ALADIN-HIRLAM Rolling Plan 2011-2015 15/11/2013

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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 considered as alternatives capable of introducing greater flow-dependency within the variational data assimilation framework, such as the use of hybrid ensemble assimilation techniques. The assimilation strategy for the convection-permitting scale therefore is to focus on optimizing 3D-Var and enhancing variational techniques by including advantages of ensemble assimilation techniques, while keeping open the door to standard 4D-Var. The promising combination of ensemble and assimilation techniques brings with it a new important challenge, namely the consistent design of ensemble prediction and data assimilation systems.

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 (e.g. radar, Mode-S). Different ways to use large scale information from the host model in the analysis will be considered (focussing in 2014 on improving the performance of a large scale error constraint, and later on improving the treatment of the LBC constraint in the 4D-Var framework).

The next challenge is to proceed towards data assimilation algorithms with greater flow-dependency. 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 background error modelling, including dry and moist balances. Priority will be given to methods already available or with developments closely related to plans for ensemble forecasting: introduction of flow-dependent background error covariances by applying ensemble data assimilation (Berre et al., 2007) or hybrid ensemble variational techniques (Bojarova et al. 2011; Gustafsson et al 2013), and/or 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 handling of model errors is a relevant long-term area 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. Variational data assimilation methods are not well versed in handling such errors. For this reason, so-called image warping or field alignment techniques, in which displacement errors are first identified and corrected for, after which a "normal" variational analysis is performed, are of potentially great interest. Recent demonstrations of the capabilities of a hybrid field alignment-3D-Var setup, and of a "super-hybrid" technique, combining a hybrid 3D-Var with image warping, illustrate the strength of these methods.

The potential of 4D-Var at convection-permitting scales in terms of handling 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 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. Research will be done on the further improvement of the numerical performance and scalability of 4D-Var. In an externally funded study the performance and feasibility of Gaussian quadrature 4D-Var will be evaluated. This method, which uses an iterative technique to resolve higher-order non-linearities and thereby avoids multiple outer loops, has the potential to significantly reduce the computational costs of 4D-Var.

In view of the increased importance of non-linear processes on small scales, a 4DEnVar approach, which eliminates the need for a tangent linear and adjoint model, may be an attractive alternative to 4D-Var. Recently, the potential of an 4DEnVar technique has been demonstrated in the Hirlam model. The evolution of model increment is described through the local combinations of the non-linear evolved ensemble. Provided that it contains a rich enough ensemble of model states, 4DEnVAR is presumably able to handle complicated non-linear processes in a more realistic way than 4D-Var, while having lower computational costs and better scalability. An important area of research will be the localisation technique to extract local information from the ensemble of perturbations when the horizontal, vertical and time dimensions are taken into account.

For the long term, it is aimed to achieve a framework enabling the implementation of any of the presently targeted configurations of ensemble and variational methods (we call this framework "4DEnsVar"). The 3- and 4D-Var schemes, 3- and 4D-Var hybrid ensemble assimilation scheme, the 4DEnsVar scheme and variations of 3D-Var 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.

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, GNSS, 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 planned 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 and the meaningful scales for data assimilation in convection-permitting models are issues to be investigated. Relatively large domains are needed to avoid the impact from lateral boundary conditions starting to dominate too quickly after the start of the forecast. To allow more efficient use of observations, research is needed on the optimal scales for superobbing or thinning, taking into account the effective model resolution. It is not evident that all scales resolved by the high-resolution models can be constrained by observations due to the turbulent and chaotic character of the atmospheric flow. Constraining the errors on the large scales in LAM applications is another topic which requires attention. Further work on the overall tuning of the data assimilation system, including the optimal way to generate structure functions and tuning of observations usage (biases, representativeness errors, thinning strategy), will be done in 2014 and beyond.

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.

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 now also rapidly taking off. Considerable resources are being devoted to pre-processing, quality control and impact assessment of these data. Arranging real-time data exchange across national borders is an important issue. OPERA-4 plans to redistribute flagged radar volume data to the member NMS's by the end of 2014. Meanwhile, SMHI has established a demonstration infrastructure for providing radar volume data from Eumetnet members which have agreed to allow access to their raw radar data for NWP needs.

Other sources of spatially and temporally dense observations which will be introduced and assessed, are e.g. ground-based GNSS, SEVIRI, Mode-S, ADM/Aeolus and MTG-IRS. Experiences with Arome-France (Fischer, 2012) and Hirlam (De Haan, 2012) have shown the relevance of some 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 with dual-polarimetric capability.

Thirdly, better use should be made of data types already 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, 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. Meteo-France is investigating the use of IASI cloudy radiances with the CO2-slicing technique (where cloud top pressure estimates are derived from specific CO2-channels). More advanced assimilation methods might be required for the efficient use of surface-affected radiances over land. The possibility to use the assimilation system as a device to estimate the "best fit" emissivities for various surface conditions diagnosed from Ecoclimap will be tried in the assimilation of low-peaking IASI channels. The use of maps of surface emissivity will be further studied in both infrared and microwave spectra.

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 of clouds and hydrometeors as compared to humidity and dry dynamical variables (Fabry and Sun, 2009). Assimilation of cloud products will be tried within nowcasting/very-short range forecasting applications up to +6 hours. 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 physical properties products developed at DMI. The challenge how to integrate this cloud initialisation properly into the variational data assimilation framework will be addressed. 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.

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 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 2012-2015. 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. Adaptations of the OOPS design allowing to address specific LAM requirements will be done in dialogue with ECMWF experts. On the longer term, a common data assimilation framework is envisaged. However, on the short term parallel developments might be unavoidable.

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)
- 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 high-resolution observations will be added (WP DA5). Also, it will be studied to what extent better use can be made of existing observations. It will be investigated how best to assimilate cloud-, rain- and surface-affected radiances. 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, 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.

3.1.3 Work packages in 2014

DA1: Development of the 3D-Var assimilation system

- Climatic background error statistics: investigate the optimal way to generate structure functions for data assimilation on convection-permitting scales based on the large variety of structure functions for different realisations of climatological variability;
- Investigate the range of resolved processes, the optimal scales for super-obbing and the meaningful scales for analysis updates in convection-permitting systems;
- Investigate the influence of the observation network, forecast length and ensemble size when ensemble techniques are used to compute the background statistics (high priority but delayed);
- Investigate the implementation of a heterogeneous B-matrix in Harmonie (priority medium, "learning exercise");
- Continue theoretical study of the effect of bi-periodization of spectra (priority medium); adapt algorithms for the treatment of the extension zone following the implementation of the extension zone in the dynamics (priority high);
- Further development of the large-scale error constraint (priority high);
- Towards cloud data assimilation: initialize humidity fields from CPP products (priority high); investigate impact of cloud initialisation on radiation and surface analysis (priority high); design integration of cloud initialisation into the variational assimilation scheme (priority medium); develop the assimilation of cloud information for nowcasting/very short range forecasting applications; study weather regime dependent balances between hydrometeor model variables (cloud water, in first instance) and control state variables, possibly using ensemble techniques (priority medium);
- Adaptive background error statistics and online tuning.

HIRLAM staff: Dahlgren (1pm), Zhuang (2pm), Lindskog (2pm) , Landelius (2pm*), Ivanov, van der Veen (3pm), Gustafsson (1pm) , Randriamampianina (1pm*), Sanchez (1pm), Verkleij (1pm), Valkonen (1pm*), Schyberg (1pm), Geijo (1pm)

ALADIN staff: Berre, Desroziers, Montmerle, Brousseau, Faure, El Ouaraini, Monteiro, Kovačić (1 pm), Horvath (1 pm), Stanešić (1 pm), Derkova (3 pm), Nestiak(2pm), Bellus(2 pm), Gergely Boloni (2 pm), W. Khalfaoui (2pm)

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

DA2: Assessment and sensitivity studies and RUC experimentation

- Continue local installation and validation of real-time assimilation suites and sensitivity studies for different aspects of assimilation setup (frequency of assimilation update, method for generation of climatological forecast error covariances, large scale constraints, setup of digital filter initialisation; outline model deficiencies and monitor usage observation usage); (priority high);
- Assess available observation networks suitable for RUC setup (priority high); promote the exchange of data from local observation networks; adjust the assumptions of the assimilation scheme (VarBC, thinning distance, obs. error statistics) where needed (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 different observation types such as radar;

HIRLAM staff: Perttula (1pm), Thorsteinsson (1pm), Sanchez (2pm), Geijo (2pm), Schyberg (1pm), Zhuang (3pm), de Haan (1pm*), Ridal (2pm), Barkmeijer (1pm) , Verkleij (1pm) , Müller (2pm*), Randriamampianina (1pm*), Marseille (1pm*), Valkonen (1pm*)

ALADIN staff: Brousseau, Auger, Strajnar (2pm), Meier (2pm), Pietrisi(2pm), R. Ben Romdhane (2pm)

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

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.
- Investigate spatially varying flow-dependent background error variances in Aladin and Arome from sigma B maps of global and limited area ensemble systems
- Towards hybrid ensemble variational data assimilation in Harmonie: implement the EnsDA schemes and the (L)ETKF rescaling schemes in Harmonie for generation of initial perturbations in OOPS compliant way; continue improvement and comparison of the different ensemble generation techniques with regards to affordable ensemble size, lagging strategy, the sampling “model error“ uncertainty (priority medium); design augmentation of control vector space; design the localisation operator to extract localised information from perturbations;
- OOPS-related design of the data assimilation systems: extend quasi-geostrophic (QG) OOPS prototype to allow ensemble and LAM specific frameworks (OOPS-QG-LAM is available since summer 2013); design augmentation of the control vector space to allow Jk constraint, LBC control variables and “alpha”-control variables; perform a study on the optimal way to constrain large-scale errors in LAM-QG and to account for the host model information in LAM-QG 4D-Var; extend the QG 4D-Var scheme to QG Hybrid 4D-Var; extend QG Hybrid 4D-Var to QG 4D-Ens-VAR with a constant ensemble control variable over the assimilation window; extend 4D-Ens-VAR scheme to allow time dimension in “alpha” control variables
- From 2013 onwards, efforts will start in CNRM/GMAP in order to develop En-Var for both the global Arpège and the LAM Arome DA systems. Three main areas of research are anticipated: (1) assess possible strategies for the localization of perturbations; (2) progressive implementation of 3D-En-Var then 4D-En-Var in the 3D NWP models driven from the OOPS layer (Note: a 4D-En-Var framework already has been coded in OOPS and is available for the toy models since summer 2013), study computational efficiency issues and parallelization; (3) assess optimal (consistent) strategies for generating the perturbations (ensembles of En-Var’s ?). When applicable, similar solutions for global and LAM En-Var will be studied.
- 4D-Var: enable the use of centered 3D-Var FGAT in Harmonie; continue further technical development of 4D-Var; optimize configuration of 4D-Var for convection-permitting scales and high-resolution observation types (radar, GNSS, Mode-S) with regard to length of the

assimilation and observation windows and increment resolution; investigate possible further improvements of 4D-Var with regards to computational performance and scalability (Gaussian quadrature 4D-Var; lower regularization norm);

- Further develop image warping and field alignment techniques, with the emphasis on their integration in the variational (hybrid) framework (priority medium);
- Finalize coding of LAM wavelets

HIRLAM staff: Escriba, Landelius (2pm*), Lindskog (2pm), Geijo (3pm), Gustafsson (4pm, 2pm*) , Bojarova (4pm) , Dahlgren (2pm) , Barkmeijer (1pm) , Valkonen (2pm*)
ALADIN staff: Berre, Desroziers, Arbogast, Montmerle, Ménétrier, Michel, Raynaud, Legrand, Deckmyn Z. Sassi (2pm)
Priority: medium
Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova/Fischer

DA4: Assimilation of radar data

- perform pre-operational feasibility study of radar volume data exchange between NMS's based on the demonstration infrastructure established by SMHI; spread expertise and establish routines on use of CONRAD (ongoing, high priority).
- Further investigate performance of Baltrad QC Toolbox and collect user experiences to outline con's and pro's of the package, 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 NMSs (priority high); shift emphasis from technical implementation of radar assimilation to impact assessment on RUC systems;
- Prepare for the assimilation of dual polarization radars;
- Radar data exchange between LACE NMSs to investigate impact study, demonstration study in mesoscale Arome and/or Alaro over Central Europe with high coverage of radar observations.

HIRLAM staff : Haase (2pm), Thorsteinsson (2pm) , Dahlbom (2 pm), Geijo (1pm) , Zhuang (2pm), Ridal (2pm), Whelan (1pm), Verkleij (3pm), Yang (0.5 pm), de Haan, Ivanov* , Müller (3pm*), Randriamampianina (1pm*), Saltikoff (1pm*)
ALADIN staff: Wattrelot, Montmerle, Mahfouf, Stanešić (2.5pm), Kovačić (3pm), Monteiro (1.5pm), Pietrisi (2pm), Nestiak (3 pm), Meri (2pm), Okon (2pm), Bujnak(2pm), Mile (3pm), Steib (1.5pm), Meier (3pm)
Priority: high
Responsible HIRLAM project leader/ALADIN CSSI member: Bojarova/Fischer

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

- IASI radiances: extend assimilation algorithms for water-vapour sensitive channels to allow cloud-affected (CO2 slicing) and cloudy (hydrometeors in observation operator) radiances, improve the VarBC procedure to be better in handling heterogeneous data distributions, improve estimation of surface emissivity and skin temperature ("best-fit" emissivities for different surface types diagnosed from Ecoclimap) to allow assimilation of lower peaking channels;
- 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: refine white- and black- listing of GNSS stations (dependent on producing center, representativity error, orographic conditions) and further tune the station-dependent VarBC (high priority); perform impact assessment in Harmonie RUC suites (high priority); investigate possibilities for the refinement of VarBC by introducing an optimal set of predictors (priority medium); start investigating assimilation of GNSS STD;
- Mode-S and other aircraft data: Implement Mode-S observations, including optimal configuration of VarBC and quality control (off-set/ optimal set of predictors) and perform impact assessment (priority high); refine assimilation of AMDAR temperature observations (bias correction and optimal thinning distances) and perform impact assessment; prepare for the assimilation of information from AMDAR humidity sensors;
- scatterometer surface winds: perform further tuning of the assimilation setup (update frequency, domain size, structure functions, initialisation) and assess impact on forecast quality;
- Cloudy infra-red SEVIRI radiances: implement in 4D-Var using the simplified ECMWF physics package and perform impact assessment on forecast quality of moist variables (priority high);
- Implement near-surface (T2m, RH2m, low level wind) observations in the upper air data assimilation, including refinement of observation operator, improved quality control procedure,

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
- Investigate the potential of assimilating Aeolus level-2 wind product and future MTG-IRS data
- 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 (1.5pm), Valkonen (6pm*), Ridal (2pm), de Haan (2pm*), Sanchez (4 pm), Whelan (1pm), Marseille (5pm*), Geijo (2pm) , Dahlgren (2pm*), Müller (3pm*), de Bruin (1.5pm*), Vedel (1pm), Lindskog (3pm), Randriamampianina (2pm*)

  ALADIN staff: Guidard, Moll, Saint-Ramond, Payan, Meunier, Jany, Fourrié, Martinet, Sahlaoui, Hdiddou, Strajnar (4pm), Yan (4pm), Schneider (1pm), Mile (2pm), Toth (2pm)

  Priority: medium

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

DA5.2: Further development and improvement of pre-processing / monitoring software

- Participation in ECMWF's COPE Project (extraction of quality control filters from the pre-processing software and replacing them with C++ filters following the COPE-filter templates, implementation of local data formats into the common pre-processing system; development of the common blacklisting software)
- 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 (5 pm), Aspelien (2 pm), Dahlbom (4 pm), Amstrup (3 pm)

  ALADIN staff: Puech, Guillaume, Moll, Mile (2pm), Toth (1pm)

  Priority: medium

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

DA6: Comprehensive observation impact and network design studies

- Analyse results of coordinated extended radar data impact studies (radar, GNSS ZTD, 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 scales (e.g. FSO, DFS; priority high).

  HIRLAM staff: Thorsteinsson (1pm), Sanchez (2pm), Geijo, Verkleij (1pm), Barkmeyer (1pm), Schyberg (1pm), Müller (2pm*), Randriamampianina (2pm*)

  ALADIN staff:

  Priority: medium

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

3.2 Dynamics

3.2.1 Scientific considerations

The 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. First, a number of activities aim at the further development of the non-hydrostatic (NH) dynamical core. Secondly, work will be done concerning the long-term evolution of the NH core and comparison to alternative cores in terms of meteorological performance, computational efficiency and stability. A third topic is boundary conditions and nesting. The numerical efficiency and 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 accuracy. Nowadays these are the spectral method in the horizontal, which is presently used, and the cubic (or higher order) 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 have been pursued. For the height-based hybrid vertical coordinate formulation developed by Hirlam and ECMWF, stability problems occur in numerical experiments using higher than 4th order discretizations of the vertical differential operator. The mass-based VFE formulation developed within Aladin appears to be stable. Further developments of VFE will therefore take place on the basis of this mass-based formulation.

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 sought which better conserve mass but do not involve a large increase in computational cost. Alternative approaches have been tried (MetOffice ENDGAME approach, non-interpolating scheme, combinations of cubic and linear interpolation), but with disappointing results. The elimination of aliasing on vorticity over orography has led to improved mass conservation of the SL scheme for dry air in the global IFS. A further improvement of the conservation of the mass of dry air has been achieved by eliminating the quasi-monotonicity in the high-order bidimensional interpolation used in the solution of the continuity equation. This method will be implemented and tested in Harmonie. As a next step, manpower permitting, 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:

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? Aspects on 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, namely at high accuracy orders, and when taking into account both divergent and vortical aspects (in more than one dimension); investigate potential of unstructured 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 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 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 knowledge of incoming and outgoing signals at the lateral boundaries to perturb lateral boundary conditions, in order to estimate the propagation of 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. Following the implementation of Boyd's bi-periodization procedure in the code, the data flow in the Davies scheme can be modified to reduce calculations in the boundary and extension zones. A 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, might be included to avoid the need for truncation. This work will nevertheless have a low priority as some studies have shown very little difference in the quality of the forecast between truncating or not truncating the trajectories. 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. Some of these crashes can be avoided by the use of the predictor-corrector method of time integration (this makes the model more expensive to run) and the application of the advection to the vertical velocity instead of the vertical divergence, which needs an invertible conversion between these two fields (integral and derivative operators inverse of each other).

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 16 km 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 is desirable when going to sub-km mesh sizes, modifying the map factor near the boundaries.

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 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 2014

DY1: Development of the dynamical core

- **DY1.1:** Investigation of a possible **vertical finite element (VFE) discretization** for the non-hydrostatic (NH) model.
  Two different approaches have been followed for this by Aladin and Hirlam/ECMWF. The VFE approach developed by Aladin has been shown to have satisfactory stability properties, so Aladin and Hirlam will join forces on the further testing and development of this method. Issues to be addressed: the phasing into cy40t1; adaptation to the global model ARPEGE/IFS; testing of stability, accuracy and convergence of the SI solver; generalization for higher spline orders. 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.**
  Eliminate the quasi-monotonicity in the interpolations used for the semi-Lagrangian treatment of the continuity equation. This quasi-monotonicity is not needed (it was introduced in the first place for consistency with the treatment of the other equations) and worsens the conservation of the mass of dry air. The method developed by Wedi for the elimination of aliasing on vorticity over orography, which has shown a better conservation of the dry mass of air, will be implemented in the limited-area version of the model.

The different available options for computation of trajectory and interpolation at departure point for terms of the continuity equation for dry air, and later for other atmospheric components (water, ozone, chemical constituents) will be compared in terms of global conservation.

- **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:**
  Submission 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 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: DY1.1: Hortal (2pm), Simarro(1pm), Subias(10pm); DY1.2: Hortal (1pm), Morales (0.5pm);
  ALADIN staff: DY1.1: Bénard (liaison with AEMET colleagues), Yessad (code aspects); Vivoda (3pm), Smolikova (3pm) 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. Adding a “local” option for the computation of the derivatives (horizontal finite elements) besides the spectral one, while keeping the SI option, a 3D grid-point solver should be implemented, all the rest being kept identical, allowing clean scientific comparisons.
- Analyze results from the scientific (steep slopes) and computer points of view (scalability).
- Examine the relative advantages of A and C grids for high accuracy order schemes, and when taking into consideration both vortical and divergent aspects (in two dimensions).
- Writing a literature review of alternative methods (e.g. unstructured grids)
- Start development of so-called Horizontal Explicit Vertical Implicit (HEVI) methods in combination with unstructured grids to build expertise and tools to anticipate potential future difficulties with very steep slopes.
  ALADIN staff: Caluwaerts, Degrauwe, Voitus, 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.
- Apply boundary conditions together with Boyd’s bi-periodization in spectral space, and test with Degrauwe’s test. This procedure will allow, against a negligible computational cost, to increase the extension zone width in order to avoid the influence, in data assimilation, of observations close to one edge of the domain to influence analyzed fields at the opposite edge.This will be tested in WP DA1. Prepare documentation to easily implement Boyd's solution operationally.
- Prepare an exportable script system for applying MCUF.
  HIRLAM staff: Hortal(2pm)
  ALADIN staff: Voitus, Degrauwe, Termonia, Tudor (1pm)
  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 current Arome model 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 are the sometimes overactive convection in weakly forced situations, the occasional strong outflow from convective cells, and, 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, the AAAH partners participate in international idealized studies of clouds and convection. To improve the description of low convective 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), the turbulence scheme (top entrainment), the statistical cloud scheme (distinction thermals/environment) and the surface (soil moisture). Also, the impact of vertical resolution increase on clouds and convective behaviour is being considered.

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. 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.

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 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. Further steps include introduction of a new cloud droplet description, and implementation and testing within Hirlam. Following this, the updated STRACO version 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. Such a second-moment scheme has been developed within Méso-NH and will be evaluated to develop a new version adapted to NWP constraints. As a preliminary step, Météo-France plans to extend the present microphysics of Arome to including a diagnostically evolving cloud water droplet distribution (parameter Nc).

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 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. These will be transferred to Harmonie, starting with the introduction of the direct effect in the radiation scheme. Input information on atmospheric aerosol distribution and its optical and chemical properties can be derived from climatology, MACC analyses or assimilation of satellite-based observations, or provided by coupling Harmonie with chemistry models. 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.

<u>The stable boundary layer (SBL)</u>

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 is being made on improving the description of SBL effects by an interdisciplinary team, with connections to other consortia and university researchers. In this study, attention is being paid e.g. to the following aspects:

- Test new theoretical concepts for turbulence parametrizations (Zilitinkevich et al. 2008) in several models within the IFS/AAAH framework.
- 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 the 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.
- Study the influence of snow, ice, vegetation and the 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 T2m diagnostics in local applications of Alaro-0 and study T2m bias behaviour.

<u>Some transversal issues</u>

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.

<u>Tools for learning, testing and diagnosis of the physical parametrizations</u>
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.

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 for upper air physics parametrizations research is to tackle existing model deficiencies at present resolutions (1-5km):

- an improved description of the stable boundary layer behaviour (all WPs) has first priority, together with research aiming at an improved representation of low level clouds (fog) and the daily cycle of precipitation and convection under unstable circumstances (WP PH1).
- For Alaro, an extensive overhaul has been achieved; the highest priority for the ALARO team will be to integrate and test the various components of it to create ALARO-1 (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 (i) radiation intercomparison studies, (ii) the development and assessment of second moment microphysics schemes, (iii) the inclusion of direct and indirect aerosol effects in radiation and cloud scheme, and (iv) a more consistent use of cloud 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 TR4)

3.3.3 Work packages in 2014

PH1: Convection and turbulence

- Arome: investigate shallow convection behaviour at kilometric and sub-kilometric scales
- Arome and Arpège: validation of diurnal evolution of the PBL with respect to the BLLAST field campaign measurements.
- Arome: Comparison of EDMF and EDKF schemes and their associated cloud parameterizations
- Cloud study: In-depth evaluation of model cloud/convection behaviour with a variety of diagnostic 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 overprediction of fog over sea.
- Shallow convection parametrization: Feasibility study on the ideas of Arakawa (2011) for a multi-scale 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-grid scale clouds in convection, cloud and radiation schemes. Further development of the Rasch-Kristjansson scheme in Alaro-1. Priority: medium.
- Alaro: continue development and evaluation of 3MT and CSD 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
- Alaro: simulate 3D effects of turbulence in the model (with the extension of vertical turbulence scheme TOUCANS by consistent components for horizontal part obtained from SL interpolation stencil); validation of the existing code and inter-comparison with LES. Priority: low
- 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 (4pm), Bengtsson (4pm), Ivarsson (2pm), Fortelius (5pm), Kadantsev (3pm), Niemela(1pm), Morales(6pm), Martin (3pm), vdVeen (1pm), Calvo, Finkele

ALADIN staff: Honnert, Piriou, Bouteloup, Riette, Bazile, Seity, Couvreux, Szintai (8 pm), Geleyn, Bastak, Gerard, Banciu (2pm), Brozkova, Wittmann (1pm), Pristov (1pm), Cedilnik (1pm), Lancz (9 pm)

Priority: high

Responsible HIRLAM/LACE PL/ALADIN CSSI member: Rontu /Pristov /Degrauwe

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. Priority: low
  - ○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.

●Implementation in ICE3 microphysics of a 3D daily updated Nc (Number of cloud droplets) using aerosols models outputs (MACC/MOCAGE) instead of the current land/sea fixed values.

●Developing a 2 moments microphysics scheme for AROME will continue in Méso-NH, and the ICE4 scheme (hail) will be tested with some modifications.

●Improvement of statistical representation of sub-grid clouds, using a bi-Gaussian PDF

●Evaluation of SRTM and McICA schemes for representing short wave radiation interactions in Arpege and Arome

●Alaro: Continued development of ACRANEB2 radiation scheme. Evaluation of adaptations in radiative cloudiness and water content computations. Checking the intermittency usage to reduce CPU. Priority: high

●Harmonie radiation intercomparison: Finish interfaces to call hlradia and ACRANEB-2 from apl-arome. Improve various aspects of the RRTM, hlradia and ACRANEB-2 parametrizations in Harmonie/Arome. Prepare reference radiation transfer model data and observational data for validation, perform tests and intercomparison experiments for short- and longwave radiation, publish the results in journal papers. Orographic radiation parametrizations are developed and tested within WP SU7.

●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 Liu-Penner scheme in Arome/Alaro. Before introducing any of these Hirlam-based formulations in Harmonie, study the existing cloud-radiation schemes to ensure consistent usage of cloud microphysical information throughout the model code.

●Aerosol-radiation experiments: Perform a Harmonie case study for the 2010 Russian forest fires, to study model sensitivity to an aerosol radiation parametrization by coupling the model to aerosol input from SILAM. The results obtained by the RRTM, hlradia and Acraneb-2 parametrizations will be compared to each other and to weather, aerosol and radiation observations. The influence of replacing the presently available climatological aerosol information by 3D observation-based data from SILAM will be studied. The possibility to compare also the indirect aerosol effects via various cloud microphysics paramentrizations will be studied

●Prepare the interfacing of an external library including aerosol and chemical parameterizations, including its interactions with existing atmospheric and surface parameterizations.

●Study possibilities how to include the effect of orographic shadowing in the radiation schemes of Arome/Alaro.

HIRLAM staff: Korsholm (4pm), Sahyoun* (PhD student), Pagh Nielsen (4pm), Gleeson (6pm), Nuterman*, Ivarsson (0.5pm), Rontu (1pm), Mannik, Kaasik, Toll, Reis, Prank*, Ermakova*

ALADIN staff: Riette, Lac, Bouteloup, Seity, Honnert, Van den Berg, Van Ginderachter (3 pm); radiation: Masek, Brozkova, Kuma (1pm),Wastl (1pm); desert dust (expert on this field): Mokhtari
Priority: medium
Responsible HIRLAM/LACE PL/ALADIN CSSI member: Rontu / Pristov / Degrauwe
Main contacts from ACT community: Alexandr Baklanov, Mihail Sofiev, Tanya Ermakova

PH3: International boundary layer, clouds and convection studies

- Participation in GABLS-4 study
- Participation in DICE intercomparison study
- 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.

HIRLAM staff: de Bruijn (3pm), de Rooij (1pm), Martin (2pm), Vihma*, Kilpelainen*
ALADIN staff: Voitus (DDH), Bazile (MUSC), Van Ginderachter (5 pm).
Priority: medium
Responsible HIRLAM/LACE PL/ ALADIN CSSI member: Rontu / Pristov / Degrauwe

PH4: Integration and testing of ALARO-1

- the basic steps regarding code design: tests of new CPTEND_FLEX physics-dynamics interface (see TR2)
- Devise an assembling strategy for putting the developments on TOUCANS, unsaturated downdrafts and ACRANEB2 together.
- Readdress the interface with Surfex, such that the copling of Surfex can be used consistent with the underlying hypotheses of TOUCANS
- validation: invest in validation testbeds common with Arome and Arpege, facilitating cross testing of our paramaterizations.

ALADIN staff: Pristov (1pm), Cedilnik (1pm), Derkova (2 pm), Gerard, Banciu, Brozkova, Van Ginderachter (2 pm), Wittmann (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 is being studied of additional sources of sub-km scale information (CORINE, GLOBCOVER, ASTER, national databases etc.). For the future use of sub-km scale models, it will need to be considered which high-resolution orographic and physiographic data sources will be the most appropriate to use for the various domains in the Euromed area. 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:
The assimilation of surface observations has 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 being developed for snow and lakes. 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. The 2DEnVAR scheme, where long time series climatological ensemble are used to describe non-homogeneities and anisotropy induced by land-sea mask and orography, has large potential and is being tested. The big advantage of the 2DEnVAR is that this scheme uses the same framework as the hybrid ensemble variational data assimilation scheme, currently considered as the main framework of the flow-dependent data assimilation for upper air. A path towards coupled upper air and surface data assimilation scheme could be defined in this way. Promising alternative techniques for surface data assimilation, 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 put emphasis on the use of observations particularly important in nordic conditions, such as lake and snow observations, and Aladin staff on the assimilation of 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, MODIS lake water temperature and ice fraction, various existing remote sensing products derived for snow, ice and SST (GLOBSNOW, EUMETSAT SAFs, EU FP7 Cryoland products). 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. More advanced data assimilation techniques such as Extended Kalman Filter or Ensemble Square Root Filter are to be developed for these purposes

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. 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 planned, 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, 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 high resolution orographic and 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:

- Development of the SODA framework (SU1). Introduction of an 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;
- 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 2014

SU1 : General aspects

- continue development of SODA (priority high)
- continue development of new horizontal spatialisation tool MESCAN: emphasis 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)
- finalize coupling of Surfex to Alaro and validation.
- 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.
- 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 the new Globcover dataset. Compare Globcover, Ecoclimap-2 and GLCC, study gross errors and biases
    - o Consider how to adapt Ecoclimap using local data of better quality/ resolution.
- Enhance surface elevation description (see also WP TR3)

  HIRLAM staff: Aspelien (1pm*), Landelius (1pm*), Samuelsson(0.5pm), Shoulga*, Kurzeneva (2pm)

  ALADIN staff: Marguinaud, Martin, Soci, Bazile (EURO4M), Seity (Ecoclimap), Mary, Hamdi, Cedilnik(0.5pm), Szucs, Jidane, Essaouini, Ivatek-Šahdan (1pm), Pietrisi (2pm), Habrovsky (3 pm), B.Bochenek (3pm), Z.Sassi (1pm)

  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: Landelius (1pm*), Lindskog (2pm), NILU* (MET Norway)
ALADIN staff: Hamdi, Schneider (2pm), Parrens, Calvet, Mahfouf, Guedj, Carrer, Toth (6pm)
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 assessing 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 evaluation of Multiple Energy Balance (MEB) scheme in stand-alone Surfex-v7.3 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(2pm, 1pm*), Eerola (2pm), Bojarova (0.5 pm), Kurzeneva (1pm), S. Thorsteinsson (0.5pm), H. Thorsteinsson (1pm), Samuelsson (1pm), Lindskog (1 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 Surfex. Connection to Canari sea ice optimum interpolation (priority medium);

HIRLAM staff: Homleid (1pm), Kurzeneva (3pm), Eerola (1pm), Bin Cheng (2pm), de Bruijn (2pm)
ALADIN staff: Salas y Melia, Martin, Taillefer
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 OI algorithms for lake temperature in CANARI (priority high); derive structure functions depending on lake depth and elevation for OI of lake surface temperature (priority medium)
- Development on Flake parametrization in Surfex: Prepare Flake for operational use in Cy40. 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: Shoulga*(3pm), Kurzeneva (6pm), Eerola (1pm), Kheyrollapour*, de Bruijn (1pm) , Aspelien (0.5pm)
ALADIN staff: Taillefer, Seity
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 depends on possible external funding. It is planned to use TEB in climate runs to study UHI. This will count as extra validation of the TEB scheme.
HIRLAM staff: Fortelius (0.5pm), Drebs*, Luhamaa
ALADIN staff : Masson, R. Hamdi, Rio
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 (2pm)
  ALADIN staff : Seity, Mary, Wastl (1pm)
  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 has been upgraded in June 2013 to higher resolution (11km/45 levels) and to a larger domain. The new version involves a breeding-blending cycle for upper air perturbations, ensemble CANARI for surface perturbations and an optimized multi-physics scheme. A GLAMEPS suite has been running at ECMWF since 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.

<u>Development of convection-permitting ensemble systems</u>

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 perturbations to physiographic fields (soil wetness, roughness), inflation techniques and/or observation perturbation in the CANARI surface analysis. Model error uncertainty 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 and development 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).

LACE has set up a convection-permitting EPS based on Arome with 2.5km resolution which is in test status. The EPS is run for several small Central European domains. Different coupling strategies are tested. The EPS is coupled with PEARP and Aladin-LAEF. Tests are also performed with lateral boundary conditions of ECMWF-EPS at resolutions T1279 and T639 for specified cases. For initial condition perturbations, global perturbations are blended with fine structures derived from a single data assimilation cycle of deterministic Arome. This basic centralized DA is currently enhanced to a full EDA using ensemble 3D-Var and CANARI. Further studies focus on the impact and growth of perturbations induced by SPPT.

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 in hindcast mode. Experiments will be carried out with different nesting configurations, with data assimilation in the control members and with perturbations of physics, surface and 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 a EnDa system. The multi-model setup of HarmonEPS accounts for some degree of model uncertainty already. Additionally, the potential will be considered of adding surface (analysis) perturbations and of upper air perturbations in the form of perturbations in physics parameters and SPPT (Stochastically Perturbed Parametrization Tendencies scheme). Cellular Automata (CA) to introduce stochasticity, horizontal communication and convective memory to the parameterization will be tested for the Alaro members of the ensemble. 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. ETKF perturbations are combined with large-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.

A set of hindcast experiments to define the next version of GLAMEPS, v2, started in 2012. As control, the operational GLAMEPS-v1 setting is used. The experiments include blending with large scale perturbations, use of CAPE SVs, use of surface data assimilation in all LAM members, ETKF, replacement of the ECMWF EPS members by Aladin members, a lagged approach to enable running 4x/day, and a higher horizontal resolution (~7.5km). Most of these experiments are finished, some still need to be evaluated. GLAMEPS-v2 is expected to be introduced in the first half of 2014.

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 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. Two possible approaches are being evaluated: (1) a mixed-effect ELR variant (more advanced, less need for long training periods) and (2) an ELR model in which latitude and longitude are used as predictors (spatial variations are possibly not very smooth, computationally expensive). Experiments so far indicate that ELR calibration appears to be very beneficial for the quality and reliability of near-surface parameters.

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;
- and the development of calibration and post-processing techniques (WP E3).

3.5.3 Work packages in 2014

E1: Development of a PEARO:convection-permitting ensemble

- 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:

- Implement cycle 38 in HarmonEPS. Implement schemes from planned Alaro1 that is/will be ready in 2014.
- FROST14: use high-resolution observations in assimilation. Prepare for delivery of HarmonEPS to FROST-2014. Analyze and write paper on HarmonEPS for FROST-2014.
- SPPT: Box-SPPT working in HarmonEPS; basic implementation of complete SPPT in HarmonEPS; SPPT adapted to different scales; verification and tuning; intercomparison of the performance of multi-physics vs Box-SPPT and complete SPPT
- Experiment with perturbation of surface parameters (e.g. soil moisture, albedo, snow, SST, LAI, vegetation fraction, roughness length and soil temperature).
- Surface physics - study perturbations in momentum, heat and moisture flux parameterizations.
- Tune the CA-scheme for 2.5 km. Explore the role of "different treatments of convection" for the Alaro members.
- Explore the influence of humidity perturbations in HarmonEPS by including humidity in SV's, and by use of the MSG cloud mask for computing humidity perturbations.
- Make stochastic perturbations for critical threshold for autoconversion (cloud drops>raindrops). Improve freezing computation of supercooled clouds, and apply stochastic perturbations to 'freezing probability per unit time' (given a certain supercooling) in HarmonEPS.
- Include perturbed observations in surface assimilation for the different members.
- Investigate the issue of domain size requirements for DA. Experiment with RUC with cy38. Introduce lagging.
- Nest in ECMWF deterministic model by use of random field perturbations to the initial and lateral boundary conditions. Random field perturbations can simply be the difference between two ECMWF analyses or forecasts from randomly chosen dates (but same season and same initial hour) scaled to make the perturbations suitably small.
- Study the importance of boundary perturbations in connection with the big jump in resolution from host model to HarmonEPS.
- After proper sanity check of LETKF working in HarmonEPS, compare its performance with available methods for generating Initial Conditions already implemented in Harmonie.
- Investigate the amplitude of the uncertainty associated with different physical processes in the models. Develop stochastic parameterizations or parameter perturbations that address uncertainty for each sub-grid scale process (longer term work).
- Make use of parameter perturbations developed in LAEF system.
- Implementation of a HarmonEPS suite using ECFLOW.

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

HIRLAM staff: van der Veen(3pm), Barkmeijer(2pm), Feddersen(2pm), Bengtsson(2pm), Escriba(5pm), Callado (6pm), Frogner(5pm), Vignes(1pm), Singleton(8pm), Garcia-Moya (2pm), Stensen(4pm), Johansson(4pm), Sattler (0.5pm)

ALADIN staff: Arome EPS team: Bouttier, Nuissier, Vié, Raynaud; LAEF team: Wang (0.5pm), Gorgas (3pm), Weidle (2pm), Wittmann (0.5pm), Szucs (4 pm), Bellus (1 pm)

Priority: high

Responsible HIRLAM project leader / CSSI member: Frogner / Deckmyn

E2: Further development of ~10km-scale LAM EPS
GLAMEPS:

- Establish GLAMEPS-v2 for operation, based on the outcome of the latest experiments on e.g. a resolution increase to ~7.5km on a smaller domain, a 6-hour lagged cycling setup with product delivery 4 times a day, calibration, and a new ensemble setup, replacing ECMWF EPS members by Alaro members using two flavours of surface scheme (ISBA and Surfex);
- Test an alternative method for rescaling within the ETKF methodology. It is based on the fact that the observation error contains not only measurement errors, which are uncorrelated, but also representative errors, which are correlated and have structures related to the flow.

LAEF:

- Upgrade of operational ALADIN-LAEF
- Test with increased resolution of 5km
- Optimization of multi-physics scheme
- Combination of multiphysics with SPPT and stochastic surface physics (interaction with physics experts)
- Investigation on the impact of ensemble size on the ensemble system quality
- Verification of the new LAEF system

ALADIN/HU EPS:

- Upgrade of the operational ALADIN/HU EPS
  - implement local initial perturbations through ensembles of data assimilation (EDA)
  - initialization of the EPS system at 00 UTC based on fresh observations (based on EDA analyses at 00 UTC)
  - development of probabilistic products related to convection to forecasters

HIRLAM staff: Sattler(1.5pm), Yang(0.5pm), Johansson(6pm)
ALADIN staff: Deckmyn, Smet, Wang (1pm), Weidle (6pm), Wittmann (1pm), Gorgas (1pm), Bellus (2 pm), Tascu (2pm), Szucs (4 pm)
Priority: medium to high
Responsible HIRLAM project leader/ALADIN CSSI member: Frogner / Deckmyn

E3: Statistical post-processing and calibration

- Continue the calibration work on GLAMEPS (ELR), focusing on wind and/or precipitation and specifically the higher thresholds (“extremes”).
- Fit the ELR-code into the GLAMEPS scripts and prepare for inclusion in the next GLAMEPS upgrade
- Test local calibrated GLAMEPS forecasts, including verification, for the Sochi area.
- Tracking of low pressure systems, using the algorithm that is used for tracking polar lows at MET Norway.
- 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.

HIRLAM staff: Bremnes(3pm), C.Santos(1pm), Kilpinen(1pm), Schmeits(?), Nipen(1pm), Sattler(0.5pm), Singleton(1pm)
ALADIN staff: Deckmyn(?), A.Ouali (1pm)
ECMWF contact: Leutbecher
Priority: medium
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 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 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 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. Starting from late 2013, a Harmonie RCR will be regularly implemented for new cycles at one or several operational services. This is envisaged to become one of the key vehicles in the future for the Hirlam programme to quality assure and monitor development of the Harmonie forecast system.

With the move towards km-scale resolutions and greater emphasis on probabilistic forecasts, an extension of the verification systems in the Hirlam and Aladin communities with methods suitable for high resolution and for probabilistic forecast is urgently needed, such as algorithms and tools for comparisons between models at fine and coarse resolutions, and between deterministic and probabilistic forecasts, with special attention to high impact weather. Of particular interest are verification algorithms featuring spatial and/or scale-sensitive techniques (SAL and FSS), methods to use the upscaling concept in the assessment of forecast skill for high impact weather (e.g. Significant Weather Score (SWS)), and use of 2- or 3D remote sensing observations. To address the needs as mentioned above, Aladin and Hirlam started the joint development of a verification system called Hirlam-Aladin R-based verification Programme (HARP). While the primary focus of the HARP work during the initial stage is to build a system framework that enables monitoring and verification of mesoscale NWP models and for probabilistic forecasts, it shall be designed with a view to address comprehensively the needs in verification for both operational and research applications at the NWP centers. For Hirlam, the idea of developing an NWP index composite, using a combination of point verification (for e.g. T2m, W10m), and some sort of weighted sum for precipitation (threat scores, SAL and SWS using point or 2D obs etc.) will be pursued, both in connection with Reference Harmonie releases and for use at member services. Coordinated efforts are needed to secure the collection of observation data suitable for high-resolution (spatial)verification, in particular radar reflectivity and satellite-derived parameters (e.g. cloud physical properties, radiation, …).

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, the new HARP package has been developed for probabilistic verification of operational forecasts of precipitation, 10m wind and wind gusts, mslp and T2m. For LAEF, GLAMEPS and HarmonEPS, the FROST-2014 project is a golden opportunity for verification and intercomparison of high resolution probabilistic forecasts. For Arome-EPS, validation and experimentation will focus on the HYMEX field experiments and selected cases of other events, and on improving ensemble calibration and post-processing (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 the development of verification tools / framework suitable for mesoscale verification and probabilistic forecasts (WP QV1). Extension of the monitoring and verification systems with utilities suitable for assessing the performance of high-resolution models and their added value (WP QV2), and of ensemble prediction systems (WP QV3)
- Hirlam only: Continued Harmonie quality assurance and monitoring (WP QV4). The introduction of a Regular Cycle of Reference (RCR) Harmonie at several operational services will be a major enhancement on the quality assurance and monitoring of the Harmonie system. However, pre-release evaluation and regular quality assurance remains a community-wide task for all Hirlam services. The arrangement with on-duty staff for monitoring and quality assurance will be maintained.

3.6.3 Work packages for 2014

QV1: Joint Aladin/Hirlam development of HARP verification package

- Introduction of the HARP package. The work so far has resulted in a basic system framework for HARP tools which is under GIT revision control, the definition and implementation of a common data format (SQLite) suitable for storage of verification data, test of spatial and probabilistic verification under the new framework. During 2014, this work will be continued and two joint working weeks are scheduled about the HARP system, with the following focus:
    - Release of the first HARP system so that it is documented and can be accessed by the communities to enable test and implementation by staff beyond the core developer-group. The HARP package shall include a selected number of spatial verification tools, and a selected number of deterministic and probabilistic scores for point verification.
    - Development of a preliminary tool package suitable for graphics and web-display. This includes follow-up action after relevant strategy discussion for both verification and observation monitoring of using either/and pre-generated and on-the fly graphics.

  HIRLAM staff: van der Plas(1pm), Singleton(1pm), Andrae (0.5 pm), Bjørg Jenny Engdahl (1pm?), Sattler (1 pm), Yang (1pm), Callado (1 pm), Bremnes*, Aspelien*, Dahlgren*
  ALADIN staff: Deckmyn? Zingerle (1pm)...
  Priority: high
  Responsible HIRLAM project leader/ALADIN CSSI member: Yang /Zingerle

QV2: Algorithm development for quality assessment and verification of deterministic forecasts

- Development of mesoscale monitoring and verification tools and methods:
    - Test and implement spatial/scale-selective verification methods such as FSS, upscaling, SAL.
    - Development of scores and quality index mainly with station-based verification.
- Collection of model and observation/analysis data for joint monitoring and verification of 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.

- Maintenance of the Harmonie verification tools for deterministic forecast (MONITOR).
- Further develop and maintain the Aladin quality monitoring package (installed in Ljubljana), e.g. introduction of significance tests.
  HIRLAM staff: van der Plas(2pm), Eerola (?pm), Fortelius (?pm), Bjørg Jenny Engdahl (2 pm?), Pagh Nielsen(0.5 pm), Kryzanauskiene (? mm); Yang (1 pm)
  ALADIN staff: Stein, Amodei, Pouponneau, Tardy, Sanchez, Razagui, B.Bochenek (1pm), M.Jerczynski (3pm), M.Kolonko (1.5pm), M.Szczęch-Gajewska (3pm), J.Woyciechowska (3pm), Pristov (1pm), Gorgas (1pm), Kacer (6pm), Vivoda (1pm), Zingerle (1pm)
  Priority: medium
  Responsible HIRLAM project leader/ALADIN CSSI member: Yang / Zingerle

QV3: Tools for quality assessment and verification: probabilistic

- 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.
- Spatial verification of EPS: Ensemble FSS (which gridded data to use as observations?).
- Identification of important/different verification regions / station types – e.g. coastal / mountain / climate zones.
- Use of available high-resolution observations in the Sochi-area for verifying HarmonEPS.
- Test MODE (Davies et al, 2006) method in hppv.
- Set Harmonie fullpos to needed EPS parameters to verify against SYNOP/TEMP observations with HARP.
- Quantify the loss of skill as a function of scale. That is, some form of spectral verification.
- 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), Singleton (1pm), Stensen (3pm), Callado(1pm)
ALADIN staff: A. Deckmyn, Bouttier, W.Khalfaoui (1pm)
ECMWF contact: Leutbecher
Priority: high
Responsible HIRLAM project leader/ALADIN CSSI member: Frogner / Deckmyn

QV4: Monitoring and quality assurance

- Coordinated pre-release quality assurance.
- Follow-up and monitoring of Harmonie/Hirlam operational suites. Maintenance and extension of the Hirlam data portal featuring the main operational suites at hirlam.org.
- Production, delivery and local monitoring of the monthly report for Aladin members.
- Comparison of the Arome-France and KNMI-Harmonie forecasts on the spatial domain corresponding to the intersection of their simulation domains
- Report regularly about performance and needs to both developer and user communities
  HIRLAM staff: Pre-release quality assurance: ca 6-10pm with approximately one contact staff pm per operational centers (Kazlauskas? de Rooy? Calvo? Whelan? Benghtsson? Homleid? Andersen? Niemela?). On-duty team: a total of 6pm, with preliminary assignment per member service about on-duty week specified on wiki page). Regular maintenance and analysis: Andrae(0.5 pm), Eerola (1pm, monitoring interface), Niemela (1pm), Homleid (1pm, evaluation), Kangas (0.5 pm, mast data and interface), Kazlauskas (1 pm, monitoring interface), Tijm (1pm), Yang (1pm)
  ALADIN staff: Stein, Bénichou, Zingerle (0.5pm)
  Priority: high
  Responsible HIRLAM project leader: Yang

3.7 System development

3.7.1 Considerations

<u>General system aspects:</u>

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 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

The Hirlam cooperation does 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.

At the beginning of Hirlam-B, Harmonie has reached a stage where quality-assured Reference versions can be defined. 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.

GLAMEPS and 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 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 provided 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, a similar RCR is being introduced for Harmonie. However, 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 intended to ensure the technical (and meteorological) capability of the model to be used in an operational environment. The responsibility to act as RCR center will 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 model characteristics).

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.

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).
- 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 2014

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
- Monitor most recent cycle performance on various platforms for operational applications
- Prepare an operational-devoted version of the codes based CY40T1
- 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, 3 pm), 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
- Work on LAM OOPS aspects in cy41 with the main goal to have the forecast model running from the OOPS layer.

HIRLAM staff: Sokka(3pm), Moene(2.5pm), Andrae(2pm), Vignes(2pm)
ALADIN staff: Fischer, Yessad, GCO team, Moll, Guidard, Wattrelot, Taillefer, Bouteloup, Montmerle, Desroziers, Berre, Mary, Arbogast E., Brousseau (femars), El-Khatib, Degrauwe / Note (by Claude): the MF list of staff includes contacts for OOPS in the global system, since some aspects will be Arpège/LAM transversal, Bujnak (1 pm)
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
- 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)
ALADIN staff: Degrauwe, Spaniel (1 pm), 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 for cy40h1, 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
- 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 training in Harmonie and its components (MUSC/SURFEX) for newcomers

HIRLAM staff: Andrae (1pm), Dahlbom (1pm), Moene (1pm), Sokka(1pm), Vignes (1pm), Yang (1pm), Aspelien(1pm), Andersen(3pm RCR),Sattler (0.5pm), Palmason*, Kazlauskas*
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), 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. Five 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.

In data assimilation, the introduction of ways to treat model error is generally seen as a crucial but still very open topic. Research on this is getting started in the Aladin/Hirlam community. 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. The observability of the atmosphere will always be limited with regards to the high resolution NWP models. In the convection permitting models it is not evident anymore that all scales must be updated by analysis. The initialisation on scales where phenomena is described realistically in the probabilistic way only must be addressed. 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. Hybrid ensemble variational techniques play an important role in the realisation of the idea of flow-dependent data assimilation. The efficiency of these methods depends on how rich and adequate structures the ensemble of perturbations can describe. An important topic of investigation is how best to introduce model uncertainty in ensemble forecasting systems. Methods which are presently used are stochastic perturbations of physics tendencies, parameter perturbations, 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. The option of running the physics and dynamics on different grids was close to being finalized in an earlier cycle of the model, but this work has been severely delayed by several staffing changes. A second-order accurate interface based on the SETTLS technique has been implemented and tested. When applied on humidity, significant time oscillations appear. Application on temperature and wind components only, remains stable but without improvement in accuracy. The attempt to have a second order interface will be repeated after introduction of the new physics-dynamics interface prepared by Degrauwe. 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 will be introduced. 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. Its introduction is also an opportunity for cleaning up the main physics steering routines and improving their internal consistency.

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 sub-km resolution are likely to require (quasi-)3D parametrizations. Investigations are planned on the use of 3D schemes for turbulence and radiation at such scales (see WP TR4). 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 reduces the amplitude of horizontal scales smaller than ~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. 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 spectral 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 high quality orographic and physiographic datasets of higher resolution than those which are used at present. Several global, European and national sources of geospatial data will be assessed and inter-compared for this purpose.

V. 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. 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, and apply the boundary conditions and the biperiodization of fields in spectral space.

In terms of parallelization, several existing and potential bottlenecks can be identified. For the most urgent of them, the parallelization of Surfex, some 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 any NWP model 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 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. The recently proposed Gaussian Quadrature 4D-Var, where an iterative approach is used to resolve high-order non-linearities and multiple outer loops can thus be avoided, deserves attention. Another option would be the use of weak constraint 4D-Var with sub-windows running in parallel. In the 4D-Ens-VAR approach, the time evolution of the model increment is described through local combinations of a non-linearly evolved ensemble of the model state perturbations. Because TL/AD model integrations are not needed there anymore, the scalability and computational efficiency of 4D-Ens-VAR is significantly improved in comparison with standard 4D-Var. The treatment of the ensemble of model trajectories over the assimilation window should be designed with care, though. The feasibility of the 4D-Ens-VAR scheme for the full-dimensional NWP models has been demonstrated using the HIRLAM forecasting system. 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, or the related Intel Mic architecture, 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 recoding (either fully into the CUDA language or by adding OpenAcc directives in the code). Experiences with these architecture gained in Ireland and elsewhere have shown that accelerations of a factor of about ~3-4 appear to be possible, but at the cost of a more or less extensive source code refactoring.

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 numerical and computational performance (WP TR5), and to study forecast model aspects in relation to assimilation and ensemble forecasting (WP TR1).
The following subjects will be tackled at intermediate priority:

- 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).
- Cleaning and rationalizing the calls to the physics parameterizations (WP TR 2).
- 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 TR4):

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

3.8.3 Work packages in 2014

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; investigate meaningful scales for analysis update in convection-permitting models; 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(1pm), Yang(0.5pm), Gustafsson(1pm), Bengtsson(2pm), Bojarova (1.5 pm), Frogner(1pm), Johansson(1pm), Garcia-Moya(3pm), Ivanov*
ALADIN staff: A.Ouali (2pm)
Priority: high
Responsible HIRLAM project leader/ALADIN CSSI member: Onvlee / ?

TR2: Physics-dynamics interaction

- complete the new CPTEND_FLEX interface; (i) phasing it to cy40t1, (ii) take part in the re-arrangement of options and setup of GFL and physics-dynamics interface in IFS/AAAAH, (iii) further validation of AROME based on cy40t1.

- cleaning of the physics calling routine(s): (a) removing computations and (b) simplifying the arguments in derived types facilitating the identification of big blocks such as radiation, turbulence and microphysics.
- Assess impact of higher-order accurate physics-dynamics coupling. Subject to the 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 (if manpower becomes available), 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)
- Perform an exercise of radiation cleaning within the Arome physics, with the aim of replacing the preparation of cloud and aerosol input from inside of the three available radiation schemes (RRTM, hlradia, Acraneb) with the usage of variables consistent with the microphysical parametrizations.

HIRLAM staff: Hortal (1pm), Rontu (1pm)
ALADIN staff: Degrauwe (8 pm), 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 / Degrauwe

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.
- Prepare the orographic fields needed by the atmospheric model and surface parametrizations in PGD using high-resolution geospatial data sources.
- Evaluate resulting orography in high-resolution experiments and operational environments.

HIRLAM staff: Rontu (1mm), Guerrero (2mm), Atlaskin*, O'Brien*
ALADIN staff: Seity, Voitus, Mary
Priority: medium to low
Responsible HIRLAM project leader/ALADIN CSSI member: Rontu, Hortal / Vana

TR4: 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.
- Validate the ALARO baseline version between 1km and 2km resolution: first tests.
- Compare Arome/Harmonie at various resolutions against LES (WP PH3, Grey zone project).
- High-resolution experiments with the non-hydrostatic core, in order to find optimal dynamics options suitable for these resolutions and detect the most urgent needs for the development of numerical methods. On the longer term, also the physics will be included.
- Continue and coordinate experiments to assess model performance at sub-km resolutions. 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: Guerrero (4mm), Atlaskin (1mm), O'Brien*
ALADIN staff: Arome 1.3km: Bouyssel, Seity, Yessad (expertise on hybrid level distribution), R.Ben Romdhane (1pm); other high-resolution experimentation: Auger, Hagelin (post-doc at MF), Bastak, M. Vanginderachter.
Priority: medium
Responsible HIRLAM project leader / ALADIN CSSI member: Hortal/ ?

TR5: Numerical efficiency and computational performance

- Profiling and optimization: perform regular scalability measurements, preferably on agreed common datasets;
- Consider parallel and sequential splitting
- Continue optimization of Surfex (investigate I/O packing) and the surface analysis (Canari and related tasks)
- 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 Fullpos-2 (in relation with OOPS actions)
- Improve code design, interfaces, output/input file formats and optimization of the integrated Surfex code in order to improve its effectivity and compatibility with the atmospheric model.
- Update RAPS benchmark with new cycles and extend it to 3D-Var configurations
- Support external studies on new computer architectures (e.g. GPGPU's) and on innovative programming languages related to these new architectures

HIRLAM staff: Leiden, Delft and Vilnius Universities*; Hortal
ALADIN staff: El Khatib, Marguinaud (optimization and scalability), Benard, Seity, Bouteloup
Priority: high
Responsible HIRLAM PL/ALADIN CSSI member: Hortal, Andrae / Fischer, Tudor

4. Activities on operational cooperation and applications

4.1 Considerations

The Hirlam-B programme has been tasked to support and enhance collaboration in operational aspects among member services. Several lines of work will be developed. The organisation and maintenance of the operational GLAMEPS ensemble forecast production is the first area of consortium-wide operational collaboration. During 2014, the first Harmonie-RCR will be launched by DMI and MetCoOp, providing an enhanced vehicle for quality assurance to the community. Additional possibilities to be explored are:

- joint monitoring, troubleshooting, and pre-release testing and tuning of operational suites;
- joint efforts on observation data handling, exchange and pre-processing (especially for the 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.

4.1.1 HIRLAM operational cooperation activities

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. Therefore implementation of the 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.

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.

LAM EPS 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 contained 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. Part of the daily monitoring is shared by the on-duty team, ensuring that production anomalies are reported in a timely manner. In 2014, an upgrade of GLAMEPS is scheduled, which most likely will feature a doubling of production frequency, an increased horizontal grid resolution and a adjustment in model components. With the official launch of GLAMEPS-v2, the range of output parameters, documentation and instruction materials will be further enhanced.

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 observations, and these needs will only increase as the number of observation types continues to grow. Thus, a more effective cooperation in observation handling 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 turn will facilitate many other aspects of operational cooperation. With the introduction of Harmonie, 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 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 here 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. This has been implemented in 2013 and will continue.
- 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. The atmospheric chemistry modelling community is considering to eventually create a similar coupled atmosphere-chemistry setup for Harmonie, using the experiences gained with Enviro-Hirlam. 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), operational GLAMEPS remain a high priority. With introduction of Harmonie-RCR, it will help enhancing collaboration and common efforts on pre-release evaluation and tuning, 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)

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 2014

AP1.1: GLAMEPS maintenance, monitoring and support

- maintenance and upgrade of operational suites 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.
- Quality assurance in form of regular monitoring of products (partly via onduty team), preparation and update of verification results, monitoring and inter-comparison of control suites vs. deterministic run
- Ensure smooth product distribution and member service access to GLAMEPS products.
- Maintenance of data flow for the FROST-2014 project
- Provide range of graphical products and basic documentation for presentation at *glameps.org*, and for downloading as digital fields.
- Maintenance of data server for web graphics and other real-time products.
- Maintain connection and feedback between member services and developers.

HIRLAM staff: Sattler (4pm), Frogner (1pm), Feddersen (0.5pm), Johansson (1pm), Singleton (1pm), Tijm (0.5pm), Yang (1pm), member service contacts on GLAMEPS products*, on-duty task team (~1pm)

ALADIN staff: Belgium (potentially extended later to the ALADIN consortium)

Priority: high

Responsible HIRLAM project leader/ALADIN CSSI member: Yang/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, Eurocontrol, ECMWF), on satellite observations, Mode-S, GNSS and GPS-RO
- Exchange of local data for operational use; arrange maintenance, monitoring and troubleshooting for these data streams
- Consultation with member services on related observation matters
- COPE related activities as in DA5.2, SY2

HIRLAM staff: Dahlbom*, Onvlee*, de Haan*, Ridahl*, Vedel*, Whelan*,member service contact points on data issues, Nestiak (2pm)

Priority: medium to low during 2014

Responsible HIRLAM project leader: Yang

AP1.3: Cooperation on operational implementation, evaluation and monitoring

- Harmonie-RCR related monitoring and evaluation activities
    - Development of RCR monitoring facilities including those for data assimilation
    - Evaluation, tuning and report about pre-operational RCR-CY38 and CY40
    - Regular monitoring and reporting (each quarter) analysing RCR performance issues

- Consultation and exchange of experiences on operational Harmonie with member services, 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: Amstrup*, Andrae (0.5pm?), Andersen (0.5pm), Aspelien (1.5pm), Dahlbom (0.5pm), Dahlgren (0.5pm), Midtbø (1pm), Woetman-Nielsen (2pm), Ivarsson (0.5pm?), Homleid (0.5pm?), NN(SMHI) (1pm), staff from RCR-CY40 service(s)*; member contacts on operational activities, Andrae*, Tijm(post-processing, diagnosis,1pm), Yang (1pm), Kazlauskas
Priority: high
Responsible HIRLAM project leader: Yang

AP1.4: Assessment of user satisfaction and requirements

- regular meetings with user representatives via member state visits by MG or sub-MG groups; participation in relevant user meetings
- 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 limited 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

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Annex 1: **Work packages and resources for 2014:**

Work Package	Description	Resources Hirlam (pm)	Resources Aladin (pm)
DA1	Development of 3D-VAR	17	
DA2	Assessment/sensitivity studies, RUC experimentation	20	
DA3	Development of flow-dependent methods	22	
DA4	Assimilation of radar data	20.5	
DA5.1	Other ground- and space-based upper air observations	41	
DA5.2	Pre-processing and monitoring software	14	
DA6	Observation impact and network design studies	10	
DY1	Development of the dynamical core	14.5	
DY2	Long-term dynamics evolution and testing alternatives	0	
DY3	Boundary conditions and nesting	2	
PH1	Convection and turbulence	29	
PH2	Cloud microphysics, radiation and aerosols	15.5	
PH3	International boundary layer, cloud and convection studies	6	
PH4	Integration and testing of ALARO-1	0	
SU1	Surface: general aspects	4.5	
SU2	Soil	3	
SU3	Snow and forest	10	
SU4	Sea ice	9	
SU5	Lakes	11.5	
SU6	Urban modelling	0.5	
SU7	Orographic effects on radiation and momentum	2	
E1	Development of a convection-permitting ensemble	44.5	
E2	Further development of ~10km scale LAM EPS	8	
E3	Statistical postprocessing and calibration	7.5	
SY1	System maintenance and development	11	
SY2	Developments related to OOPS	9.5	
SY3	Contribution to Interoperability and long-term maintenance	1	
SY4	Harmonie Reference, RCR, user support and documentation	9	
QV1	Development of the HARP verification system	6.5	
QV2	Tools for quality assessment/verification mesoscale	5.5	
QV3	Tools for quality assessment/verification probabilistic	8.5	
QV4	Monitoring and quality assurance	21	
TR1	Forecast model aspects in assimilation, ensemble forecasting	12	
TR2	Physics-dynamics interaction	2	
TR3	Treatment of orography	3	
TR4	Towards sub-km scale resolutions	5	
TR5	Numerical efficiency and computational performance	0	
AP1.1	GLAMEPS operation, maintenance, monitoring, support	10.5	

AP1.2	Observation preprocessing	0	
AP1.3	Cooperation operational implementation and benchmarking	10.5	
AP1.4	Assessment of user satisfaction and requirements	0	
AP2	Model version for use in academia	0	
AP3	Climate	0	

Annex 2: **Time schedule of activities for main deliverables of the programme (for HIRLAM, not checked by CSSI)**

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. Study 3D-Var settings for rapid update cycling. 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 and Jlbc. Continue with field alignment and cloud initialization experiments. Make design for 4DEnsVar system in OOPS context; participate in COPE. Start experimentation with cloud assimilation. Start development of SODA and develop EKF for soil, snow and lake data; develop more realistic structure functions for lakes.. Dynamics: VFE stability testing. Study improved conservation of dry air. Implement elimination of needless extension zone calculations/Boyd bi-periodization operationally. Test second order physics-dynamics interface. Physics: Cloud working group experiments on low clouds/fog, BL and convection behaviour. Continue SBL study and radiation intercomparison. GABLS-4 preparations. Test upgrades to microphysics. Introduction of aerosols in radiation scheme. Feasibility study on handling aerosol-cloud interactions. Continue sub-km modelling and work on introducing/assessing high-resolution orographic and physiographic datasets.
	2014	Testing of hybrid ensemble assimilation (in ensemble and data assimilation mode). Optimize 4D-Var. Refactoring of LAM IFS code in OOPS and COPE context. Start implementation of 4DEnsVar framework for Harmonie. Finalize SODA. Continue work on cloud assimilation and field alignment/image warping. Introduce more high-resolution observations in upper air assimilation and more satellite observations in surface assimilation. Introduce modified to physics-dynamics interface and related code cleaning of steering routines. Implement improvements for fog/low clouds. Introduce and test aerosols in cloud scheme. Continuation of radiation intercomparison with Acraneb2, impact of aerosols, and consistency between radiation, cloud and microphysics schemes. Contine sub-km modelling on various domains.
	2015	Experimentation with 4DEnsVar. Upper air and surface data assimilation systems enhanced with respect to use of various suitable remote sensing data.
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 different nesting scenario's. Consider GLAMEPS data policy. Incorporate user feedback in product generation/ dissemination. GLAMEPS training for forecasters. Preparations for FROST-14.

	2013	Continue testing of GLAMEPS-v2, prepare for operation. Continue HarmonEPS evaluation of nesting experiments, test with different physics and initial perturbations. Prepare for real-time production. Preparations for FROST-14. Develop and test calibration of near-surface parameters.
	2014	Implementation of GLAMEPS-v2 and calibration. Continue HarmonEPS experimentation with physics, ensDA perturbations, start with surface perturbations. Start real-time runs of HarmonEPS and evaluation. Evaluation of FROST-14.
	2015	HarmonEPS first version ready for operational use.. 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. StartLAM IFS design and coding for OOPS and COPE. Make Harmonie External User guide available. Harmonie RCR testing of Cy38 by DMI/MetCoop. Finish GPGPU/ OpenAcc studies. Start work on ECFLOW..
	2014	Complete LAM part of COPE revision of observation pre-processing, largely introduce LAM IFS OOPS changes. Introduction of GLAMEPS-v2, real-time runs of HarmonEPS. Continue work on ECFLOW.
	2015	Release Cy40h1. First HarmonEPS version ready for operational use. 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. Preparation and testing of GLAMEPS-v2. 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	Implement GLAMEPS-v2. Prepare HarmonEPS for real-time use. Continue user consultation activities Start consideration of cooperation in postprocessing.
	2015	Continue user consultation activities

Annex 3: Planned meetings in 2014

ASM/Workshop: 7-11 April, Bucarest
EWGLAM: 29 September - 3 October, Offenbach
HIRLAM working weeks:
- Data assimilation algorithms:
- Observations: fall?
- Radiation: 2 meetings
- Cloud working group: 1 meeting?
- Surface: 1 meeting?
- EPS: spring, fall
- System: spring, fall
- Verification: 1 meeting?

Aladin/LACE working days:
- Surface
- ALARO-1
- Radar

SRNWP EPS meeting: spring