form of the Surfex offline data assimilation (SODA) system. For soil temperature and soil moisture, the OI-based analysis is to be replaced by an extended Kalman Filter (EKF) assimilation scheme, better capable of exploiting remote sensing observations; this EKF scheme is presently being evaluated. Similar EKF setups are presently being developed for snow and lakes. Furthermore, the surface assimilation algorithm should be able to handle highly heterogeneous surface conditions. Météo-France and Hirlam are therefore working on an improved horizontal spatialisation tool, taking surface heterogeneity into account. Promising alternative techniques such as Short Time Augmented Extended Kalman Filtering (STAEKF), Ensemble Kalman Filtering and particle filters are being studied in the longer term.

In the present surface analysis, screen level temperature and humidity observations are used for analysing soil moisture and soil temperature. A generally applicable analysis for snow, lake surface temperature or vegetation properties like LAI, is not yet available. For unobserved surface parameters (such as minimum stomatal resistance), the STAEKF will be considered. Hirlam staff are gaining experience with the use of lake temperature observations, and Aladin staff with satellite soil moisture.
        Use of a greater variety of surface observations should improve the characterisation of surface conditions. Research on this will mainly focus on exploiting satellite observations such as ASCAT and SMOS soil moisture, LAI, GLOBSNOW snow observations and MODIS data for lake water temperature and ice fraction. In particular the analysis of snow depth and/or snow water equivalent (SWE) needs to be improved with urgency, using in-situ and satellite data. At a later stage the impact of various snow albedo products will be investigated, and alternative schemes for snow assimilation will be studied, such as based ensemble square-root and a particle filter approach.

Surface modelling – Surfex:
For the model description of the surface/canopy layer and below, the externalized Surfex framework of coupled models (for snow and ice, lake and sea, urban environment, forest and vegetation, heat and moisture fluxes in the soil etc.) is used. In term of coding Surfex, having been designed by a non-NWP community, does not yet fit in optimally with other parts of the NWP system. To improve this, aspects of the Surfex code design and ergonomy will be reconsidered and adapted where needed by Aladin.
        The Hirlam team has taken responsibility for improving the description of Northern and polar conditions in the Surfex models, and on the associated underlying physiographic data. Key issues are the handling of snow, ice, forest, lakes and sea in the forecast model. A multiple energy balance approach is being developed for vegetation-covered surfaces, similar to the Hirlam snow and forest scheme. Further development of the Flake lake model is intended, as well as implementation of the High-resolution Thermodynamic Sea Ice model (HIGHTSI) within FLake. For the description of sea ice, the aim is to develop a prognostic sea ice parametrization for Surfex and couple it to the sea ice and SST analysis on the one hand and to a prognostic ocean water scheme on the other. Three approaches have been suggested for the prognostic ice parametrization: a simple 2-layer ice scheme from Hirlam,

and the more involved GELATO and HIGHTSI schemes. These will be tested and intercompared.

In view of the need for spatially detailed forecasts for urban areas, validation of the urban energy balance model (TEB scheme) will be continued in several places. Recognizing that a grid spacing of the order of city blocks is still beyond reach for Harmonie, a capacity is being developed to produce localized forecasts for urban or industrialized areas of special interest, based on running Surfex/TEB in off-line mode. Similar tests can be done for very high resolution modelling of mountainous areas.

A close connection between the surface model and surface data assimilation is of crucial importance. Surface assimilation should provide an initial state for relatively swiftly evolving variables at or below the land and water surface, such as mean lake temperature or soil moisture. A good cold start of surface conditions at any time of the year requires the existence of initial values of all prognostic surface variables in the model. Some of these, e.g. the temperature of the mixed layer in lakes, are quite unconventional and may be provided by dedicated databases like the lake climatology database. Others may be derived from archived model experiments or extracted from the host model. Within regular cycling, surface assimilation is expected to update prognostic parameters from previous cycles. For the development of fully integrated data assimilation - forecast methods at and below the surface, the approach of "peaceful coexistence" between spatialized (horizontally interpolated) and prognostic variables may provide a convenient starting point to introduce new variables and processes. In this approach, prognostic parametrizations of conditions below the surface provide a background for the assimilation (interpolation) at the surface, but sub-surface quantities only feel the influence of the analysed variables via atmospheric forcing during the forecast.

3.4.2 Summary of planned activities and priorities

Activities on surface physiography will focus on the evaluation of alternative, higher resolution physiographic databases and climatologies for all relevant surface parameters (WP SU1).

In surface data assimilation, highest priority is given to enhancement of the present analysis through:

- Introduction of a more advanced Extended Kalman Filter (EKF) for soil, initially to be applied to soil moisture, later also to other remotely sensed soil and vegetation properties (WP SU2); introduction of EKF also for snow (SU3) and lake (SU5) assimilation.
- Where possible, extension of the surface analysis to relevant quantities which are presently not analyzed, such as lake temperature or vegetation properties (with a focus for the HIRLAM team on "northern" aspects like snow (SU3), ice (SU4) and lakes(SU5));
- Development of an improved horizontal spatialization (SU1).

For the surface modelling, improvements in the Surfex general code design will be sought by Aladin (SU1). Hirlam research will focus on achieving a better balance between surface analysis and modelling for typically "nordic" aspects like snow and forests (SU3), ice (SU4) and lakes (SU5). At somewhat lower priority, improvements will be sought for the treatment of orographic effects at a range of scales (WPs SU7, TR3). Also, the use of Surfex in off-line mode for very localized forecasting (including urban areas (WP SU6) and mountainous areas), will continue to be investigated.

All of this work is carried out in close collaboration between the Hirlam and Aladin teams.

3.4.3 Work packages in 2013

SU1 : General aspects
- study code design of Surfex, in particular readdress interfacing issues.
- Improve ergonomy of Surfex: facilitate its compilation;

- coupling of Surfex to ALARO and validation. Actions on the optimization of Surfex depend on decisions made within the Surfex Steering Committee. An effort in CNRM/ GMAP should allow to use FA file format (instead of LFI) in the LAM+Surfex systems.
- Make it possible to interpolate from a Surfex+upper atmosphere output (e.g. Arome+Surfex to Arome+Surfex): establish an approach (e.g. rely on fullpos), make detailed plan; seek man power; carry out.
- continue further development of SODA (priority high)
- continue development of new horizontal spatialisation tool MESCAN: emphasis in 2013 on the treatment of 10m and accumulated precipitation (priority high); evaluate performance of the system in reanalysis and nowcasting applications (priority medium); introduce hetero-geneous and anisotropic structure functions using 2D wavelet formulation (priority medium)
- Enhance Surfex land cover description (priority medium:
    o Evaluation of Ecoclimap-2 and the new high-resolution sand and clay datasets
    o Study the feasibility of using the new high-resolution dataset Globcover. Compare Globcover, Ecoclimap-2 and GLCC, study gross errors and biases
    o Consider how to make adaptations into Ecoclimap using local data of better quality/ resolution (glaciers, towns). Consider the possibility of using EEA environmental datasets.
- Enhance surface elevation description: see WP TR3
- Fine-resolution orography datasets for Arome at subkm-scale: start assessing the available databases and their inclusion in the "prep_PGD" throughput; assess their derived model parameters; implement a model testbed for an Arome-500m over dense orography

HIRLAM staff: Aspelien (2mm), Landelius* (mm), Samuelsson (mm), Fortelius (mm), Shoulga (mm), Homleid (mm)

ALADIN staff: Marguinaud, Martin, Soci, Bazile (EURO4M), Seity (Ecoclimap), Mary, Hamdi, Cedilnik(1 pm), Szucs, Jidane, Essaouini, (Stanešić 1 pm), Ivatek-Šahdan (1 pm)

Priority: high

Responsible HIRLAM project leader/ALADIN CSSI member: Rontu, Bojarova / Mahfouf

SU2 : Soil

- soil data assimilation algorithms: finish evaluation of performance of the soil EKF for different surface conditions (delayed, manpower problem); investigate the soil moisture -T2m- radiation- precipitation interactions (priority medium, manpower problem);
- implement ASCAT soil moisture product (first with off-line Surfex, later in coupled mode); perform calibration/validation of SMOS soil moisture (orography mask, representativeness errors, biases, observation error covariance, thinning)
- Implement SEVIRI surface temperature retrievals in the soil analysis
- Implement MSG albedo analysis in Arome.
- Modelling of soil moisture under snow/ in bare land

HIRLAM staff: SMHI/DA(2mm),de Vries*,

ALADIN staff: Hamdi, Schneider (1pm), Parrens, Calvet, Mahfouf, Guedj, Carrer

Priority: high

Responsible HIRLAM project leader/ALADIN CSSI member: Rontu, Bojarova / Mahfouf

SU3: Snow and forest

- Install snow depth analysis (CANARI) in Arome-France and test with Globsnow data.. Experiment with snow masking and alternative kriging approaches.
- Improve OI/CANARI SWE analysis by implementing Globsnow satellite observations. Study sensitivity of the results to the definition of snow density. Assess impact of the CANARI SWE analysis and Globsnow assimilation.
- Usage of snow observations: implement snow measurements from local precipitation stations and assesing data quality (priority high); investigate usefulness of snow cover extent products for meso-scale forecasting system (snow probability maps based on MODIS and AVHRR, Land-SAF snow cover product based on SEVIRI and AVHRR; NESDIS/NOAA SCE product) (priority high);
- Design and implement EKF for snow in connection with the 3-layer snow scheme;
- Continue extensive evaluation of Multiple Energy Balance (MEB) scheme in stand-alone Surfex-v7.2 and in 3D Arome/Surfex. Consider the consistency of air-vegetation interactions in MEB and the CANOPY sublayer scheme. Study initialization of the combined 3-layer snow and MEB schemes within SODA (priority medium).
- Improve and test handling of permanent snow (glaciers) (priority medium).

  HIRLAM staff: Homleid (3mm), Eerola (mm), Bojarova (1mm), Kurzeneva (mm), S. Thorsteinsson (mm), H. Thorsteinsson (mm), Samuelsson (mm).
  ALADIN staff: Taillefer, Bouyssel, Boone, Brun, Cedilnik (1pm), Meier (1pm)
  Priority: high
  Responsible HIRLAM project leader/ALADIN CSSI member: Rontu, Bojarova / Mahfouf
  External consultant: Richard Essery

SU4 : Sea and sea ice
- development of sea ice data assimilation algorithms: design "interface" between CANARI sea ice analysis and the variables of the simple Hirlam-based sea-ice model (priority high); investigate accounting of the upper air – sea ice – ocean model interactions with the simple sea ice model (priority medium);
- sea ice observations: investigate usefulness of different sea ice cover and ice drift products for assimilation into the sea ice model; start implementation of assimilation of sea ice concentration and sea ice drift products into Surfex (priority medium)
- prognostic sea ice for Surfex: Implementation of 2-layer sea ice model in Surfex7.2. Connection to Canari sea ice optimum interpolation (priority medium)

  HIRLAM staff: Homleid (2mm), Gollvik*, Kurzeneva (mm), Bin Cheng (mm)
  ALADIN staff: Salas yMelia, Martin, Taillefer
  Priority: medium
  Responsible HIRLAM project leader/ALADIN CSSI member: Rontu, Bojarova / Mahfouf

SU5 : Lakes
- Maintenance of lake and lake climatology databases. Implementation of GLDB-2.
- Refine the EKF for lake temperature assimilation(priority high); design and implement optimal interpolation algorithms for lake temperature in CANARI (priority high); derive structure functions depending on lake depth and elevation for optimal interpolation of lake surface temperature (priority medium)
- Development on Flake parametrization in Surfex: Prepare Flake for operational use in Cy38 or 39. Special attention to the correct use of lake description and climatology in any spatial grid, and to testing and improving the snow and ice parametrization.

HIRLAM staff: Choulga (mm), Kurzeneva (mm), Eerola (mm), Kheyrollapour*
ALADIN staff: Taillefer, Seity, Rio (2pm)
Priority: medium
Responsible HIRLAM project leader/ALADIN CSSI member: Rontu, Bojarova / Mahfouf

SU6 : Urban modelling

- The feasibility of using the Surfex TEB scheme in offline mode for downscaling NWP forecasts and climate runs for cities has been assessed for Helsinki and Brussels, respectively. TEB has shown its ability to reproduce the essential features of observed annual and diurnal cycles of the surface energy budget components for heterogeneous urban landscapes. Continuation of this work in 2013 depends on possible external funding. It is planned to use TEB in climate runs to surtdy UHI. This will count as extra validation of the TEB scheme.
  HIRLAM staff:
  ALADIN staff : Masson, R. Hamdi, Rio (2pm)
  Priority: medium
  Responsible HIRLAM project leader/ALADIN CSSI member: Rontu / Mahfouf

SU7 : Orographic effects on radiation and momentum

- Implement Hirlam orographic radiation parametrisations into Surfex, and upgrade this code following suggestions by Manners et al., 2011. Study existing approximations in Surfex related to slopes and introduce improvements or alternative treatments based on the modified Hirlam parametrizations. Introduce the required slope statistical parameters based on very high resolution digital elevation data (see also WP TR3).
- Study possibilities to introduce in Surfex the Hirlam smallest-scale orography parametrisations based on Wood et al., 2001. Check the usage of orographic roughness in Surfex and switch it off in case SSO parametrisations are applied. The required orographic slope statistics needed for the parametrisations is to be prepared in WP TR3. Check the consistency of these parametrisations with the atmospheric turbulence parametrisations, which use the surface layer momentum as lower boundary condition.Consider introduction of the Alaro/Hirlam buoyancy wave parametrisations into Arome.
  HIRLAM staff: Senkova*, Rontu (mm)
  ALADIN staff : Bouyssel, Mary
  Priority: medium
  Responsible HIRLAM project leader/ALADIN CSSI member: Rontu / Mahfouf

3.5   Probabilistic forecasting

3.5.1   Scientific considerations

Weather predictability is inherently limited by unstable atmospheric dynamics. Uncertainties on small spatial scales penetrate upscale over the forecast range (the "butterfly effect"). For the smaller scales, perturbations grow faster and saturate at smaller magnitudes. As model spatial resolution increases, forecasts will increasingly contain spatial details which, with the possible exception of features closely tied to orography, likely have little predictive value beyond lead times of ~12–24h.

Over the past years, the LAEF system, developed by LACE and RMI, and GLAMEPS, developed by Hirlam and Aladin, have been readied as tools for probabilistic prediction at ~10km resolution on pan-

European domains. Verification has shown significant added value of both systems compared to ECMWF's EPS. LAEF has run operationally at ECMWF since March 2011, and recently been upgraded to higher resolution, a new breeding-blending non-cycling surface breeding configuration, and a larger domain. A pre-operational GLAMEPS suite has been installed in November 2011.

Motivated by the need for accurate forecasting of high impact weather, there is a growing demand to produce probabilistic predictions on finer scales than those covered by GLAMEPS and LAEF. Peaks of extreme weather events often are strongly influenced by dynamic features of small extent and duration. Hirlam, Aladin and MeteoFrance all aim to develop in the coming years a convection-permitting scale probabilistic predictive capacity for sub-domains of Europe for up to ~+24 hours, i.e. for lead-times that cover potential predictability on these fine scales.

In the coming years, probabilistic research will focus on achieving the following goals:
- Make a probabilistic system for convection-permitting scales, and assess its performance;
- Develop new or improved methodologies for ensemble generation and calibration at both the 10km-resolution and convection-permitting scale, aiming at greater accuracy in the detection of severe weather and in the very short range (12-24h);
- Extend the range of probabilistic products where needed according to user requests;

In order to fulfill these deliverables, several parallel lines of work will be carried out:
1. Develop a non-hydrostatic convection-permitting EPS based on Arome (called PEARO or Arome-EPS) and Harmonie (hereafter called HarmonEPS);
2. Further improve the existing GLAMEPS and LAEF systems on the ~10km scale; Prepare and maintain operational production;
3. Enhance post-processing: calibration, product generation, and verification.
4. Study the potential of combining different high-resolution LAM EPS systems.

Development of convection-permitting ensemble systems

The basic rationale behind the development of ensembles at these resolutions is the possibility to probabilistically forecast high-impact weather events of short duration and small spatial extent. Realization of this goal relies on considerable new developments on a range of issues, such as fast (within a fraction of an hour) and frequent (at least 3-hourly) determination of initial states as well as their uncertainty. To adequately account for uncertainty in model formulations is also important.

One critical obstacle is the short predictability and fast error growth of the small-scale atmospheric features often involved in severe weather events. This calls for highly accurate analyses and very frequent updates of the forecasts, with Rapid Update Cycling (RUC).

The development has started of prototype convection-permitting EPS systems for Arome and Harmonie. The LAEF team will initially focus on predictability studies on the convection-permitting scale, before setting up a convection-permitting version of LAEF (AROME-LAEF). Cooperation in the research on convection-permitting EPS is planned. The partners will initially adopt different approaches, keeping in touch on research results. During the process of developing a convection-permitting EPS, we aim to develop crucial experience with error growth rates and predictability limits at convection-permitting scales, rather than merely design a system which only takes the consequences of limited computer resources into account. In particular, experience should be gained with the predictability, and the potential and limitations for probabilistic prediction, of severe weather.

Météo-France has built a convection-permitting EPS system based on Arome-2.5km and using lagged forecasts. Various aspects are being studied on the side of model error representation and link with ensemble data assimilation. The role of surface uncertainties has been investigated in 2012, through

27

perturbations to physiographic fields (soil wetness, roughness), inflation techniques and/or observation perturbation in the CANARI surface analysis. Model error is being investigated on the one hand through cooperation with CNRS/LA on physics parameter perturbations (turbulence, mixing length etc), on the other through implementation of a stochastic physics scheme derived from ECMWF. PEARO perturbations will be improved and validated objectively in full-size experiments:

- the selection of lateral boundary conditions from PEARP will be configured as an automatic procedure suitable for operations.
- Perturbations of initial conditions will be tested on new periods using the latest versions of the Arpège and Arome EDA, where the calibration is being improved.
- Stochastic physics will be extended to the PBL and surface, with new projects to tune it using observation-based diagnostics, and to optimize its impact in specific weather types (thunderstorms, snow high precipitation, actual weather parameters).
- A review of the open operational implementation options will be carried out, viz. lagged ensembles and the optimal cost distribution between ensemble assimilation and forecasts.

Validation and experimentation focus on the Hymex field experiments, selected case studies, improving ensemble calibration and post-processing (esp. regarding convection and actual weather).

For HarmonEPS a basic research system has been set up and experiments have started in 2012. It is aimed to have a version of HarmonEPS ready to be run in (quasi-)operational mode in time for FROST-2014. HarmonEPS has been set up with Alaro and Arome physics, thus continuing the multi-model approach introduced in GLAMEPS. An important element is to prepare boundary data as model levels that are needed to run HarmonEPS are not stored operationally. Boundary data can come from operational ECMWF EPS, a high-resolution version of ECMWF EPS or PEARP. One important experiment will be to test the possibility to use the operational EPS as compared to using a high resolution ECMWF EPS. Two test datasets with ECMWF EPS at T1279 resolution and the operational resolution T639 have been prepared and ECMWF are planning to run high resolution EPS for some new test periods in 2013 that can be used for HarmonEPS testing.

HarmonEPS experiments will be made for a few selected sub-European domains. Initially experiments are made in hindcast mode. Experiments will be carried out with different nesting configurations, with data assimilation in the control members and with perturbations of initial conditions. For convection-permitting ensembles, the latter is a greater challenge than for synoptic-scale ensembles like GLAMEPS. The reason is that the forecast errors saturate at lower absolute levels for small-scale systems than for larger scales. As a consequence, very short-range predictions only have reasonable predictability if the estimates of initial states are considerably more accurate than what is considered as sufficient for synoptic scales. A connected practical problem is the short time window available before mesoscale prediction errors are saturated. The methods for estimating initial states must be both accurate and computationally fast. Limited predictability at convection-permitting scales also calls for frequent generation of new forecasts, i.e. Rapid Update Cycling (RUC). An increased initial state accuracy can be obtained by exploiting high-resolution observations (e.g. radar), and by utilizing information on flow-dependent model uncertainty from e.g. ensemble data assimilation (EDA) or a (local) ensemble transform Kalman filtering (ETKF/LETKF) (see section 3.1). Data assimilation experiments with HarmonEPS will start with 3D-Var assimilation for control forecasts. Later experiments with rapid update cycling will be made. Finally, ETKF/LETKF and EDA will be introduced and tested. It is aimed to have a tuned ETKF/LETKF version ready for experimentation in HarmonEPS in 2013/2014.

The multi-model setup of HarmonEPS accounts for some degree of model uncertainty already. At a later stage, the potential will be considered of adding surface (analysis) perturbations and of upper air perturbations in the form of e.g. perturbations in physics parameters and/or SPPT. Cellular Automata (CA) to introduce stochasticity, horizontal communication and convective memory to the

parameterization will also be tested. Application of stochastic physics at the process level, rather than multiplying the total physical tendencies, will also be studied. This will be done in close contact with the relevant experts in those areas (see WP TR1).

Technically, a script system has been developed for HarmonEPS in analogy to the one used in GLAMEPS. Changes in these job submission and monitoring scripts, e.g. a transition to SMS or ECFLOW, may be desirable depending on ECMWF plans. However, such changes may reduce portability to local platforms, so it should be assessed to what extent this might affect HarmonEPS production on local systems.

Further development of the GLAMEPS and LAEF systems
Although the prime target for 2011-2015 is the development of a convection-permitting scale ensemble, a continued attention to the operational systems GLAMEPS and LAEF is likely to remain necessary throughout this period. Certain developments foreseen in them will secure research investments of the past few years, and experimentation with these and other adaptations following its operational introduction will provide useful guidance for similar later developments in convection-permitting EPS. During the second half of the period, priorities will shift towards the convection-permitting scale.

The main focus in development activities for both GLAMEPS and LAEF is on achieving improved forecast accuracy and an improved accounting for sources of prediction uncertainty. Experiments will be carried out to establish the impact of higher spatial resolution and more frequent ensemble production on forecast accuracy, in particular for severe weather. In addition, new sources of uncertainty will be tested.

For GLAMEPS, an Ensemble-Transform Kalman Filter (ETKF) re-scaling technique is being developed and implemented for generating initial-state perturbations on smaller scales than provided by ECMWF EPS, with the aim to obtain improved spread-skill relationships especially in the first 24h. In parallel with this, EDA based on perturbations of observed quantities is used. Both ETKF and EDA perturbations are combined with the larger-scale perturbations, and can be used to estimate a flow-dependent model error covariance matrix (B-matrix) for hybrid data-assimilation. Another approach for generating fine scale initial-state perturbations is to use LAM-specific singular vectors optimized for maximum (or minimum) convective available potential energy (CAPE). The LAM-specific perturbations need to be combined with those provided for the larger scales. Preliminary experiments indicate mixed results, but with positive impacts in summer cases with strong convection.

Apart from the multi-model and multi-physics nature of GLAMEPS, limited experience has been gained with model perturbations from stochastic physics or perturbations of parameters, showing some positive impact over a short test period. Development of Forcing SVs in combination with EuroTEPS has also been tested, but not in a full-scale experimentation with GLAMEPS.

A set of hindcast experiments started in 2012. As control, the operational GLAMEPS-v1 setting is used. The experiments include blending with large scale perturbations, use of ETKF and EDA, use of CAPE SVs, use of surface data assimilation in all LAM members, ETKF and EDA. Some of these experiments are finished but need to be evaluated, and some will continue in 2013.

For LAEF the lateral boundary conditions are provided by ECMWF-EPS. Initial perturbations on smaller scales than resolved by ECMWF are provided by the Breeding-Blending scheme that combines small scales from LAEF bred-vector with larger perturbations from ECMWF-EPS. To better account for uncertainties in the model a revised multi-physics scheme is developed that better accounts for uncertainties on smaller scales and thus better represents uncertainties on the convective scale. The implementation of a stochastic surface scheme is implemented to test the impact of perturbed surface fields on the probabilistic forecast quality of LAEF. For a better representation of small scale initial

29

perturbations a surface data assimilation scheme will be tested. Further developments of a LAMEPS on high resolutions include studies with an Arome-EPS to study convective scale predictability.

It is intended to evaluate the added value of combining GLAMEPS and LAEF output in different manners. Closer co-operation between GLAMEPS and LAEF is also considered desirable in order to optimize staff resources for the research on initial, physics and surface perturbations, calibration and verification, and for maintenance activities.

<u>Statistical post-processing and product generation</u>
These issues are common for the synoptic and convection-permitting scale, even though the requirements on relevant observational data are higher for the latter. Both systems in principle will make use of the same post-processing and product generation tools.

Statistical calibration of LAM EPS data is a way of reducing model-specific systematic errors in areas with adequate observation coverage. To what extent calibration can improve the forecasts of extreme weather, or in areas where observational data are sparse, needs to be investigated. Probabilistic verification and calibration require long time series for statistical significance, particularly when trying to make statements on the probability of severe events, which by definition are rare. Ideally, one should use ensemble re-forecasting over a climatologically relevant period (order 30 years). However, this is prohibitively costly in terms of computer resources. We will therefore adopt simpler forms of calibration, which may be less capable of accounting for weather extremes.

Calibration should be done over regions with similar climatology, as well as for a range of single sites. In GLAMEPS calibration has originally been performed with Bayesian Model Averaging (BMA). Overall verification statistics are improved by this approach when all observations are used to estimate a single pan-grid calibration. However, application of BMA has proven difficult in the case of non-Gaussian variables (like precipitation), and prohibitively costly when used for many smaller areas to account for spatial inhomogeneities in climatology. As an alternative to BMA the computationally faster method of extended logistic regression (ELR) has been adopted. Three possible approaches are being evaluated: (1) fit ELR separately to each station (requires long training series to deal with "extremes"), (2) use a mixed-effect variant of ELR (more advanced, less need for long training periods) and (3) an ELR model in which latitude and longitude are used as predictor variables (spatial variations are possibly not very smooth, computationally expensive). It will be investigated to what extent these three approaches for ELR are beneficial in terms of quality and reliability.

Both LAEF and GLAMEPS have a full set of products at ECMWF. On their web sites a selection of graphical products is available. Adaptations to local products will largely have to be made by member institutes after downloading the raw data. When required, the set of centrally provided products can be revised according to stated user needs (see also section 4.1).

3.5.2 Summary of planned activities and priorities
A basic setup of the PEARO and HarmonEPS systems has been made, and further experimentation is ongoing (WP E1). The operational LAEF system has been upgraded and an operational setup for GLAMEPS has been created. In the coming years, research activities on LAM EPS will focus on:
- Experimentation aimed at bringing convection-permitting EPS to operational stage (WP E1):
  - First with LAM EPS components in downscaling and in full data assimilation mode
  - At a later stage experimentation with hybrid ensemble assimilation techniques, perturbations of initial conditions, stochastic physics and multi-model setups
- In parallel, the continued improvement of the operational LAM EPS systems (WP E2) through
  - the introduction of new/improved ensemble generation methods,

- ○ continued adjustments to meet operational needs,
  - ○ studies on combinations of GLAMEPS and LAEF;
- ● and the development of calibration (WP E3) and product generation techniques (WP E4).

3.5.3   Work packages in 2013

E1: Development of a convection-permitting ensemble
PEARO:
- ● Improve PEARO perturbations and objective validation in full-size experiments
- ● Configure the selection of LBC from PEARP as an automatic procedure suitable for operations. Test perturbation of initial conditions on new periods using the latest versions of Arpege and Arome EDA.
- ● Extend stochastic physics to the PBL and surface, tune it using observation-based diagnostics, and optimize its impact in specific weather types
- ● Review currently open operational implementation options and optimal cost distribution between ensemble assimilation and forecasts

HarmonEPS:
- ● Experiment in hindcast mode with a system with Harmonie data assimilation with perturbations imported from the BC data.
- ● Test nesting in EPS T639 vs. EPS T1279, and the ECMWF deterministic model.
- ● Apply separate surface assimilation for each member (like in GLAMEPS)
- ● Assess impact of extra (high-resolution) observations on ensemble generation based on ETKF/LETKF or EnsDA perturbation schemes
- ● Explore the influence of humidity perturbations in HarmonEPS by including humidity in SVs, and by use of the MSG cloud mask for computing humidity perturbations
- ● Adapt SPPT for use in HarmonEPS
- ● Test Cellular Automata (CA) in Alaro component of the ensemble
- ● Investigate whether the triggering mechanism in the CSU scheme of ALARO is a good handle to perturb the convective activity.
- ● Implement and test perturbations in physical parameters
- ● Longer term studies with the aim to introduce stochastic physics on process level rather than multiplying total tendencies; estimate "how stochastic should each physical process be?"
- ● Define a small number of experimental integration domains for HarmonEPS, including a domain that satisfies the requirements of the FROST-2014 project. The resolution to be used is 2.5km, and the multi-model approach is to be tested using both Alaro and Arome.
- ● Technical work associated with the preparation for running HarmoneEPS for Sochi in a pre-operational setting (e.g. estimate observation error statistics)
- ● Prepare for delivery of HarmonEPS to FROST-2014

AROME-LAEF:
- ● Development of an AROME-LAEF version
- ● Study on convective scale predictability with AROME over Eastern Alpine Region
- ● Publication of scientific results
- ● Investigation on initial condition perturbation for AROME-LAEF system (in cooperation with the other teams dealing with convective scale EPS)
- ● Description of uncertainties of AROME physics;
- ● Participation in WMO/WWRP FROST-14 project

31

HIRLAM staff: van der Veen (3), Barkmeijer (2), Feddersen (?), Bengtsson (?), Escriba (4), Callado (?), Frogner (3), Vignes (?),New met.no (5)
ALADIN staff: Arome EPS team: Bouttier, Nuissier, Vié, Raynaud; LAEF team: Wang (0.5pm), Gorgas (3pm), Weidle (2pm), Wittmann (0.5pm), Szucs
Priority: high
Responsible HIRLAM project leader / CSSI member: PL EPS / Deckmyn

E2: Further development of ~10km-scale LAM EPS
GLAMEPS:
- Carry out and report on configuration experiments for GLAMEPS-v2:
  - LAM CAPE singular vectors in GLAMEPS, EXP_2.1, to be evaluated and reported
  - Integrate and test ETKF/ETKF-Hybrid rescaling: EXP_2.2, to be finished.
  - Integrate and test EDA or EDA-Hybrid rescaling, EXP_2.3, if manpower available.
  - Increase the number of Aladin members and exclude the use of pure EC EPS members, EXP_2.4
  - Combine GLAMEPS and LAEF: offline study with historical data, EXP_2.5
  - Experiments with combining runs from different ensembles and/or runs to make a larger ensemble, EXP_2.6
  - Implement and test structural changes to optimize GLAMEPS run-time and to have a more frequent delivery (4x/day) by introducing time lagging, EXP_2.7
  - Test increased model resolution (to ~8km) after the upgrade of ECMWF HPC platforms, EXP_2.8

LAEF:
- Upgrade of operational ALADIN-LAEF
  - Increase horizontal and vertical resolution: 18km to 11km, 37 levels to 45
  - Re-design and optimization of multi-physics scheme
  - Investigation on the impact of ensemble size on the ensemble system quality
  - Ensemble land surface data assimilation
  - continue studies on stochastics surface physics, Interaction with physics experts for diagnosing uncertain parameters (WP TR1).
  - verification of the new LAEF system
  - implementation of new LAEF on upgraded HPC at EMCWF

HIRLAM staff: Sattler (?), Yang (?), Frogner (3), Johansson (6), New met.no (5)
ALADIN staff: Deckmyn, Smet, Wang (1pm), Weidle (6pm), Wittmann (1pm), Gorgas (1pm) ,Bellus, Tascu
Priority: medium to high
Responsible HIRLAM project leader/ALADIN CSSI member: Frogner / Deckmyn

E3: Statistical post-processing and calibration
- Develop ELR calibration method; Investigate the feasibility and optimality of the three different ELR approaches. Fit the ELR-code into the GLAMEPS scripts and prepare for inclusion in the next upgrade of the operational GLAMEPS.
- Upscaling/neighborhood method: study different approaches for GLAMEPS and HarmonEPS
- Further develop the LAEF statistical calibration and post-processing, the emphasis will put on calibrating wind and precipitation forecast.

- Test local calibrated GLAMEPS forecasts, including verification, for the Sochi area.
  HIRLAM staff: Bremnes (3), Kok (?), C. Santos (1), Kilpinen (?), Escriba (1)
  ALADIN staff: Deckmyn(?)
  ECMWF contact: Leutbecher
  Priority: medium
  Responsible HIRLAM project leader/ALADIN CSSI member: Frogner / Deckmyn

E4: Product generation
- Construction of raw output data in regular lat/lon grid for the FROST-2014 project
- Provide range of graphical products for presentation at *glameps.org*, and for downloading as digital fields.
  HIRLAM staff: Sattler (2?), C. Santos (?)
  ALADIN staff: Deckmyn?, Costa (1pm), Weidle (0.5pm)
  Priority: high
  Responsible HIRLAM project leader/ ALADIN CSSI member: Frogner / Deckmyn

3.6 Quality assurance and monitoring

3.6.1 Scientific considerations
Continuous monitoring of model performance is an essential step to ensure the progress of NWP systems in terms of forecast quality in a measurable way. A thorough evaluation is required in connection to the release of new cycles, to ensure technical and meteorological robustness. In addition, regular inter-comparison between model versions and operational suites is a powerful tool to assess model performance and expose deficiencies. The new generation of operational convection-permitting models and LAM EPS systems requires the introduction of new automated quality assessment tools. A stronger Hirlam-Aladin collaboration on these aspects will be pursued. In addition, in accordance to its strategic objective of stronger quality assurance, Hirlam will make a dedicated effort in terms of manpower to analyze verification results and interpret them in terms of model weaknesses. In-depth quality assessment is a demanding activity, requiring an adequate level of manpower and know-how.

Permanent effort at Météo-France is devoted to monitoring of the operational models. The new data assimilated in the operational models are automatically monitored and this information is shared with other NWP centres through an external web site. The radar data assimilated by Arome are very important for the analysis quality and specific screening for assimilation of satellite data at a higher resolution is also crucial. A new diagnostic called Degree of Freedom of Signal (DFS) quantifies the influence on the final analysis of a given observation system. Its computation after every major change in the model allows to monitor the quality of the use of the observations in the assimilation system.
For Arome-France, classical scores against radio soundings, surface station measurements and analysis (Arome or Arpège) have been complemented by testing new references and scores for accumulated rain, cloudiness and wind gusts. The neighbourhood method (Roberts and Lean 2008, Ebert 2009) is used on Arome, Aladin and Arpège 24h accumulated rain forecasts; this has been extended to simulated 10.8 micron brightness temperature and 6-hourly accumulated rain and wind gusts in order to document the diurnal cycle of errors. These scores are combined into a synthetic index analogous to the one used for the UM regional model (Wilson 2009). Some problems of temporal variability linked with the inter-annual variability have been documented in particular for the maximum wind gust. This has led us to reduce our synthetic index to its rain component for administrative verification but the studies

will be carried on to try to solve these problems through a better choice of scores. New object based verification will be explored by using as a first step the sofware MODE of NCAR to see the benefits and drawbacks of this kind of methods, and in a second step a more specific and optimized tool, developed in Météo-France.

In both Hirlam and Aladin, tools and platforms for the monitoring and inter-comparison of models are available. Aladin has a common verification facility for the operational models of their members in Slovenia. For Hirlam, a monitoring portal is maintained to help the community identify model deficiencies in a timely manner, and to trigger research actions to mend them. The information which is routinely gathered on the portal includes forecast charts, observation and field verification, observation usage and analysis statistics, meteograms, verification of boundary layer profiles against masts, etc. An on-duty monitoring team has been set up by Hirlam to assess, and ensure the follow-up of, problems and deficiencies encountered in real-time applications. A discussion forum has been created to report and exchange experiences with the evaluation of operational or pre-operational suites. Emphasis is put on model performance during high impact weather.

Harmonie and Aladin verification so far has been mostly done in terms of traditional scores applied against synoptic observation data. With the move towards km-scale resolutions, extension of the verification system with methods suitable for high resolutions is urgently needed: algorithms and tools suitable for comparisons between coarse and fine models, and between high resolution models, with special attention to high impact weather. Of particular interests are verification algorithm featuring spatial, scale-sensitive techniques such as SAL and FSS, methods to use upscaling concept in assessment of forecast skill for high impact weather such as the Significant Weather Score (SWS), and use of remote sensing, 2D or 3D observation. In recent years, several options have been tried in the Hirlam community with the use of verification tools such as MetPy, GL/Monitor and MET. During 2012, an agreement between Aladin and Hirlam has been made to explore the development of a common verification package or tools, suitable for the evaluation of mesoscale as well as probabilistic forecasts. The work force to carry out the joint research and development of these common verification tools needs to be allocated on both sides and a close collaboration will be carried out during 2013. The idea of developing an NWP index composite using combination of point verification (for T2m, W10m), and some sort of weighted sum for precipitation (threat scores, SAL and SWS using point or 2D obs etc.) will be pursued in the near future, both in connection with Reference Harmonie releases and for use at member services. Meanwhile, coordinated efforts are needed to secure the collection of observation data suitable for high resolution verification, in particular radar reflectivity and satellite-derived cloud physical properties.

Requirements for a probabilistic verification package include among others the ability to use both raw and calibrated data, the inclusion of relevant verification parameters such as significance tests, flexibility in the selection of verification domains, quality and flexibility of graphical visualizations, and the need for routine (quarterly?) operational verification against observations. Even more than in deterministic verification, a sufficiently long temporal base is needed to ensure statistical confidence.

For Arome-EPS, a research-oriented, observation-based probabilistic verification package 'obsco' has been developed for the diagnosis of experiments. It produces the most common probabilistic scores on T2m, RH10m, ff10m, gusts, precipitation, snowfall, and cloudiness. Bootstrap testing is used to compare between experiments. A simple observation quality control procedure is included. Obsco will be extended and improved to new parameters and scores, to statistical calibration and PDF dressing of small ensembles. For GLAMEPS and HarmonEPS, probabilistic verification for operational forecasts and experiments is presently done offline by an R-based package on a monthly basis for

precipitation, 10m wind and wind gusts, mslp and T2m. This R-based package is still under development.

The development of probabilistic verification is a potent area for co-operation between LAEF, GLAMEPS, HarmonEPS and Arome EPS. For the first three, the FROST-2014 project is a golden opportunity for verification of high resolution probabilistic forecasts. For Arome-EPS, validation and experimentation will focus on the HYMEX field experiment and selected cases of other events, and on improving ensemble calibration and post-processing (notably regarding convection and actual weather).

3.6.2 Summary of planned activities and priorities
Activities on quality assessment tools and monitoring will focus on
- A coordinated effort between Hirlam and Aladin on joint development of verification tools suitable for mesoscale verification and probabilistic forecasts. Extension of the monitoring and verification systems with utilities suitable for assessing the performance of high-resolution models and their added value (WP QV1), and ensemble prediction systems (WP QV2)
- HIRLAM: Continued Harmonie quality monitoring by a on-duty monitoring team (WP QV3).

3.6.3 Work packages for 2013

QV1: Tools for quality assessment and verification: mesoscale
- Development / introduction of mesoscale monitoring and verification tools and methods:
  - Joint Aladin/Hirlam development of verification system/tools
  - Introduce and test new scores for station-based verification (SWS, SEEPS);
  - Evaluate spatial/scale-selective verification methods (FSS/upscaling, SAL, …)
  - Collection and evaluation of gridded, 2D/3D data (MESAN, calibrated radar data).
- Collection of model and observation/analysis data for joint monitoring about operational NWP suites at member services, with the short term emphasis on high density raingauge data, radar rain rate data, and satellite derived cloud information. Attention will be paid to ensuring general applicability of both algorithms and data at member services;

HIRLAM staff: Emiel der Plas (3pm?), Andrae (system, ? pm), Eerola (?pm), Feddersen (SEEPS, ? pm), Fortelius (algorithm, data, ? pm), Nielsen (Satellite derived cloud data and model intercomparison, ? pm), Kryzanauskiene (algorithms;? mm); Vignes(1 pm?), Yang (2 pm)

ALADIN staff: Stein, Amodei, Pouponneau, Tardy, Sanchez, Razagui, B.Bochenek (3pm), M.Jerczynski (5pm), M.Kolonko (4pm), M.Szczęch-Gajewska (5pm), J.Woyciechowska (4pm), Pristov (1pm), Gorgas (1pm)

Priority: medium

Responsible HIRLAM project leader/ALADIN CSSI member: Yang /

QV2: Tools for quality assessment and verification: probabilistic
- <mark>Continue work on R-based verification package to be used for real-time operational verification of GLAMEPS and for verification experiments.</mark>
- Extend the 'obsco' software to new parameters (fog/visibility, aircraft data, satellite clouds, convection indicators), statistical calibration, PDF dressing of small ensembles, economic value, computation of 'trivial forecast' scores. Apply EPS scores to Arpege and Arome analysis ensembles: spread/skill reliability, error correlations, model error contribution.
- Further develop the Aladin quality monitoring package (installed in Ljubljana), e.g.

introduction of significance tests and production of monthly reports.
- Monitoring and verification of GLAMEPS, LAEF and HarmonEPS for the region of Sochi in the context of FROST-2014.

    HIRLAM staff: C. Santos (3pm?), Bremnes (0.5pm?)
    ALADIN staff: A. Deckmyn, Bouttier, B.Bochenek (2pm), J.Woyciechowska (1pm)
    ECMWF contact: Leutbecher
    Priority: high
    Responsible HIRLAM project leader/ALADIN CSSI member: Frogner / Deckmyn

QV3: Monitoring and quality assurance (QV3)
- Coordinated pre-release quality assurance and reporting for the Reference Harmonie
- Regular follow-up and monitoring of Harmonie/Hirlam operational suites.
- On-duty team for monitoring and quality assurance
- Comparison of the Arome-France and KNMI-Harmonie forecasts on the spatial domain corresponding to the intersection of their simulation domains
- Maintenance and extension of the Hirlam data portal featuring the main operational Hirlam/Harmonie suites in the common monitoring pages on hirlam.org, including charts, meteograms, mast profiles as well as observation and field verification
- Report regularly about performance and needs to both developer and user communities

    HIRLAM staff: Pre-release quality assurance: ca 6-10 mm with approximately one pm per operational centers. On-duty team: a total of 6 mm, with preliminary assignment per member service abiout on-duty week specified on wiki page). Regular maintenance and analysis: Andrae(0.5 pm), Eerola (1pm, monitoring interface), Fortelius (1 pm), Kangas (0.5 pm, mast data and interface), Kazlauskas (1 pm, monitoring interface), Tijm (1 pm), Yang (2pm)
    ALADIN staff: Stein, Bénichou
    Priority: high
    Responsible HIRLAM project leader/ALADIN CSSI member: Yang /

3.7   System development

3.7.1   Considerations

General system aspects:
Maintenance of the model involves both the upgrading of code in the central repository, and participation by Aladin and Hirlam staff in phasing activities together with Meteo-France and ECMWF. New releases are brought out about once per year. For Hirlam, more staff will need to acquire the transversal code expertise required to effectively participate in the phasing process. However, it is also important to develop new working practices which allow more efficient maintenance of the complex distributed code development environment which the IFS has become.

The Object Oriented Prediction System (OOPS) is a redesign of the IFS code to a more modular, object-oriented system. It is mainly driven by the need for more flexibility in the inclusion of new components in the assimilation system, which is a disproportionally time-consuming activity at present. However, OOPS developments also are an opportunity to clean and restructure other parts of the code, and to reconsider how the LAM-specific parts are implemented in it. A more structured code leads to greater code transparency and should ease the steep learning curve which new developers face at present. Hirlam and Aladin intend to participate actively in OOPS activities.

The present LAM model system hosts three upper air physics packages, Arome, Alaro and Aladin. In addition, an interface to the ECMWF physics has been created to facilitate application of Harmonie in regional climate modelling.It has been beneficial to maintain this variety both for research and operational purposes. The idea of a HIRLAM physics package has been abandoned, while the Aladin physics will remain in the system in terms of code since they primarily are the physics package of MF's global Arpège system (plus being the basis of the Arpège-Climate and Aladin-Climate versions). Over the period considered in this plan, it is anticipated that several "old" Aladin NWP systems (LAM versions of Arpège) will remain in operations, though a number of applications in Aladin countries will move towards Alaro or Arome configurations, using their corresponding physics packages. The different packages can be used with different combinations of upper air and surface assimilation or downscaling. Each option has a maintenance cost, and the high-level options should therefore be kept sensible both in numbers and in what they mean in meteorological terms. It should be clear at every release which combinations of options have been well tested and which ones have not.

A balance needs to be maintained between portability and flexibility on one hand, and stability and efficiency on the other. The system should be simple to install on local platforms and easy to distribute for benchmarking. To facilitate the latter, a standard benchmark package can be introduced, to be updated for major new releases (section 4.1). The introduction of utilities like ECFLOW (for job submission and scheduling) and Prep-IFS or Vortex (preparation of experiments) may increase user-friendliness, robustness and efficiency, but at the cost of increased local maintenance of these tools. Different options for introducing new utilities, and their consequences, will be reviewed in the light of finding the best balance between these requirements, in cooperation between all IFS/AAAH partners.

The Hirlam/Harmonie Reference System

In contrast to Aladin, the Hirlam cooperation not only concerns the NWP code, but covers all parts of the NWP chain, from observations handling to post-processing of model output. This so-called Reference System consists of source code, scripts, utilities and documentation. A robust high-quality Reference System suitable for operational use is the main deliverable of the Hirlam collaboration.

Following the official release of Hirlam v7.4, in May 2012, further developments in the Hirlam Reference System will be limited to (a) upgrades required for GLAMEPS, (b) the development of new releases of the Hirlam chemistry branch by the Enviro-Hirlam community, and (c) maintenance and troubleshooting for operational Hirlam use, until the model has been phased out. At the beginning of Hirlam-B, Harmonie has reached a stage where quality-assured Reference versions can be defined. During its initial development, care was taken not to let local implementations differ in aspects other than cycle version, domain, resolution and the associated choice of physics package (Arome for horizontal resolutions of ~2.5km or less, Alaro otherwise). Consequently, the various Harmonie suites are far more homogeneous (with fewer local code deviations) than those of Hirlam. Also, tools locally developed for Harmonie have almost all been shared and included in the central repository.

GLAMEPS and its future convection-permitting variant, HarmonEPS, represent probabilistic extensions of respectively Hirlam and Harmonie. As such, the GLAMEPS and HarmonEPS code, scripts and tools are considered to be an integral part of respectively the Hirlam and Harmonie Reference Systems (similar to the situation in the IFS).

In the past, a Regular Cycle of Reference (RCR) has been developed, in which one member service (FMI) undertook the responsibility to adopt the Hirlam Reference System as its operational model. The RCR provides a direct benchmark for the evolution of model forecast quality. It helped reduce the gap between scientific developments and operational implementation in member services, significantly improved the quality assurance of the Reference System, and facilitated harmonization of operational

suites towards the Reference configuration.Given the positive role of the RCR for Hirlam, it is aimed to introduce a similar RCR for Harmonie. However, in contrast to Hirlam, it will not be feasible to have a Harmonie RCR with a domain relevant to all Hirlam members. In view of the unavoidable diversity of operational domains, it has been decided to commit to pre-release testing of new Reference releases on all domains, taking their different weather characteristics into account. The role of the RCR in this setup becomes a more technical one: not acting as THE sole quality standard for Harmonie, but instead intended to ensure the technical (and meteorological) capability of the model to be used in an operational HPC environment. It is envisaged that the responsibility to act as RCR center can rotate among Hirlam institutes, in line with major new releases. Pre-release testing of forecast quality and computational efficiency in this context will be much more of a community effort than was the case in the past. This stronger contribution by all members to the release process should be reflected in committed staff contributions for pre-release activities. Testbed and verification facilities have been adapted to take into account the need to validate the model not for one, but for a number of Reference configurations (in terms of domain, resolution and forecast model characteristics).

3.7.2 Summary of planned activities and priorities

System maintenance and development by its nature represents a continuous stream of work, which is essential to enable and facilitate other research activities. High priority areas in the coming years are:

- Maintenance of the common IFS/AAAH code (participation in phasing activities). For Hirlam staff: gain in-depth experience with the code (WP SY1);
- Activities to make the LAM code conform to OOPS standards are mandatory (WP SY2), as is the work required to complete the SRNWP/Interoperability program and maintain this code in the future (WP SY3). Both will be done in close cooperation between ALADIN and Hirlam.
- HIRLAM only: Maintenance of the Harmonie and HIRLAM Reference System (WP's SY4.1 and SY4.2, respectively);

3.7.3 System work packages in 2013

SY1: System maintenance and development

- Implementation of upgrades, maintenance and support of the AAAH systems; coordination of and participation in phasing activities
- Pre-phasing activities and coordination for more efficient phasing
- Update RAPS benchmark of Arome forecast to the most recent cycle, extend to 3D-Var
- Monitor most recent cycle performance on various platforms for operational applications
- Prepare an operational-devoted version of the codes based on either CY38T1 or CY39T1: until January 2013 at MF, later in Aladin and/or Hirlam countries
- Follow and contribute to the COPE development

HIRLAM staff: Andrae (1pm), Moene (2pm), Aspelien (2pm), Vignes(1pm), Sokka(2pm), Phasers(2pm), Experts(1pm)

ALADIN staff: Fischer, Yessad, GCO team in MF, A. Mary, invited Aladin phasers, Spaniel (LACE ASCS), various GMAP staff as required for their field of expertise

Priority: high

Responsible HIRLAM project leader/ALADIN CSSI member: Andrae / El Khatib

SY2: Developments related to OOPS

- Study OOPS code; install and study the 3D-Var prototype; design and code a LAM version of the OOPS/IFS code (close coordination between MF/Aladin, Hirlam and ECMWF staff);

- Continue to train staff to C++ and OO-design;
- On the Fortran side, take care about the future "Geometry"-derived type which will be the Fortran counterpart of the OO-Geometry object and will contain most of the grid and projection information (parameters, setup including distribution);
- Adapt (or check) the LAM code to (with respect to) the progressive encapsulation of the IFS code towards more modularity: observation operator codes, control variable code, implications on LAM of the break-up of setup routines, possibly recoding of LAM-used options (like DFI).
- Further encapsulation and modernization in an OO-spirit of the Full-POS/(e(e))927 code;
- Analysis and coding of a solution for making FEMARS (sampling diff stats for B-matrix computations) a 9xx configuration => will require coordination with ECMWF
- Extend toy OOPS with new assimilation methods
  HIRLAM staff: Aspelien(1pm), Sokka(3pm), Gustafsson(2pm), Moene(1pm), Montero(2pm), Andrae(1pm)
  ALADIN staff: Fischer, Yessad, GCO team, Moll, Guidard, Wattrelot, Taillefer, Bouteloup, Montmerle, Desroziers, Berre, Mary, Faure, Arbogast E., Brousseau (femars), El-Khatib, Degrauwe, Jidane / Note (by Claude): the MF list of staff includes contacts for OOPS in the global system, since some aspects will be Arpège/LAM transversal
  Priority: high
  Responsible HIRLAM project leader/ALADIN CSSI member: Andrae / El-Khatib

SY3: Contribution to Interoperability and long-term maintenance
- Continuation of the work on the geometrical aspects of different consortia models
- Implement the SWI conversion for Harmonie in the new 903 frame-work
- Reports on standard format of data; provision of test files to other consortia
- Development: prototyping of a conversion tool for post-processing files; finalize its implementation as a new configuration; extend it to model re-entering files
- Maintain an up-to-date documentation
- Establish the configurations of the other consortia's geometries that will be tested after the SRNWP-I program will be finished and specify the current limits of our software.
  HIRLAM staff: Moene (1pm), Andrae(1pm)
  ALADIN staff: Degrauwe, Spaniel, Pietrisi, Fischer
  Priority: medium
  Responsible HIRLAM project leader/ALADIN CSSI member: Andrae / El-Khatib

SY4.1: Harmonie Reference, RCR, user support and documentation
- Consult Hirlam services on agreements to run a Harmonie RCR, and prepare for real-time or operational running of Harmonie.
- Implementation, monitoring, validation, release, maintenance and support of the Reference system at one or more operational platforms.
- Work on backup and trouble-shooting guidelines to ensure smooth operational running
- Test injection of observation data at ECMWF and operational platforms running RCR
- Ensure platform equivalence between the Reference system at ECMWF and operational RCR platforms on meteorological aspects
- Continue to enhance Harmonie postprocessing
- Enable easier output of arbitrary fields from the forecast model.
- Set up a new hirlam.org server.
- Prune all dependency of GRIBEX in gl

- Implement proper GRIB encoding of Surfex fields
- Streamline the usage of Harmonie under ecflow at ECMWF.
- Improve efficiency by removing unhealthy mix of serial/parallel tasks in the suite.
- Prepare a move to GIT as the major version control system. Priority depending on the progress of the GIT implementation at Meteo France/ECMWF
- Provide support through the forum at hirlam.org
- Collect and enhance online and offline Harmonie documentation
- Arrange Harmonie training for newcomers

HIRLAM staff: Andrae (1pm), Dahlbom (1pm), Moene (1pm), Sokka(1pm), Vignes (1pm), Yang (1pm), Kazlauskas(1pm), Aspelien(1pm), Sattler (1.5pm), Palmason(1pm?)
Priority: high
Responsible HIRLAM project leader: Andrae

SY4.2: HIRLAM maintenance and support
- maintenance of RCR at FMI and parallel suites at ECMWF
- maintenance of Reference Hirlam, including necessary bug fixes, and the necessary adaptation to accommodate change of ECMWF computational platform and boundary data with increased vertical levels
- Technical assistance for operational activities using Hirlam system.

HIRLAM staff: Eerola (0.5pm), Vignes (0.5pm), Sattler (0.5pm), Moene (0.5 pm)
Priority: high
Responsible HIRLAM project leader: Andrae

3.8   Transversal issues

A number of transversal research issues has been identified, which will require coordinated and combined efforts from more than one of the traditionally recognized research areas within Hirlam and Aladin. Six main issues involving cross-disciplinary efforts are described below.

3.8.1   Scientific considerations

I.   Forecast model and model error in relation to data assimilation and ensemble forecasting:
The forecast model, and uncertainties and errors therein, affects the data assimilation and ensemble forecasting systems in many ways, and vice versa. It is aimed to form a multi-disciplinary team which can plan and carry out research on these issues in a comprehensive way.

The introduction of ways to treat model error is generally seen as a crucial but still very open topic in data assimilation. There has been little or no activity on this yet in Hirlam and Aladin, and research on this topic urgently needs to get started. TL/AD models in variational assimilation make use of simplified linear physics. Improvement of the level of realism of this physics with respect to moist processes without unduly compromising the assumption of linearity is of critical importance to enhance the performance of 3- and 4D-Var schemes. An obvious first step in this respect will be to replace the simplified physics in 4D-Var by the more advanced ECMWF linearized physics, and assess its impact.

The final step in an analysis is initialization, usually by means of a digital filter (DFI). In Arome and Harmonie DFI is not applied, as experience at Meteo-France has shown that it may filter out relevant information. A scale-selective version of DFI (SSDFI, Termonia 2008) has been developed which should prevent unnecessary filtering of small-scale signals. After the introduction of the option

of filtering for spectral and grid-point fields simultaneously in a DFI step, the impact of no initialization versus DFI and SSDFI can be assessed. The influence of the adopted nesting strategy, domain size and observations used on spin-up for different variables will be studied as well.

Studies of the inherent predictability of atmospheric phenomena can help to formulate both more realistic deterministic forecast models and ensemble systems. An important topic of investigation is how best to introduce model uncertainty in ensemble forecasting systems. Methods which are presently used are perturbations of physics tendencies, parameters, stochastic physics, multi-physics and multi-model ensemble approaches, but little is known about their relative strengths and weaknesses. It is also relevant to introduce and study stochasticity in a deterministic model context, e.g. through the use of cellular automata in the context of a statistical cloud scheme.

II. Physics-dynamics interaction:

The interaction between dynamics and physics parametrizations will remain an important topic of research. When going to higher resolutions, some processes will become explicitly resolved, starting with deep convection and then shallow convection and turbulence. It is important not to double-count these processes. The introduction of a higher-accuracy physics-dynamics coupling, the impact of running physics and dynamics at different grid resolutions, and the consequences of a reorganization of the time-stepping between dynamics and fast and slow physics processes, are aspects to be studied in this respect. Both the implementation of a second-order accurate interface and the option of running the physics and dynamics on different grids are close to being finalized, but this work has been severely delayed by several staffing changes. Implementation and testing will hopefully be carried out in 2013. According to the experience gained at ECMWF when a similar interface was developed, one relevant aspect is that fast physical processes cannot be averaged along the time step or the semi-Lagrangian trajectory but should be treated at single points and therefore with first order of accuracy only. Another thing to study is how to ensure that positive definite quantities such as kinetic energy or mixing ratios keep being positive after the second order interfacing.

Additionally, studies will be continued on the effect of different dynamics settings on model behaviour, such as the smoothing of orography and the intensity of horizontal diffusion. In particular the interaction between dynamics and microphysics and the effect of different formulations of horizontal diffusion on the strength and organization of resolved convection, will be considered more deeply.

The new physics-dynamics interface prepared by Degrauwe should be verified in Arome still in 2012. The interface is already prepared for the future introduction of more elaborate microphysics schemes using more condensate species, and for the addition of aerosol or chemical components.

At present, the physics-dynamics interface treats the model grid as a series of vertical columns without any information about their relative positions, and physics parametrizations treat these columns as completely independent entities. Future models at very high resolution are likely to require (quasi-)3D parametrizations. Investigations are ongoing on the use of 3D schemes for turbulence and radiation (see WP TR5). A 3D interface will have to be constructed to permit such developments.

III. Treatment of orography:

A terrain-following vertical coordinate system such as used in the IFS/AAAH models is based on a (spectrally) smoothed surface elevation. This filtering of orography typically removes horizontal scales of ~3-4 grid lengths; thus, orographic effects smaller than ~6-8 grid lengths – such as buoyancy waves, flow blocking and sheltering due to sub-grid scale obstacles, drainage flow and cold pools, shadow effects on radiation, triggering of convection by forced ascent over unresolved slopes etc – are typically unresolved and require parametrization. However, the data assimilation and many physical

parametrization schemes assume that the resolved orography represents the grid-scale features of the orography, or they treat the difference between real and smoothed elevation in some simplified way. This may lead to inconsistencies, e.g. when the observation station height differs from the model elevation or when the smoothed orography near a mountainous coastline occurs below mean sea level.

It is planned to improve the treatment of orographic parametrizations and the consistency between resolved and parametrized orographic waves and turbulence. This requires a proper filtering of surface elevation, based on the highest-resolution digital elevation data available (e.g. SRTM, ASTER). For describing the smallest-scale effects on orographic momentum and sloping surface radiation, the Wood et al. (2001) parametrizations may be applied in Surfex, and compared with the corresponding schemes in Hirlam. Surfex has an option to take into account the difference between "surface" and "atmospheric" orography and enhancement of the sloping surface area; this option requires further study.

A smooth transition from the parametrization of mesoscale orographic effects (mountain waves and flow blocking) to resolving them, requires consistency between atmospheric and surface-based parametrizations. The Arome turbulence scheme should be able to handle the dissipation of resolved mountain waves into turbulence. The behaviour of resolved and parametrized orographic circulations of thermal origin in the near-surface layer (katabatic winds, valley cooling etc.) should be studied, learning from experiences elsewhere (MetOffice, ICAM mountain meteorology community).

IV.   The stable boundary layer (SBL):

Weather prediction under stable boundary layer conditions is of great practical importance especially at northern latitudes, where cold temperatures and fog are frequent. A comprehensive approach is needed, since problems with SBL representation have been shown to be common to all NWP models independent of their horizontal resolution and dynamics. A concerted effort will be made on improving the description of SBL effects by an interdisciplinary team, with connections to other consortia and university researchers. In this study, attention should be paid e.g. to the following aspects:

●Testing of new theoretical concepts for turbulence parametrizations (Zilitinkevich et al. 2008).
●Study the potential of QNSE formulations (Sukoriansky et al 2005) to handle wave-turbulence interactions and the conversion from vertical to horizontal diffusion with increasing stability.
●Study the influence of model vertical resolution, lowest model level height and the canopy scheme on the decoupling between upper air and near-surface layer in the model.
●Study cloud microphysics and radiation interactions. Investigate existing radiation schemes as to the treatment of long-wave radiation near the surface, also when using input about clouds and aerosol from the microphysics scheme. Study cooling at the surface and at the top of fog/stratus.
●Influence of snow, ice and vegetation. Impact of the multiple energy balance scheme.
●Study the relative role and interaction of parametrizations and data assimilation for the SBL.
●Carry out systematic tests of Kullman's diagnostics of T2m in local applications of Alaro-0 and study T2m bias behaviour..

V.   Towards sub-km scale resolution:

When continuing the road towards higher spatial resolutions, both the model physics and dynamics schemes themselves, and their interaction, will need to be reconsidered. The question has been raised if a spectral formulation of the model dynamics is still appropriate when model mesh sizes approach scales of several 100m. In order to check whether there are limitations in the spectral technique at such resolutions, for example at or near steep slopes, the model will be run in LES mode at resolutions down to tens of meters over areas where orographic data of sufficient resolution are available.

When increasing resolution to sub-km scales, deep convection becomes fully resolved and the

new scientific challenge becomes to devise schemes which ensure a realistic transition from parametrized to partially resolved shallow convection and, at higher resolutions still, turbulence. Large eddy simulations or cloud-resolving models are required to study the interactions between resolved and parametrized processes related to convection, turbulence, waves, radiation and microphysics.

At sub-km resolutions, a 3-dimensional approach is presumably required for several parametrizations. The physics-dynamics interface may need to be adapted to permit this. For turbulence, a quasi-3D approach is currently being tested using semi-Lagrangian horizontal diffusion. The relation between the horizontal diffusion applied by the model dynamics (SLHD or conventional horizontal diffusion) and the parametrized vertical diffusion should be understood better for different flow conditions.

At sub-km resolutions, shadowing effects of clouds on radiation become relevant. Studies elsewhere have shown that a tilted column approach is a simple but still accurate approximation of a (far more costly) 3-D radiation parametrization, and that the cloud shadows which can be represented with it may have significant impact on convective evolution. DMI staff have experimented with tilted column modelling of radiation in HIRLAM, and this can be extended to Harmonie when needed.

A correct handling of surface heterogeneity in sub-km resolution models will depend critically on the availability of higher resolution orographic and physiographic data than those which are used at present. Several newer, presumably more accurate, sources of orographic and physiographic data will be tested for this purpose. An issue to be studied in this respect is whether the tiling approach presently used to describe surface-atmosphere interactions is still appropriate at these scales.

VI.   Numerical efficiency and computational performance

In the coming years, computational resources in the member institutes will be strained by the introduction of convection-permitting operational models and LAM EPS systems. The computational performance of these systems depends on the intrinsic numerical efficiency of the algorithms and on coding aspects depending on computer architecture, in particular the need for communication between processors. Care will be taken to optimize algorithmic and computational efficiency and scalability, to permit optimal use of the model on current and future massively parallel computer systems ($O(10^5)$ cores). Comprehensive profiling is needed at the introduction of each new cycle, to establish which parts of the code are the most limiting in these terms.

The efficiency of the present IFS dynamics is based on the usability of long time steps in the semi-implicit semi-Lagrangian scheme. In the non-hydrostatic dynamics this efficiency is decreased by the need to use, in some circumstances, a predictor-corrector scheme for stability reasons. It is aimed to make the code more stable, thus allowing to dispense with the need for a predictor-corrector scheme, and enhance efficiency. The planned change in vertical coordinate from one based on hydrostatic pressure to one based on geometrical height goes in this direction. Another way to improve numerical efficiency is to avoid unnecessary calculations. Recently the possibility has been introduced of eliminating such calculations in the extension zone, together with the substitution of bi-dimensional periodization by one-dimensional ones which do not involve any inter-processor communication.

In terms of parallelization, several existing and potential bottlenecks can be identified. For the most urgent of them, the parallelization of Surfex, good progress has been made already. The best way to improve parallelization on the longer term is to restrict as much as possible the need for communications among processors. A major bottleneck for scalability, in our as well as most other models, is the need for I/O to read initial and boundary data and to write forecast fields at required intervals. This can be done more efficiently by using an I/O server or by dedicating specific nodes to

43

I/O.The LAM model code hosts a variety of file formats, produced by different parts of the system. A natural step to achieve a more scalable system is to minimize intermediate file format transformations, and limit I/O to a few standard formats. The current use of intermediate FA and LFI fields is less efficient than the I/O handling done in the IFS, which uses a Fields DataBase (FDB) and GRIB as internal field format. For observations the situation is similar, and it has been proposed to move from BUFR observations immediately to the ODB database, skipping any intermediate format. This will be tackled within the COPE project.

From the scalability point of view, the 4D-Var code is one of the potentially most troublesome issues. The main problem, as shown in ECMWF studies, is the interpolation from high to low resolutions in incremental 4D-Var; this could be improved by allowing outer and inner loops within the same execution of the code, avoiding the writing of intermediate files. Another option would be the use of weak constraint 4D-Var with sub-windows running in parallel. Ultimately, if these solutions would prove to be insufficient, the decision might be taken to abandon the 4D-Var concept altogether, in favour of e.g. an ensemble Kalman filter approach.

A recent investigation into scalability limitations of the present code has shown that the factors affecting model scalability are quite complex. Aspects to consider are the frequency and amount of exchanged data, the potential of load imbalances, and the possibility of shared memory parallelism. Also the bandwidth of interconnects and CPU-memory access, compilers, system libraries, and additional software can play a significant role. To improve scalability, a careful step-by-step development strategy is warranted. Studies of numerical efficiency and scalability at large processor numbers and high resolutions should be continued. Expertise in this area is thin, and should be strengthened with high priority.

The evolution of HPC architectures is highly unpredictable at present. Decisions on fundamental code algorithmic changes (e.g. explicit or implicit dynamics) certainly cannot be related only to assumptions on future architectures. The best strategy seems to keep a close eye on the evolution of the computer market, and to benchmark the model 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, …).

One of the latest developments in the computer market is the use of GPGPU (General Purpose computing on Graphical Processing Units), which are much faster than normal CPU's but less flexible in terms of I/O requirements. Although the use of GPGPU's is in principle unlikely to bring greater scalability (as the communications between processors are not affected by use of GPGPU's), they can provide the model with a possible speedup, at the cost of some recoding. Thus, it is considered useful to test their potential, and this is being done at ICHEC (Ireland). A recent, very interesting alternative to GPGPU's, is the new Intel Mic architecture, which can be handled by standard compilers without recoding. Experiences with this architecture will be gained in Ireland.

3.8.2   Summary of planned activities and priorities

Highest priority in the transversal activities described above will be given to the concerted efforts to improve model behaviour under stable boundary layer conditions (WP TR4), and its numerical and computational performance (TR6).

The following subjects will be tackled at intermediate priority:
- Study forecast model aspects in relation to assimilation and ensemble forecasting (WP TR1)
- Study of physics-dynamics interactions at different scales, and the changes required in the physics-dynamics interface to permit introduction of 3D physics parametrizations (WP TR2).
- Study of an improved and more consistent treatment of orographic effects (WP TR3).

In parallel to the efforts to enhance performance at present resolutions, but with less urgency and a longer time perspective, studies will be done to prepare the model for use at sub-km resolutions (WP TR5):

- studies of model performance at sub-km resolutions in comparison to LES or CRM.
- testing (quasi-)3D parametrizations for turbulence and radiation
- the implementation of physiographic databases of sufficient spatial resolution

All of these efforts will be done in close cooperation between Aladin and Hirlam.

3.8.3 Work packages in 2013

TR1: Forecast model and model error in relation to data assimilation and ensemble forecasting

- Study background field uncertainty for mesoscale data assimilation:
  - predictability limits of mesoscale phenomena: study validity of tangent-linear regime; investigate time scales of error propagation from one model state component to others; investigate conditioning of moist variables via hydrometeor observations; investigate ways to sample/simulate model error in the assimilation.
  - sampling error-of-the-day uncertainty: perform a theoretical study in idealized environment on the "best" ensemble generation strategy from both probabilistic forecasting and data assimilation perspectives;
  - TL/AD modelling of hydrometeors: investigate advantages and disadvantages of a reduced model state to be applied in the TL/AD modelling for assimilation of hydrometeor observations;
- Develop initialization scheme which allows digital filtering for gridpoint fields; assess impact of (scale-selective) DFI in RUC experiments; consider possible improvements;
- Study the impact of the nesting strategy on hydrometeors initialisation and spinup properties for balances between thermodynamical and moist variables;
- Study different approaches (stochastic physics, perturbation of physical parameters, energy backscattering) to account for the impact of model deficiencies and uncertainty in parameter estimations on forecast uncertainty; in particular address moist processes and investigate methods to simulate forecast uncertainty related to convection; experiment with different ways of introducing upper air and surface perturbations in the LAM EPS systems
- Continue experimentation with cellular automata in physics (cloud) parametrizations

  HIRLAM staff: Barkmeijer(2pm), Yang(0.5pm), Gustafsson(1pm), Nielsen(1pm), Bengtsson(2pm), Iversen(1pm), Frogner(1pm), Rontu(1pm), Johansson(2pm), Garcia-Moya(4pm), Ivanov*(1pm)
  ALADIN staff:
  Priority: high
  Responsible HIRLAM project leader/ALADIN CSSI member: Onvlee / ?

TR2: Physics-dynamics interaction

- complete the new CPTEND_FLEX interface; take part in the re-arrangement of options and setup of GFL and physics-dynamics interface in IFS/AAAAH
- Assess impact of higher-order accurate physics-dynamics coupling. Subject to the continued availability of manpower, the implementation of the second-order accurate interface between physics and dynamics will be completed and tested. This involves deciding which processes can be treated with second order of accuracy and which should be kept with only first order, and devising a method to ensure that positive-definite quantities remain positive

- Assess impact of physics and dynamics calculations on different grids, and the impact of the calling order of different processes
- Study projection of heat source/sink on pressure as well as temperature
- Make the option of allowing horizontal homogenization of physics available in the code
- Couple the physical tendency of vertical velocity (at least from turbulence) to the prognostic equation for this quantity (the so-called d variable)

HIRLAM staff: Hagel (6pm)
ALADIN staff: Degrauwe, Bouyssel (CPTEND_FLEX), other Arpège physics experts for support if required for the "3MT in Arpège" action.
Priority: high
Responsible HIRLAM project leader/ALADIN CSSI member: Hortal / Benard

TR3: Treatment of orography

- Study availability of high-resolution (O(100 m)) global digital elevation data, which could used as basis for the derivation of surface elevation for the terrain-following vertical coordinate and variables for orography-related parametrizations (see WP SU7)
- Study and apply optimal method to filter these source data, taking care about consistency between model dynamics, data assimilation and physical parametrisations at the surface and atmosphere. Determine how to optimally include these filtering routines in the model.
- Simplify where possible the combination of Surfex/PGD and atmospheric climate generation, as presently applied for orography preparation.
- Evaluate resulting orography in high-resolution experiments and operational environments.

HIRLAM staff: Rontu (mm), Guerrero (mm), Atlaskin (mm), O'Brien*
ALADIN staff: Seity, Voitus, Mary
Priority: medium to low
Responsible HIRLAM project leader/ALADIN CSSI member: Rontu, Hortal / Vana

TR4: The stable boundary layer (SBL)

- Stable boundary layer study: identify deficiencies and ways to improve the treatment of the stable boundary layer. In the planning of this study, the recommendations of the SBL workshop of December 2012 will be followed. Experimentation will focus on the GABLS-4 boundary layer study over Antarctica.
- Participation in GABLS-4 study: comparison of single column and 3D models with observations over very stable boundary layer conditions on Antarctica.
- Assess the use of potential turbulent energy within CBR
- Tuning and testing of Kullman's T2m diagnostic computation in Alaro-0.

HIRLAM staff: Ivarsson, Woetmann Nielsen, Kangas, Kadantsev, Morales, de Rooij, de Bruijn, Calvo, Finkele, Rontu, Vihma*, Kilpelainen*
ALADIN staff: Bazile
Priority: high
Responsible HIRLAM project leader/ALADIN CSSI member: Rontu / Vana

TR5: Towards sub-km resolution

- 1.3km resolution version of Arome: assess choice of vertical discretization (number of levels, distribution of hybrid levels); assess impact and choices for horizontal diffusion; perform evaluation on test cases of convection.
- Compare Arome/Harmonie at various resolutions against LES (WP PH3, Grey zone project).

- High-resolution experiments with the non-hydrostatic core, to test if the current dynamics is still suitable at these resolutions. On the longer term, also the physics will be included.
- Continue and coordinate experiments to assess model performance at sub-km resolutions, e.g. on Gran Canaria and Ireland. Test Harmonie/Arome over the Sochi domain at various resolutions and with usage of high-resolution surface elevation data (SRTM).
- Consider best way to introduce stochasticity at very high resolutions (related to PH2,TR1).

HIRLAM staff: de Rooy (1pm), Siebesma*, Guerrero (mm), Atlaskin (mm), O'Brien*

ALADIN staff: Arome 1.3km: Bouyssel, Seity, Yessad (expertise on hybrid level distribution); other high-resolution experimentation: Auger, Hagelin (post-doc at MF), Bastak

Priority: medium

Responsible HIRLAM project leader / ALADIN CSSI member:

TR6: Numerical efficiency and computational performance

- Profiling and optimization: perform regular scalability measurements, preferably on agreed common datasets; Study scalability of 3DVar with open-mp and mixed parallellization mpi/open-mp; optimize Bufrdc library in the scope of intensive use of radar data
- Extend the I/O server prototype to post-processing files; assess the prototype and spread knowledge on its use; Investigate changes needed to put an I/O server into operations;
- Consider parallel and sequential splitting
- Continue optimization of Surfex (I/O, parallelization) and of the surface analysis (Canari and related tasks)
- Move from LFI to FA surface file format for Surfex applications in NWP; isolate constant surface fields in a single file and keep only prognostic fields in surface FA historical files.
- Study implicit treatment of the surface in the surface-atmosphere interface (link with SU1)
- Studies on the possible removal of the ICI scheme (DY1.1) and unnecessary computations from the extension zone (in combination with Boyd's bi-periodization; DY3)
- Further research on non-linear instabilities. - link with ICI and VFE developments (DY1.1)
- Invert vertical loops in EDKF and ICE3 for Arome (from meso-NH to Aladin-type loop)
- Continue the work on the new configurations (e)e927 (partly related to OOPS actions)
- Update RAPS benchmark with new cycles and extend it to 3DVar configurations
- Support external studies on new computer architectures (e.g. GPGPU's) and on innovative programming languages related to these new architectures

HIRLAM staff: staff at ICHEC*, Leiden, Delft and Vilnius Universities*; Hortal

ALADIN staff: El-Khatib, Marguinaud (optimization and scalability), Benard, Dalkilic (optimization in e927), Seity, Bouteloup, Faure

Priority: high

Responsible HIRLAM PL/ALADIN CSSI member: Hortal, Andrae / Fischer, Tudor

4.   Activities on operational cooperation and applications

4.1   Considerations

4.1.1   HIRLAM operational cooperation activities

Operational collaboration is a new task for the Hirlam programme. Several lines of work will be developed to support this. The first, most obvious, area of consortium-wide operational collaboration will be the production of GLAMEPS ensemble forecasts. Additional possibilities to be explored are:

- activities involving the configuration of a Harmonie RCR at multiple services and quality

assurance, maintenance and data sharing
● joint monitoring, troubleshooting, and pre-release testing and tuning of operational suites;
● joint effort on observation data handling, exchange and pre-processing (especially for new high spatial and temporal resolution remote sensing data);
● collaboration on computational (hardware-dependent) aspects, profiling and benchmarking;
● sharing of experiences on the requirements of, feedback from and interaction with users.

Although in many cases the actions and pace for such collaboration will subject to decisions outside the Hirlam-B framework, the programme is expected to play a key role in the exploration of what is feasible and in enabling these processes in a technical manner.

The coming years will see a continued trend in European NMS's towards reducing operational costs by sharing work and services. With the expected reduction in domain of operational LAM and LAM EPS systems and an increasing model focus on national territories, probably the most effective way for member services to benefit from operational NWP collaboration is to put efforts on greater NWP system harmonization. Harmonizing operational NWP environments is a prerequisite for shared production and backup facilities, downstream applications, and eventually, shared services. Such a harmonization effort is best achieved through a high-quality Reference system which is used by the whole community. Implementation of RCR at multiple centers, sometimes in rotation, will be pursued.

Not all areas for potential operational collaboration can be tackled at once, and member services need to be involved in assigning adequate priority and resources during the course of the programme. A stepwise approach will be adopted. Initially, the main focus is on the operation of GLAMEPS, implementation of the Harmonie RCR, intensification of joint operational monitoring, and joint efforts and mutual support in local operational implementations. In the field of observation pre-processing, a start has been made with common work on the ingest and quality control of radar data. Other activities will be tackled at a later stage.

To facilitate all this, communication facilities like discussion fora and mailing lists have been created. An on-duty team with user support and monitoring duties has been set up on a rotation basis, involving staff with different backgrounds to ensure a system-wide expertise and support. Specifically, the team has the following tasks: 1) function as a helpdesk/discussion forum on system and technical issues; 2) monitoring of operational GLAMEPS production; and 3) evaluation of the Reference and operational Hirlam, Harmonie and GLAMEPS suites via the hirlam.org data portal.

GLAMEPS operation, maintenance, monitoring and support:
In November 2011 the experimental system GLAMEPS_v0, which was running daily at ECMWF since early 2010, was replaced by the pre-operational GLAMEPS_v1 system which uses 06 and 18h UTC as base hours for production. Besides adjustments in domain size and resolution, it contains several upgrades in the LAM EPS components. The script system has been adapted to the requirements for time-critical facility option 2 (TCF-2). TCF-2 status implies that ECMWF staff takes care of daily execution of GLAMEPS runs, while the GLAMEPS team is responsible for troubleshooting in case of production problems. Daily monitoring is done by the on-duty team, ensuring that production anomalies are reported in a timely manner.

Maintaining operational production with distributed staff is a new challenge. Experiences gained here may be valuable for other forms of operational collaboration later. Hirlam considers to organize trainings to help operational staff to get acquainted with the GLAMEPS system. When forecasters have had opportunity to become familiar with GLAMEPS output, meteorologically oriented training activities can be organized to teach them how to interpret and apply GLAMEPS information, and to collect user feedback and requirements. Dedicated mailing lists and web fora will be launched

for discussions and information exchange on GLAMEPS product generation and interpretation, monitoring and reporting.

Observation pre-processing

The success of LAM forecasts relies critically on the model's ability to make good use of observations. Unfortunately, for individual NMS's optimal utilisation of observations in NWP is a very challenging issue. Considerable expertise and effort is needed for the acquisition, pre-processing and quality control of observation streams, and these needs are only likely to increase as the number of observation types continues to grow. Thus, a more effective cooperation in observation handling for NWP is very much an issue of common interest.

A large diversity exists among NMS's in the observations used, data handling procedures and formats. Collaboration in observation handling can take various forms, such as sharing or harmonization of pre-processing software, sharing of pre-processed and quality-controlled data, and centralized pre-processing. In data acquisition, a possible form of cooperation could be for individual institutes to take responsibility for the pre-processing of a certain data stream (AMSU, IASI, Mode-S etc). This would allow more effective use of the available but highly dispersed expertise on specific data types.

Efforts to promote collaboration in this area can best start on observation types for which there is a strong perceived common need. For this reason, the initial focus is on radar data needed for assimilation, involving sharing pre-processing software and expertise, pushing international data exchange, and coordinated experimentation on the use and quality control of radar data. A start will also be made to organize real-time sharing of local SST, ice and snow data. Other areas for coordinated could be the handling of new BUFR-format GTS data, or reception and pre-processing of satellite data. In general, harmonization of observation exchange is something to promote in Eumetnet context.

Observation monitoring at the hirlam.org portal is being extended to Harmonie, and will include bias correction and updated black/whitelist information. More data types are being added. In the past years, a start was made with systematic testing of observation handling in individual services. These exercises will be continued. A discussion forum on observation handling has been set up on hirlam.org, to raise the awareness of observation processing aspects, and to encourage collaboration.

Collaboration on operational implementation and benchmarking

One important activity in Hirlam operational collaboration will be to strengthen common efforts on preparing implementations of Hirlam and Harmonie models. Given the fact that Harmonie is a new element in the operational chains of the Hirlam services, first emphasis will be given to the provision of support and sharing experiences for creating local operational Harmonie suites. The aim is to achieve a high degree of harmonization between the services in terms of model configurations and versions, and quicker adaptations of local suites to the latest Reference release. This harmonization in turns will facilitate many other aspects of operational cooperation. In the past, Hirlam operational systems showed a significant, historically grown diversity in model versions, resolution, nesting strategy, assimilation and physics options, script system etc. With the introduction of Harmonie, in which as yet little diversity exists, the Hirlam community has a golden opportunity to achieve a far-reaching harmonization of operational suites. Members that can meet certain minimum requirements are encouraged to run an RCR based on the latest Reference release. With the adoption of a new policy about not limiting the RCR role to a single member service, the implementation of the Reference system at member services should become easier.

The official launch of a new Reference version is always preceded by an extensive evaluation process

49

in both technical and meteorological aspects. Hirlam will continue to seek a more active contribution by all member services to pre-release testing for the full range of local domains and configurations. Through this wider staff involvement, it is hoped to improve on meteorological and technical quality assurance. The introduction of more local operational configurations and platforms in Reference system testing will both enhance its general portability and robustness, and reduce future needs for local adaptations.

In operational implementations, adaptations to local infrastructures are inevitable, e.g. related to optimal use of computational hardware, local data streams, formats and post-processing, and additional procedures. Where appropriate, local features can be included in the main repository or in national branches, with a view to ease maintenance. For the post-processing of Harmonie in particular, shared work can be envisaged on extending the range of output quantities in the internal post-processing of the model. Such developments can probably be facilitated by a discussion forum.

SMHI and met.no are moving toward a shared NWP production. It is in the interest of Hirlam to follow this process closely. The programme may learn from their experiences, and possibly contribute to the system harmonisation which they may require.

Another area where there is a strong perceived common interest is benchmarking in connection with HPC procurements. The feasibility will be explored of maintaining a common benchmark code (the RAPS system), to be updated ideally with every major release. Other options are the establishment of a dedicated discussion forum and a shared database for benchmarking purposes, containing e.g. source code, utilities, descriptions of software characteristics, and a test dataset.

Assessment of user satisfaction and requirements

The aim is to achieve a more direct feedback of forecaster and end user experiences into the research programme, and through that achieve a quicker response to user needs. The form to realize this goal requires further exploration. Possibilities with which experience is being gained are:
- discussions with users via an online forum
- more frequent member institute visit by subgroups of the management group, involving explicit meetings with user representatives, similar to the practices of ECMWF
- Direct exchange between the management group and the HAC on the issue of user requirements and user feedback through an annual back-to-back meeting.

HIRLAM maintenance and support

Most research efforts on the Hirlam system have come to an end (the exceptions being the work on adaptations of Hirlam required for GLAMEPS, and on gaining experience with atmospheric chemistry in Enviro-Hirlam context). In 2012, the last major Hirlam version, v7.4, has been officially released. In view of the continued operational use of Hirlam at member services in the coming years, the model will continue to be monitored and upgraded where needed, but with a scope limited to technical adaptations (e.g. changes in data formats or observation streams) and bug fixing/ tuning. Research staff will be made available for dealing with meteorological deficiencies, at an adequate but limited level of resource commitment. System support is also open to implement new or modified components which are developed in synergy (e.g., in the chemistry branch, and developments within GLAMEPS context).

4.1.2 Applications

Although the focus of research is on the use of the model for NWP purposes, some efforts will be devoted to enable its use for several other important applications, in the form of dedicated system branches or tools. Recently, the first steps have been taken to enable the use of Harmonie for climate modelling, in the form of the creation of a Harmonie climate branch. For Hirlam a coupled atmosphere

- chemistry system has been made available in the form of a dedicated chemistry branch, Enviro-Hirlam. It is being considered to eventually create a similar coupled atmosphere-chemistry setup for Harmonie, using the experiences gained with Enviro-Hirlam; this is not seen as a high- priority issue, however. In order to keep a close contact between the NWP, atmospheric chemistry and climate communities, it is preferable to keep future climate and chemistry versions of Harmonie close to the NWP developments. Both Hirlam and Aladin are interested to make it easier for the academic community to use the model as research platform. Non-NWP users are encouraged to work with either "limited" versions of the Harmonie system (with selected components of the full system such as the single column model or the forecast model), or with special branches such as the climate branch. Among the sub-components that have been tested by non-NWP users are the MUSC 1D-model, the off-line Surfex system, and the RAPS benchmark. Of interest are also some new components that are in the way to be integrated into Harmonie, such as the OOPS toy model and the surface spatialization (MESCAN). An integrated offline documentation and possibly incidental access to training for university people may still be needed. For all of these system/components, emphasis shall be put to making them easy to set up, configure, adapt and run for non-NWP application. Attention will be paid to following the development of relevant technical tools in the ECMWF OpenIFS project.

4.2   Summary of planned activities and priorities

For the Hirlam operational cooperation activities (WP AP1), the emphasis initially will be largely on GLAMEPS, observation preprocessing and common testing and benchmarking.

Limited efforts will be spent on making the LAM models better suitable and more easily available as tool for non-NWP applications:

- Continued work on a more user-friendly model version for use in the academia (WP AP2).
- Further development of a Harmonie climate branch (WP AP3)
- Maintenance of the Enviro-Hirlam chemistry branch (WP AP1.5); eventually a similar coupled system may be set up based on Harmonie, but this is not a priority.

Many of these activities will be carried out in cooperation with researchers from the academic, regional climate modelling and atmospheric chemistry communities.

4.3   Work packages for 2013

AP1.1: GLAMEPS maintenance, monitoring and support

- maintenance and upgrade of operational suites as TCF-2 at ECMWF platform: work on source, scripts, boundary and observation data related to cycling and ensemble runs, product generation (probability charts, EPSgrams, upscaling plots etc.), backup measures and trouble-shooting.
- Backup and upgrade of operational suites. For 2013, this may involve adjustments on cycling structure, new or adjusted ensemble members, new parameters in the post-processing, and the introduction of additional observation data sources.
- Quality assurance in form of regular monitoring of products (partly via onduty team), update of verification results, monitoring and inter-comparison of control suites vs. deterministic runs
- Ensure smooth product distribution and member service access to GLAMEPS products.
- Maintenance of data server for web graphics and other real-time products.
- Maintain connection and feedback between member services and developers.
  HIRLAM staff: Sattler (6 pm?), Yang (2 pm?), Frogner (1 pm?), Feddersen (0.5 pm?), Vignes (0.5 pm?), Tijm (0.5 pm?), Bojarova (0.5 pm?), Eerola (0.5 pm?), member service contacts on GLAMEPS products*, on-duty task team (~1pm)
  ALADIN staff: Belgium (potentially extended later to the ALADIN consortium)

51

Priority: high
Responsible HIRLAM project leader/ALADIN CSSI member: Deckmyn

AP1.2: Operational observation pre-processing
- Activities related to radar data handling and data exchange (see WP DA4)
- Common actions with the aim to obtain external data (EUMETSAT, Euro-control, ECMWF), on satellite observation, Mode-S, GNSS and GPS-RO
- Exchange of local data for operational use; arrange maintenance, monitoring and troubleshooting for these data streams
- Explore potential future use of ECMWF ODB to supplement member service data.
- Consultation with member services on related observation matters
- COPE related activities as in DA5.2, SY2

    HIRLAM staff: Yang*, Onvlee*, de Haan*, Dahlbom*, Amstrup*, Whelan*, member service contact points on data issue
    Priority: medium to low during 2012
    Responsible HIRLAM project leader: Yang

AP1.3: Cooperation on operational implementation, evaluation and monitoring
- Consultation and exchange of experiences on operational Harmonie with member services with emphasis on RCR, configuration aspects, local adaptations, use of observations, monitoring and evaluation
- Exchange of information on benchmarking and related profiling activities
- Collection of regular feedback and suggestions from member services

    HIRLAM staff: member contacts on operational activities, Andrae*, Tijm(post-processing, diagnosis, 1pm), Yang (1pm), Kazlauskas
    Priority: medium
    Responsible HIRLAM project leader:

AP1.4: Assessment of user satisfaction and requirements
- more frequent explicit meetings with user representatives, such as member state visits by MG or by programme representatives (similar to the practices of ECMWF); participation in relevant user meetings (such as the biennial NordMet verification workshop)
- explore use of Hirlam forum for forecasters and other users for increased transparency between research programme and users
- Direct exchange between the management group and the HAC on the issue of user requirements
    HIRLAM staff: MG
    Priority: medium
    Responsible HIRLAM project leader: Yang

AP2: Use in the academia
- user support for academia use with llimited version/selected components of Harmonie system (such as MUSC, off-line Surfex, forecast benchmark). Enhance documentation accordingly.
- Get feedback from academia community and formulate follow up actions
    HIRLAM staff: Andrae*, De Rooy*, Rontu*
    Priority: medium
    Responsible HIRLAM project leader: Yang?

AP3: Climate
- coupling of ALADIN with other GCMs; ocean-atmosphere coupling
- spectral coupling and nudging techniques
- Interaction with the regional climate modelling community on high resolution climate modelling
- exchange experience in computing scenario's
  ALADIN staff:
  Priority: medium to low
  Responsible HIRLAM project leader/ALADIN CSSI member: Rontu / Farda / Hamdi

5. Reference System and release plan

From experiences of the past years, a release frequency of approximately one new official Harmonie release per year (per IFS/Arpege cycle) is to be expected. An indication of the timeline of scientific developments entering the Reference is given in Annex 2.

Greater attention will be paid to reducing the gap between the Reference system and operational implementations at member services. A more direct and wider staff involvement will be sought in coordinated pre-release porting, testing and tuning. This broader pre-release checking should make official releases more robust and portable, and should minimise the need for local adaptations, thus enabling the services to follow more closely the pace of official releases. The aim is to have operational updates within 6 months from the official release by the end of 2015.

List of references:

- Berre, L., et al., 2007: "A variational ensemble and the spatial filtering of the covariances", Proc ECMWF workshop on flow-dependent aspects of data assimilation, 11-13 June 2007, 151-168.
- Bojarova et al. , 2011: "The ETKF rescaling scheme in HIRLAM", Tellus, DOI:10.1111/j.1600-0870.2011.00513.x
- Caumont et al., 2009:" 1d+3dvar assimilation of radar reflectivity data: A proof of concept.". Tellus, DOI :10.1111/j.1600-0870.2009.00 430.x.
- Fabry, F., and Sun, J., 2010: "For How Long Should What Data Be Assimilated for the Mesoscale Forecasting of Convection and Why? Part I: On the Propagation of Initial Condition Errors and Their Implications for Data Assimilation." Mon. Wea. Rev., 138, 242-255.
- Frogner and Iversen, 2011: "EUROTEPS: a targeted version of ECMWF EPS for the European area", Tellus, DOI:10.1111/j.1600-0870.2010.00504.x
- Montmerle, T., and Faccani, C., 2009: "Mesoscale assimilation of radial velocities from Doppler radars in a preoperational framework", Mon. Wea. Rev., 137, 1939-1953.
- Montmerle, T., and Berre, L., 2010: "Diagnosis and formulation of heterogeneous background-error covariances at the mesoscale". Q. J. R. Meteorol. Soc. , 136 (651), 1408-1420.
- Seity, Y., et al., 2010: "The AROME-France convective scale operational model", Mon. Wea. Rev., doi: 10.1175/2010MWR3425.1.
- Senkova, A.V., Rontu, L., Savijärvi, H., 2007, "Parametrization of orographic effects on surface radiation in HIRLAM", Tellus 59A, 279-291
- Sukoriansky, S., B. Galperin and V. Perov, 2006: "A quasi-normal scale elimination model of

turbulence and its application to stably stratified flows", Nonlinear Proc. In Geoph. 13, 9-22

- Yan et al., 2009: "Benefit of GPS zenith delay assimilation on high-resolution quantitative precipitation forecast of the COPS cases IOP9", Q. J. R. Meteorol. Soc., 135, 1788-1800.
- Zilitinkevich et al., 2008: "The effect of stratification on the aerodynamic roughness length and displacement height", Boundary Layer Meteorology 129, 179-190
- Termonia P., 2008: Scale-Selective Digital Filtering Initialization. Mon. Wea. Rev., 136, 5246-5255.

Annex 1: Work packages and resources for 2012:

Work Package	Description	Resources HIRLAM (mm)	Resources ALADIN (mm)
DA1	Development of 3D-VAR		
DA2	Assessment/sensitivity studies, RUC experimentation		
DA3	Development of flow-dependent methods		
DA4	Assimilation of radar data		
DA5	Other ground- and space-based upper air observations		
DA6	Observation impact and network design studies		
DY1	Development of the dynamical core		
DY2	Long-term dynamics evolution and testing alternatives		
DY3	Boundary conditions and nesting		
PH1	Convection and turbulence		
PH2	Cloud microphysics, radiation and aerosols		
PH3	International boundary layer, cloud and convection studies		
PH4	Integration and testing of ALARO-1		
SU1	Surface: general aspects		
SU2	Soil		
SU3	Snow and forest		
SU4	Sea ice		
SU5	Lakes		
SU6	Urban modelling		
SU7	Orographic effects on radiation and momentum		
E1	Development of a convection-permitting ensemble		
E2	Further development of ~10km scale LAM EPS		
E3	Statistical postprocessing and calibration		
E4	Product generation		
SY1	System maintenance and development		
SY2	Harmonie Reference, RCR, user support and documentation		
SY3	Contribution to Interoperability and long-term maintenance		
SY4	Developments related to OOPS		
QV1	Tools for quality assessment/verification mesoscale		
QV2	Tools for quality assessment/verification probabilistic		
QV3	Monitoring and quality assurance		
TR1	Forecast model aspects in assimilation, ensemble		

	forecasting		
TR2	Physics-dynamics interaction		
TR3	Treatment of orography		
TR4	The stable boundary layer		
TR5	Towards sub-km scale resolutions		
TR6	Numerical efficiency and computational performance		
AP1.1	GLAMEPS operation, maintenance, monitoring, support		
AP1.2	Observation preprocessing		
AP1.3	Cooperation operational implementation and benchmarking		
AP1.4	Assessment of user satisfaction and requirements		
AP1.5	HIRLAM maintenance and support		
AP2	Model version for use in academia		
AP3	Climate		
AP4	Nowcasting- INCA		

Annex 2: Time schedule of activities for main deliverables of the programme

Area	Year	Activities
Harmonie analysis and forecast system	2011	Analysis: Enable radar data ingest, start impact experiments and quality control. Perform RUC experiments. Improve snow analysis. Introduce large scale constraint. Introduce hybrid ensemble assimilation. Start testing hybrid approaches and 4D-Var against 3D-Var. Dynamics: finish VFE development, vertical coordinate change, 2d order physics interface, and elimination of extension zone. Develop Boyd's bi-periodization and semi-analytical time stepping. Test changes to improve mass conservation. Physics: Test EDMF modifications, cellular automata, RK microphysics, STRACO-type smooth transition from resolved to explicit convection. Start radiation intercomparison study and inclusion of direct aerosol effect. Continue development of MEB scheme and implement HIGHTSI snow/ice parametrization in Surfex. Studies of FLake in Harmonie. Implement new chemistry in Enviro-HIRLAM.
	2012	Analysis: Enhance 3D-Var: radar assimilation/quality control, tuning of obs and bg error statistics. Optimize ETKF and ensDA. Start observation impact studies including radar. Continue RUC studies. Start extending 4D-VAR (towards Arome/Surfex, Jk). Investigate seasonal dependence of structure functions. Start experimentation with field alignment and cloud initialization. Include and test EKF for soil with screen level parameters, start to develop EKF for snow and lakes. Preparations for OOPS and COPE. Dynamics: test new vertical coordinate and Davies relaxation in spectral space. Study stability for VFE discretization. Implement and test semi-analytical time stepping. Physics: Start stable boundary layer study. Introduce and test orographic radiation parametrization. Integrated treatment of snow/ice in data assimilation and Surfex. Implement MEB, HIGHTSI in Surfex. Start experimentation with sub-km modelling and high-resolution orographic/physiographic datasets.
	2013	Analysis: Continue quality control and impact studies with esp radar, GNSS and ModeS. Introduce and test cloudy radiances. 3D-Var settings for rapid update cycling ready. Study 3D-VAR weather-regime dependent structure functions, experiment with heterogeneous B-matrix. Optimization of hybrid 3DVAR for Harmonie, and comparisons with 3D- and 4D-Var. Extend 4D-VAR towards use with Arome/Surfex, Jlbc and ECMWF linearized physics. Continue with field alignment and cloud initialization experiments. Make design for 4DEnsVar system in OOPS context; participate in COPE. Further develop EKF for soil, snow and lake satellite soil moisture, snow and lake data; structure functions for lakes). Dynamics: Study improved conservation of atmospheric components. Implement elimination of needless extension zone calculations/Boyd bi-periodization operationally. Test second order physics-dynamics interface. Physics: Continue with SBL study and radiation intercomparison. GABLS-4 study. Test upgrades to microphysics. Feasibility study on handling aerosol-cloud interactions. Continue sub-km modelling and work on high-resolution datasets.

	2014	Hybrid ensemble assimilation (in ensemble and data assimilation mode) at 2km scales ready. Optimize 4D-VAR. Start work on cloud assimilation. Introduce more satellite observations in surface assimilation. Introduce suggested modifications to physics-dynamics interactions - framework for building 3D parametrizations in a km-scale model.
	2015	4D-Var optimization for 2km-scales finished and quality assessed. Start work on 4DEnsVar. Upper air data assimilation system and surface data assimilation system enhanced with respect to use of various suitable remote sensing data. OSE ready and evaluated.
Probabilistic forecasting	2011	Set up GLAMEPS-v1 in ECMWF environment, start pre-operational real-time runs. Prepare GLAMEPS-v2 (including ETKF, selected higher-resolution members and possibly CAPE SV). Make HarmonEPS research setup and prepare database for experimentation.
	2012	Pre-operational testing of GLAMEPS-v2. Start experimentation with HarmonEPS, initially in downscaling mode for differnet nesting scenario's. Consider GLAMEPS data policy. Incorporate user feedback in product generation/ dissemination. GLAMEPS training for forecasters. Preparations for FROST-14.
	2013	Finish testing of GLAMEPS-v2, prepare for operation. Continue HarmonEPS evaluation of nesting experiments, test with data assimilation and physics and surface perturbations. Prepare for real-time production. Preparations for FROST-14.
	2014	Start real-time production of HarmonEPS and evaluation. FROST-14.
	2015	Operational HarmonEPS. Planning for outphasing GLAMEPS
System and quality assessment, and Reference System releases	2011	Release of Harmonie Cy36h1.4 and Cy37h1. Include MUSC prototype into Reference. Feasibility study on BUFR2ODB. Harmonie training for researchers and operational staff. Finalize HIRLAM version 7.4. Complete documentation on-line. Update Enviro-HIRLAM aerosol and chemistry. Prepare and introduce GLAMEPS as TCF-2 application at ECMWF.
	2012	Include HarmonEPS in the reference. Extend Harmonie pre-release testing and verification to all suites, include spatial verification and analysis diagnostics tools. Extend Harmonie monitoring with observation diagnostics, severe weather scores.Release Cy37h1.2. Start organizing system and C++ training activities. Develop RCR concept for Harmonie.
	2013	Release cy38h1/cy39h1, including ECMWF OOPS modifications. Start work on COPE. Make Harmonie External User guide available. OOPS implementation for LAM IFS code. Invite members for Harmonie RCR (rotating).
	2014	Complete LAM part of COPE revision of observation pre-processing. Pre-operational running and evaluation of HarmonEPS.
	2015	Operational production of HarmonEPS systems. Plan outphasing of GLAMEPS
Operational cooperation	2011	Preparation and operationalization of GLAMEPS-v1. Continue cooperation on radar pre-processing and quality control. Set up monitoring/support team. Establish discussion fora on quality aspects and benchmarking. Troubleshooting with local implementations of HIRLAM version 7.3 and 7.4. Provide support in setup of operational Harmonie systems. Initiate observation data exchange on local SST, snow and ice data. Integration of Harmonie monitoring and intercomparison information in the Hirlam data portal.
	2012	Finalize GLAMEPS TCF-2 adaptations. Monitor and collect user feedback for GLAMEPS. Continue work on radar pre-processing and quality control. Investigate other options for cooperation on observation systems. Establish common benchmark setup. Provide support in setup of operational Harmonie systems.Continue observation pre-processing cooperation on radar exchange and quality control, start with extension to local SST, snow and ice data.
	2013	Work on GLAMEPS data provision to members. Continue work on radar quality control. Investigate options for exchange of Mode-S data, local in-situ observations, possible use of ECMWF ODB after realization of COPE. Intensify member visits incl user consultation.
	2014	Prepare HarmonEPS for operations. Continue user consultation activities
	2015	Continue user consultation activities