SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	HIRLAM-B second phase (2014-2015)
Computer Project Account:	spsehlam
Start Year - End Year :	2014 - 2015
Principal Investigator(s)	J. Onvlee
Affiliation/Address:	KNMI Utrechtseweg 297, P.O.Box 201, 3730 AE De Bilt, the Netherlands
Other Researchers (Name/Affiliation):	The HIRLAM-B project leaders (Ulf Andrae (SMHI), Xiaohua Yang (DMI), Jelena Bojarova (Met.no/SMHI), Laura Rontu (FMI), Mariano Hortal (AEMET)) and research team (~70 scientists)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

To develop and improve the Harmonie analysis and forecast system, with a view to the operational needs of the HIRLAM member institutes. Experimentation with, and implementation of, new developments in the Harmonie Reference system are mainly carried out at ECMWF, using the Special Project resources plus a pool of national resources.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

The main problems encountered are:
- permanent disk space is limited compared to what is available at the HIRLAM institutes.
- the varying environment with work load spread over various hosts (for e.g. compilation vs. execution), which makes the HIRLAM and Harmonie working environments at ECMWF rather different from the ones at the HIRLAM institutes.

ECMWF user support deserves a compliment for their help and responsiveness to users encountering difficulties.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The application procedure and progress reporting is straightforward, and user-friendly with the provided template forms and information on the ECMWF web site. The advance warnings by ECMWF of when deadlines for reporting appear, is quite appreciated. In case of any questions or problems with resource allocations, account users etc., ECMWF special projects staff have always been most helpful.

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

The HIRLAM-B (phase 2) Special Project: Jan 2014 – Dec 2015

Final report

Jeanette Onvlee, HIRLAM Programme manager, KNMI

The HIRLAM-B Programme, which has started on January 2011, is a continuation of the research cooperation of previous HIRLAM projects. The full members of HIRLAM-B are: the national meteorological institutes in Denmark, Estonia, Finland, Iceland, Ireland, Lithuania, Netherlands, Norway, Spain, and Sweden. Meteo-France is an associate member of HIRLAM-B.

Within HIRLAM, research is focussed on the development and improvement of a convection-permitting non-hydrostatic analysis and forecast system within the IFS coding environment, called Harmonie, and the derivation of ensemble prediction methods suitable for the short range. The Harmonie system is developed jointly with Meteo-France and the ALADIN consortium. The emphasis in the HIRLAM-B Special Project at ECMWF has been on experimentation with, and evaluation of, the Harmonie model. The main results achieved in the past two years in the development of Harmonie are outlined below. Much of this research has been done on ECMWF platforms.

In the field of probabilistic forecasting, the goal is to achieve a reliable high-resolution production system for short-range ensemble forecasts, with an emphasis on severe weather. Existing and new ensemble generation techniques are being combined into a multi-model ensemble of HIRLAM and ALADIN members of ~8km resolution, called GLAMEPS, and in an ensemble for the convection-permitting scale, based on the Harmonie model, called HarmonEPS. Separate special project resources have been requested for these probabilistic forecast research activities (spnoglameps), so that work will be described elsewhere.

Data assimilation and use of observations:

At the beginning of this special project, the default data assimilation of Harmonie consisted of 3D-Var and assimilation of conventional data only. For surface data assimilation, optimum interpolation of screen-level observations was used in the vertical, with the CANARI system for horizontal spatialization.
The bulk of the data assimilation R&D efforts in the past years have been devoted to:

- make available a range of high-resolution (mostly remote sensing) atmospheric and (to a lesser extent) surface observations in the Harmonie data assimilation system; assess their impact in real-time suites, and optimize their impact through enhanced quality control, bias correction procedures and tuning of structure functions
- test the impact of these observations also in rapid update cycling mode, for nowcasting applications
- develop, introduce and test more advanced flow-dependent assimilation algorithms (4D-Var and ensemble assimilation techniques for the atmosphere, Extended Kalman Filters (EKF) for the surface).

The main focus in the assimilation of high-resolution atmospheric observations has been on radar reflectivities and winds, GNSS zenith total delays, Mode-S aircraft data, ATOVS, ATMS and IASI radiances, scatterometer winds and atmospheric motion vectors (AMV’s).
Software has been developed and introduced Hirlam-wide for the ingest and pre-processing of radar data, from local radars and from the OPERA data hub. The Baltrad quality control procedures to be used in OPERA have been introduced and tested, not altogether satisfactorily. Stricter quality control, improved EDA-based structure functions and more intelligent data selection by super-obbing have been introduced and proven to be beneficial. Radar reflectivities have shown some positive impact in 3D-Var in most countries (fig. 1, Zhuang et al. 2015), and are being introduced operationally or pre-operationally in several services. The quality of these data still could be improved further, in particular concerning sea clutter and beam blocking. For the assimilation of radar winds, there are generally still severe problems with the quality of OPERA data, which appear to be related to the de-aliasing procedure used. Alternative de-aliasing procedures are being investigated.

GNSS zenith total delay observations and ATOVS/ATMS radiances have shown positive impact after application of variational bias correction and careful observation statistics tuning, and these too have been or are being prepared for operational inclusion (Sanchez-Arriola et al 2015). Mode-S aircraft observations have been introduced, made available internationally and proven to be a powerful new source of dense high-quality wind data (e.g. EUMETNET ET-ADD report, 2015). SEVIRI clear-sky water vapour data have been seen to have positive impact on various moisture-related parameters. Other types of data which have been prepared for routine use in assimilation are e.g. IASI radiances, scatterometer winds, AMV's and GPS radio occultation data.

New fine-scale structure functions have been developed for 3D-Var, which are based on EDA (Gustafsson and Bojarova 2015). Using these functions, there is less spinup, and the structures in the analysis field appear to be more small-scale and realistic. Nevertheless, studies have clearly shown the severe limitations of 3D-Var in handling adequately the assimilation of high-density data such as radar, even in RUC mode. Introducing greater flow-dependency in the background errors is believed to be of critical importance, both for creating a stronger and longer lasting impact of observations, and for reducing model spin-up. The two options which are being considered for this are 4D-Var and a hybrid 3D-Var/ETKF scheme. Ultimately, it is intended to combine these two approaches into an integrated 4DenVar ensemble assimilation scheme.

A 4D-Var scheme has been developed for Harmonie, and been tested in parallel runs. Although there still are technical issues that should be improved, and there are some important functionalities that remain to be added, the 4D-Var system as it exists now has shown itself to be robust and mature enough to be used in impact assessment studies. In case studies, the strength of 4D-Var to maintain impact of observations longer into the forecast, and to provide a better position and timing of features like fronts and convergence zones, has been seen repeatedly. A beginning was made to extend the 3D-Var and rapid update cycling impact studies for radar, Mode-S and cloud initialization to 4D-Var (fig.2).

For the Hirlam analysis system, 3D- and 4DEnVar algorithms have been introduced and shown to be superior in meteorological and computational performance to 3- and 4D-Var, respectively (Gustafsson et al. 2014). As the starting point of developing a similar 4DEnVar system for Harmonie-based ensemble systems, an LETKF assimilation scheme has been developed, which has become available early 2015. After tuning of length scales for horizontal and vertical localization, and investigating the choices for multiplicative or additive inflation used in the LETKF scheme, the performance of the LETKF scheme has shown a consistent and encouraging improvement over 3D-Var.

Two methods which have been developed and proven their capabilities to enhance a variational analysis (and forecasts) in the nowcasting range are cloud initialisation by means of MSG data (de Haan and vdVeen, 2014), and the hybrid 3D-Var/field alignment (FA) system (Geijo, 2015). In the coming years, both these methods will be integrated into the variational assimilation system.

Atmospheric model:

Model aspects that remained to be improved at the start of this special project, were the over-active convection in weakly forced situations, the overestimation of low clouds, too spotty precipitation and cloud behavior, and the representation of stable boundary layer conditions. Several adaptations have been implemented and shown their ability to improve the cloud, precipitation and boundary layer wind behavior of the model significantly. A separation was introduced between fast liquid water and slow ice processes, and several other changes in the ICE3 microphysics have been evaluated, with the view to reduce an overestimation of low ice clouds (Ivarsson 2015). In parallel runs, the new HARATU turbulence scheme has proven its potential for reducing biases in cloud cover, low clouds and boundary layer winds (De Rooy et al., 2014a,b) and it has consequently been introduced in Cy40h1. The cloud initialization, HARATU and microphysics changes have all been shown to reduce the over-forecasting of fog and low clouds.

Many efforts have also been spent to assess and further improve the radiation behaviour. The treatment of the effects of the surface (slopes and vegetation) on the radiative surface flux has been improved through the introduction of sloping surface parametrizations. The impact of using a more advanced clear sky radiation transfer parametrization has been studied. A cloudy bias in the SW radiation flux was detected, which could be largely removed through a change in the cloud inhomogeneity factor and an alternative cloud optical properties parametrization (Nielsen et al. 2015, Gleeson et al. 2015). Advanced aerosol direct effect parametrizations have been introduced for short-wave radiation and shown to be significant and beneficial in specific situations, provided that observed aerosol values are used (Toll et al. 2015).

In attempts to enhance the description of the stable boundary layer, new turbulence parametrizations were introduced and tested, until now without much success. A multiple energy balance scheme for the influence of snow over vegetation was introduced and shown to be of some benefit. Hirlam staff have participated in the organization of the GABLS4 field experiment on stable boundary layer conditions over Antarctica.

The emphasis in dynamics developments has been on enhancing the accuracy and efficiency of the dynamics. To improve accuracy, a vertical finite element method has been developed in a close cooperation between ALADIN and HIRLAM. A non-hydrostatic vertical finite element discretization with a mass-based vertical coordinate has recently been introduced. Although the VFE scheme in all tests has proven to be as stable as finite differences, no obvious benefits have yet been seen in terms of classic verification scores. This may be due to the fact that the scheme is not yet fully "finite element", in that it still contains finite difference operators in the vertical velocity and top and bottom boundary conditions. New operators are being formulated to replace the remaining finite differencing operators.

Upper air Davies relaxation has been introduced and found to be beneficial for numerical stability (Hortal 2014). Experiments have been done with alternatives to the default linear spectral grid. The options of using a cubic grid (which truncates waves at 4Dx vs 2Dx for the linear grid) and a quadratic (3Dx truncation) grid have been investigated. The greater smoothing of the non-linear grids leads to small but significant deteriorations in wind and temperature scores, and is particularly damaging in mountainous areas. However, the use of non-linear grids provides greater stability and enables the use of larger time steps than the linear grid. The reduction of computational costs achieved this way may be of particular interest to the introduction of high-resolution ensembles, the configuration of which is generally limited by computational capacity.

A wide range of tools has been employed for the process studies on turbulence, convection, radiation and surface effects: use of international model case studies like GABLS4; routine model inter-comparisons in 3D and 1D in the KNMI testbed to assess sensitivities to differences in schemes; evaluation against Cloudnet sites; and the testing of model physics configurations in longer climate runs as compared to standard NWP setups. The use of this variety of methods may teach us much on the underlying causes of systematic model errors. In particular the KNMI testbed (De Rooy et al. 2015) is increasingly proving its value for the testing of physics developments, and its use will be promoted.

<u>Surface analysis and modelling:</u>
For the surface, OI assimilation of in-situ surface observations has been introduced in Harmonie for snow, lakes and sea ice. The surface analysis system still is far less sophisticated than either the atmospheric data assimilation or the surface model. Thus, the aim has been to introduce a more advanced set of extended Kalman Filters (EKF's), permitting assimilation of satellite observations of the soil, sea surface and inland waters, and snow- and ice-covered surfaces. A Surfex Offline Data Assimilation (SODA) framework for these EKF's has been developed, and EKF's are under development for soil, snow, sea ice and lakes. Studies have been made of the suitability and impact of various types of surface satellite data (e.g. Globcover snow, MODIS lake surface temperature, ice cover) in combination with these EKF's, e.g. in the context of COST action ES1402. In the context of several externally funded projects, work has started on the assimilation of hydrological information from satellite radiance and backscatter data (AMSR2/GCOM-W1, MIRAS/SMOS, SAR/Sentinel-1, ASCAT soil moisture). For lake data assimilation, investigations are ongoing aiming to develop more realistic structure functions and to assess the impact of various types of satellite observations (e.g. Kheyrolla-Pour et al. 2014).

Surface modelling developments have mainly concentrated on typically Nordic aspects like snow, sea ice and lakes: the assessment and further development of the Flake lake model (e.g. Eerola et al. 2014), the development of a simple sea ice model (SICE), and a snow-over-vegetation scheme (MEB) in the Surfex system of externalized surface modules. Most of these features have been introduced in a new version of Surfex, v8, which will become available in 2016. They will be implemented for operational NWP use, and also in the Harmonie-climate branch, from 2016 onwards. Urban studies have explored the use of the Town Energy Budget (TEB) scheme at very high resolutions in off-line mode (e.g. Fortelius and Kadantsev 2014, Karsisto et al. 2015).

The default orographic and physiographic datasets in Harmonie are GTOPO and ECOCLIMAP (presently version 2), both at 1km resolution. Efforts have been, and are being, made to assess and address potential deficiencies in these databases, particularly ECOCLIMAP, for the various HIRLAM domains. An example of this is an in-depth study of the quality of ECOCLIMAP physiographic data over Iceland and Greenland against higher-resolution data, leading to recommendations for extensive changes in the albedo, the evapotranspiration for different land cover types and the representation of snow surface properties on glaciers. In the context of sub-km resolution experiments, experience has been gained with using higher resolution datasets like ASTER. Meteo-France has recently introduced a new higher-resolution (250m) orographic database, GMTED2010; this has been tested and included in Harmonie Cy40h1 as well. A global lake and lake climatology database have been made available and maintained by Hirlam staff (Choulga et al. 2014). A start has been made with the development of a higher resolution lake database, based on Globcover data.

Efficiency, scalability and transparency

Efforts to enhance the algorithmic efficiency, scalability and transparency of the LAM codes have been and are undertaken mainly in the system and dynamics activities. Work has been done e.g. to reduce the number of computations in spectral space, to introduce an I/O server, and to reduce the number of field format transformations. Several recent dynamics developments, such as the use of upper boundary relaxation and the study of non-linear spectral grids, have been aimed at making the code numerically more stable, thus allowing the model to be run at larger time steps. MPI and OpenMP optimization has been introduced in various places where it was not yet available, and the Surfex code has been cleaned and optimized. Studies were performed to permit the model to run on GPU and mixed CPU-GPU architectures (e.g. O'Brien 2015).

.

Figures:

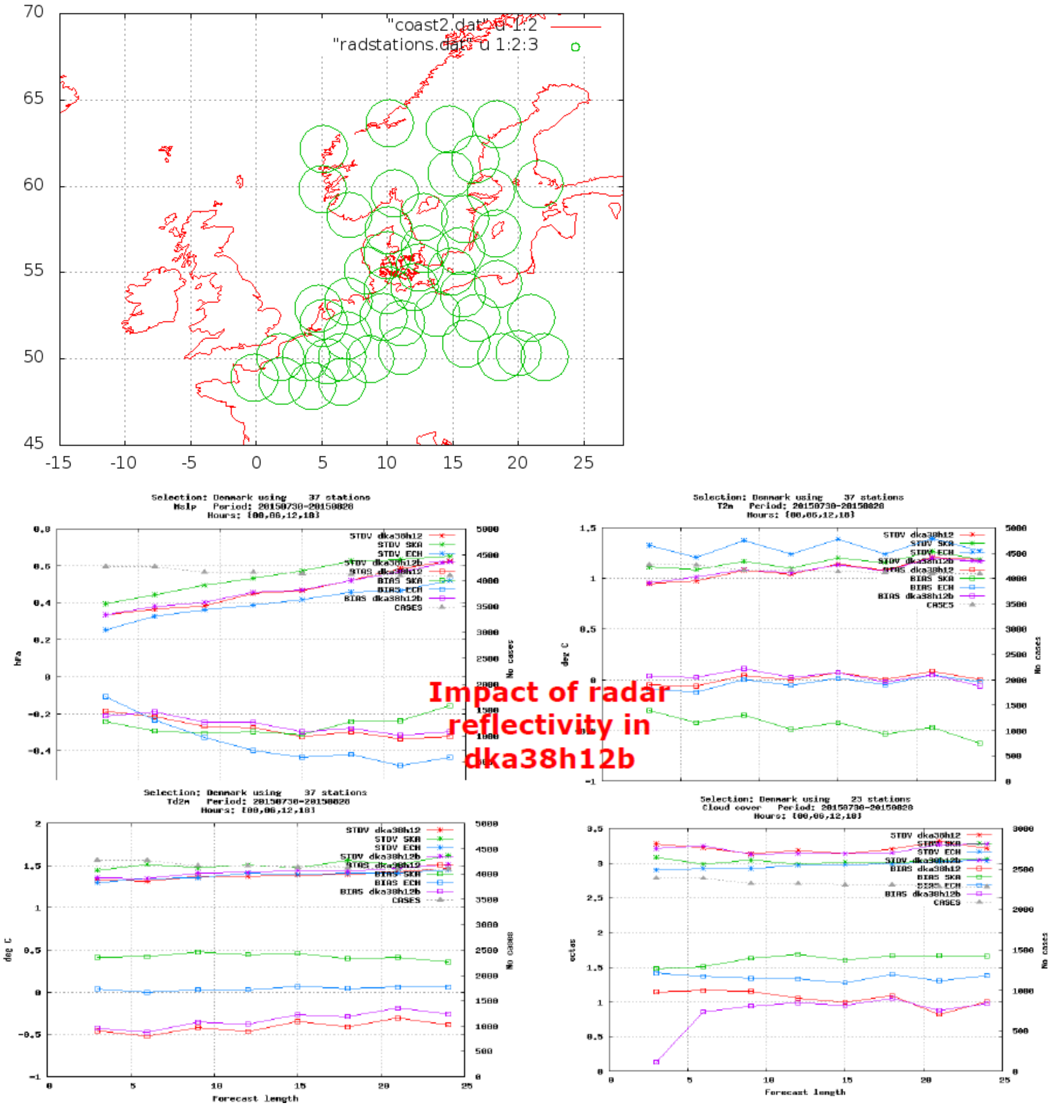

Fig. 1: Coverage of OPERA radars assimilated in experiments for the DMI domain (top figure) and impact of radar reflectivity assimilation in terms of near-surface verification scores for this domain (bottom figure). At this time (early 2015) DMI was assimilating radar information from ~40 radars from 10 countries, by now this has risen to ~70 radars from 12 countries (including UK). The bottom figure shows the standard deviation and bias of mslp, T2m, Td2m and cloud cover, for Harmonie Cy38h1.2 (red), the 3km Hirlam run (green), ECMWF (blue) and the Cy38h1.2 run with radar assimilation (purple). The scores generally show a positive impact of the radar assimilation.

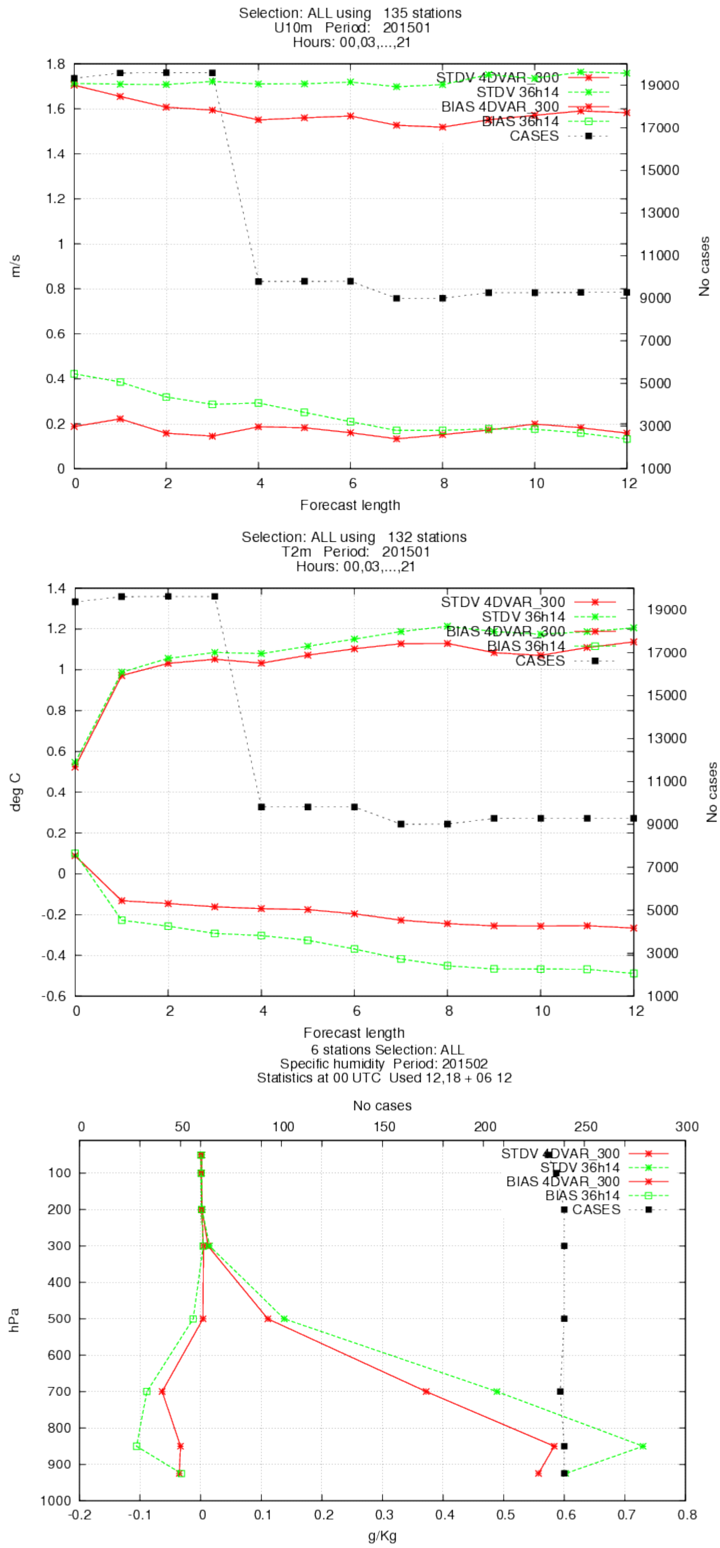

Fig. 2: Verification results for January and February 2015, comparing an experimental 4D-Var system run for the Harmonie-KNMI domain with assimilation of conventional and Mode-S data (red curves) against the operational 3D-Var run (green). Shown are the standard deviation and bias of u10 and T2m, and specific humidity profiles. In this example and for other periods, 4D-Var has shown to generally outperform 3D-Var.

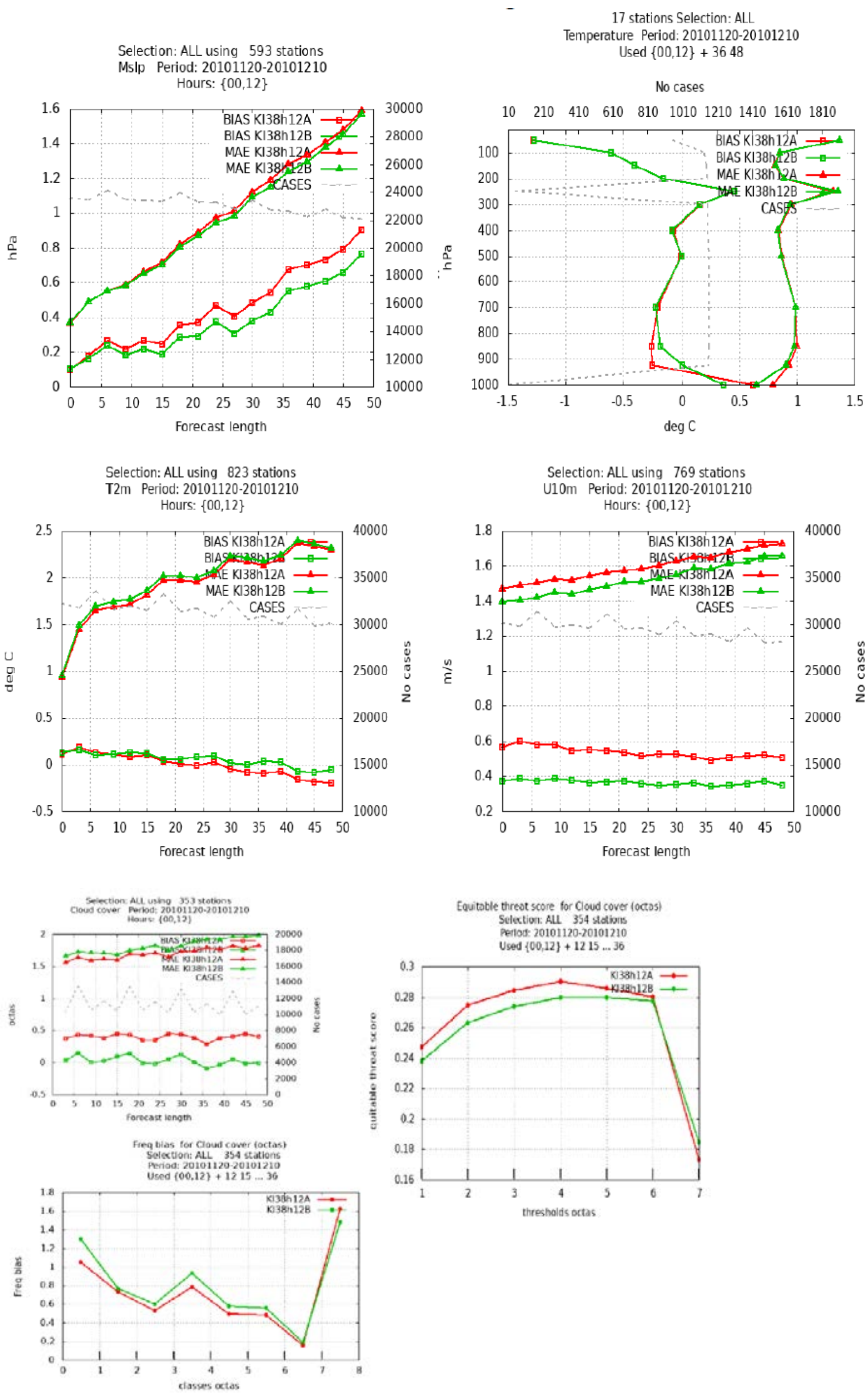

Fig. 3: Experiment on the impact of the new HARATU (HArmonie with RAcmo TUrbulence) turbulence scheme on profiles, near-surface parameters and cloud cover in a winter month over Sweden. Verification results are shown for bias and mean absolute error as a function of forecast lead time for the default Harmonie Cy38h1.2 (red) and for Cy38h1.2 with the HARATU scheme (green), for mean sea level pressure (top left), the vertical temperature profile (top right), T2m (second row left), u10 (second row right) and cloud cover (third row left). Also shown are the equitable threat score and frequency bias for cloud cover (third row right and bottom row). The new turbulence scheme generally produces stronger mixing in the lower atmosphere, leading to a beneficial reduction in (low) cloud cover, a reduction in the positive bias of u10, and general improvements in pmsl error and temperature and moisture profiles.

List of publications/reports from the project with complete references

Baklanov, A., et al., 2014: *Online coupled regional meteorology-chemistry models in Europe: current status and prospects*, Atmos. Chem. Phys. 14, 317-398

Borsche, M., A.K. Kaiser-Weiss, P. Undén and F. Kaspar: *Methodologies to characterize uncertainties in regional reanalyses*. Adv. Sci. Res., 12, 207-218, 2015. http://www.adv-sci-res.net/12/207/2015/ doi:10.5194/asr-12-207-201

Bosveld, F.C., P. Baas, E.M. van Meijgaard, E.I.F. de Bruijn, G.J. Steeneveld en A.A.M. Holtslag, 2014: *The GABLS Third Intercomparison Case for Boundary Layer Model Evaluation Part A: Case Selection and Set-up*, Bound.-Layer Meteorol. 152, 133-156, 2014, doi:10.1007/s10546-014-9917-3.

Bosveld, F.C., et al. 2014: *The GABLS Third Intercomparison Case for Boundary Layer Model Evaluation Part B: Results and Process Understanding*, Bound.-Layer Meteorol. 152, 157-187, doi:10.1007/s10546-014-9919-1.

Campins, J., and Navascues, B., 2015: *Impact of targeted observations on HIRLAM forecasts during HyMeX-SOP1*, submitted to QJRMS.

Choulga M, Kourzeneva E, Zakharova E, Doganovsky A. *Estimation of the mean depth of boreal lakes for use in numerical weather prediction and climate modelling*. Tellus A 2014, 66, 21295, http://dx.doi.org/10.3402/tellusa.v66.21295

Doscher, R., T. Vihma, E. Maksimovich, 2014: *Recent advances in understanding the Arctic climate system state and change from a sea ice perspective: a review*, Atmos. Chem. Phys. Disc. 14, 10929-10999

Eerola, K., Rontu, L., Kourzeneva, E., Kheyrolla-Pour, H., Duguay, C., 2014. *Impact of partly ice-free Lake Ladoga on temperature and cloudiness in an anti-cyclonic winter situation – a case study using a limited area model*. Tellus A. Vol. 66. Doi: 10.3402/tellusa.v66.23929

EUMETNET E-ADD Feasibility Study Expert team, 2015: *Final report of the EUMETNET ADD FS ET on the feasibility to initiate a new EUMETNET activity for aircraft derived observations under the EUMETNET observation program*. EUMETNET Report, October 2, 2015, http://mode-s.knmi.nl/documents/EUMETNET_ADD_Report_FINAL_v1.0_031015.pdf

Fortelius, C., and Kadantsev, E., 2014: *Single-column experiments with the EFB turbulence closure*, Aladin-Hirlam Newsletter 3, 28-35, http://www.cnrm.meteo.fr/aladin/IMG/pdf/nl3.pdf

Gleeson, E., Pagh Nielsen, K., Toll, V., Rontu, L., Whelan, E., 2015. *Shortwave radiation experiments in HARMONIE: Tests of the cloud inhomogeneity factor and a new cloud liquid optical properties scheme*. Aladin-Hirlam Newsletter 5, p92-105, http://www.cnrm.meteo.fr/aladin/IMG/pdf/nl5.pdf

Gustafsson, N., Bojarova, J., 2015: *Relevance of climatological background error statistics for mesoscale data assimilation*. Aladin-Hirlam Newsletter 5, p67-78, http://www.cnrm.meteo.fr/aladin/IMG/pdf/nl5.pdf

Gustafsson, N., Bojarova, J., and Vignes, O., 2014: *A hybrid variational ensemble data assimilation for HIRLAM*, Nonlin. Processes Geophys. 21, 303-323, doi: 10.5194/npg-21-303-2014

Haan, de S., and van der Veen, S.H., 2014, *Cloud initialization in the Rapid Update Cycle of HIRLAM*, Wea. Forecasting, 29, 1120-1133

Haan, de S., 2014*: Mode-S enhanced surveillance derived observations from multiple air traffic control radars and the impact in hourly Hirlam*, Aladin-Hirlam Newsletter 1, 4-8, http://www.cnrm.meteo.fr/aladin/IMG/pdf/nl1.pdf

Hortal, M., 2014: *Aliasing and upper level explosions: two fixes*, Aladin-Hirlam Newsletter 3, 9-15, http://www.cnrm.meteo.fr/aladin/IMG/pdf/nl3.pdf

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

2015 is the final year of the HIRLAM-B research programme and of this special project related to it. A new programme, HIRLAM-C, will run from 2016-2020. A new proposal has been submitted, and granted, for special project resources for HIRLAM-C (HIRLAM-C first phase (2016-2018)), along similar lines and with a similar purpose (experimentation and testing of the Harmonie Reference System), but with updated scientific goals (see the progress report submitted for that project).