# SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

**Reporting year** July 2013-June 2014……………………………………

**Project Title:** HIRLAM-B (2d phase 2014-2015) Special Project

**Computer Project Account:** SPSEHLAM………………………………………………

**Principal Investigator(s):** J. Onvlee…………………………………………………

**Affiliation:** KNMI……………………………………………………

**Name of ECMWF scientist(s) collaborating to the project** (if applicable) ---

**Start date of the project:** 1 January 2014…………………………………………

**Expected end date:** 31 December 2015……………………………………

## Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

| | | Previous year | | Current year | |
|---|---|---|---|---|---|
| | | Allocated | Used | Allocated | Used |
| **High Performance Computing Facility** | (units) | 5600000 | 5600000 (+ part of an additional pool of national resources) | 6000000 | 6000000 (+ part of an additional pool of national resources) |
| **Data storage capacity** | (Gbytes) | 15000 | 15000 | 20000 | 20000 |

## 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 any)

(20 lines max)

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.

**Summary of results of the current year** (from July of previous year to June of current year)

# The HIRLAM Special Project; July 2013 – June 2014

**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 is on experimentation with, and evaluation of, the Harmonie model. The main results achieved in the past year 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.

<u>Data assimilation and use of observations:</u>

For upper air observations, priority has been given to the inclusion of radar, GNSS ZTD, ASCAT, Mode-S and IASI observations, and observation impact studies with these data. The work in this area has focused on three issues: (1) observation quality control and pre-processing, (2) the setup of real-time observation data streams, including activities focussing on achieving international real-time data exchange, and (3) impact studies for all above-mentioned types of high-resolution observations. Aspects which were investigated in those impact studies were how to optimize the benefits from the new observations types in relation to e.g. like the impact of model bias, the scales at which high-resolution observations should be assimilated into the model, and how to best incorporate larger scales from the nesting global model analysis.

Radar volume data are routinely being assimilated in a majority of the Hirlam NMS's. In addition to national radar data, members have begun to incorporate radar data from other countries; e.g. DMI is now able to routinely assimilate data from ~40 radars from Denmark and four neighbouring countries. Late 2013 SMHI made available an ftp dissemination system for testing the technical feasibility of real-time distribution of radar data from services that permit their use for data assimilation, via Odyssey and SMHI to local Harmonie suites. For the smooth ingest of "foreign" radar data there are still quite many small technical issues to be addressed (in close cooperation with OPERA), but the focus is shifting towards how to get optimal impact from these data (in terms of quality control, level of thinning, error characteristics etc).

The assimilation of GNSS ZTD data has been refined in a number of ways: improved white-listing, stricter quality control, lower observation weight, more thinning, stiffer VarBC coefficients. With those changes, persistent positive impact was shown on humidity scores and accumulated precipitation over Spain (fig.1). ASCAT winds were shown to have a weak positive impact in general, but also the ability to improve temperature and humidity at larger scales in areas of intense storm development. Work on the assimilation of surface-affected IASI radiances has continued. Mode-S EHS data from Eurocontrol are being made available for NMS's in real-time through an ftp server at KNMI. The data are quality-controlled and provided in AMDAR BUFR format.

Rapid update cycling (RUC) studies have been done to explore optimal setups and limitations of the RUC approach for individual data sources, testing e.g. optimal levels of thinning and spin-up properties. RUC experiments were made at 3-hourly, hourly and sub-hourly intervals, involving GNSS ZTD, Mode-S observations, radar reflectivities and winds, ASCAT winds and selected wind profilers.

Until now, the impact of new high-resolution observations seen in these 3D-Var configurations has generally been positive but limited in both size and duration, and there are many indications that this is at least partly due to the strong limitations of the assumptions made in the default Harmonie 3D-Var setup (static climatological background errors, heuristic blending procedure to incorporate larger scales from ECMWF, standard thinning options). 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 imbalances and spinup. It therefore is a matter of the highest priority to include 4D-Var and hybrid 3D-Var/ETKF in these assessment studies as soon as possible.

Significant advances have been made in the development of more flow-dependent assimilation methods. The development of a 3D-Var setup with time-centered First Guess at Appropriate Time (FGAT) is close to completion. Also, it has been made possible to run 4D-Var in conjunction with Arome/Surfex. The behaviour of this configuration in both meteorological and computational sense is being tested pre-operationally, assimilating conventional and Mode-S data (soon to be extended with radar); initial results are positive (fig.2). On the longer term, it is aimed to develop a so-called Gaussian quadrature version of 4D-Var, in which multiple outer loops can be avoided, leading to a significant reduction in computational costs. Work on implementing this Gaussian quadrature method has recently started at met.no.

The aim for the coming years is to realize a 4DEnVar framework of data assimilation methods. This code environment should encompass all 3/4D-Var and ensemble 3/4D-Var configurations considered relevant for both data assimilation and ensemble forecasting. A complication in the development of this framework is that its timing is coinciding with the extensive refactoring of the assimilation code at ECMWF (the so-called OOPS project), which the Harmonie model has to follow. A main target for 2014 is to first create a 3D-Var and then a hybrid 3D-Var/ETKF ensemble assimilation scheme for Harmonie under the new code structure provided by OOPS. In 2015 and later, the 4D-Var, 4DEnVar and 3D-Var/centered FGAT configurations will be added.

Improving the initialization of clouds is considered to be an important next objective. Longer impact studies with a crude cloud initialization method by means of MSG observations have shown beneficial effects for both cloud properties and other parameters up to 24h into the forecast, and very positive impact on situations in which the model had severely overestimated fog over sea. The method will be extended to more advanced cloud products from MSG, and it will be studied to what extent the impact is affected by integrating this initialization approach within the 3D-VAR framework in different manners.

Experimentation with field alignment methods (to correct for displacement errors) has been extended from radar wind to reflectivity data. A positive impact of up to 24h has been observed.

Surface data assimilation in Harmonie is presently based on OI, but a new framework called the Surfex Offline Data Assimilation (SODA) system is under construction which is based on an extended Kalman Filter (EKF) approach for all surface variables. A basic version of SODA has been created, and this will be gradually extended in a number of ways, in particular in the number of different (remote sensing) observation types it can handle. Experiments with snow assimilation of in-situ observations and various satellite products have continued at met.no, FMI and IMO. In snow assimilation, the first priority at present is to include as many as possible in-situ snow observations. A more effective use of satellite data in an EKF snow assimilation scheme may become possible after the introduction of a more sophisticated 3-layer snow scheme (expected in 2015). For lake data assimilation, it is being investigated how to develop more realistic structure functions.

Forecast model:

Clear progress has been made in the activities to tackle some persistent types of forecast failures with respect to clouds and convection. One of the problems seen in Scandinavia is that for very cold weather the model often shows spurious ice fog or low level ice clouds. Modifications in the ice microphysics, changing the balance between mixed-phase and ice clouds, led to the elimination of most of this spurious ice fog. The problem of over-forecasting of fog over sea was shown to have several possible contributing causes. Two potential solutions (cloud initialization and a different treatment of cloud top entrainment), after having demonstrated their capability of reducing the fog problems for specific test cases, are now undergoing extensive testing in parallel suites. In some of the fog cases studied, a contributing factor appears to be a too moist upper surface layer over land, which moistens the air in the lower atmosphere too much; advection of this air over sea can lead to the formation of fog over sea. This aspect is still under study.

Wintertime surface temperature problems appear to mostly occur in highly stable conditions with very low near-surface wind speeds, which are notoriously difficult to model. In this context, it is being investigated whether Zilitinkevitch' turbulence energy and flux budget (EFB) scheme can provide a better description of stable boundary layer conditions. It is being tested in the first instance in single column mode (fig.3). A contributing factor to the temperature problems is presumably deficiencies in the model description of snow over vegetation. The introduction of a new snow over vegetation scheme which has been proposed to address this, has unfortunately been delayed until this autumn.

Work has continued on an inter-comparison study between the Harmonie default radiation scheme and that of spectrally less detailed, but more frequently run alternative schemes, such as the hlradia radiation scheme from the Hirlam model, and the updated Acraneb-2 scheme from Aladin. The radiation studies will continue with the testing of the potential benefits of a more consistent treatment of clouds and aerosols, including an orographic parametrisation and the direct aerosol effect in the radiation scheme, which has been implemented last year. Sensitivity studies with aerosol will be carried out in single column mode.

Several avenues are being explored to improve, or provide alternatives for, the ICE3 microphysics parametrizations. DMI staff has been working to develop a 1-moment scheme based on extensions of STRACO, which is being implemented in Arome. Meteo-France has been experimenting with a 2-moment scheme from mesoNH called LIMA.

A non-hydrostatic vertical finite element discretization with a mass-based vertical coordinate, developed within LACE, has recently been introduced. This 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. This may adversely influence the accuracy of the VFE scheme. Ways to eliminate its remaining finite difference features are being investigated. These formulations, however, have not yet proven to be numerically stable, and this will be studied further.

To improve the mass conservation of dry air, the elimination of aliasing in the vorticity contribution from the pressure-gradient term, introduced by ECMWF in the IFS, has been extended to the limited area model. This has also led to the elimination of noise which was sometimes observed in surface pressure fields. Now the conservation of ozone (without chemistry) is being investigated.

The Boyd biperiodization and application of boundary coupling in spectral space has recently been introduced. Use of these features will permit the elimination of unnecessary computations in the extension zone, and thus allow experimentation with the use of larger extension zones, which is believed to be beneficial in data assimilation. A method has been proposed to create a weak formulation of transparent boundary conditions based on discontinuous Galerkin methods. This will be tested in the first instance in a shallow water model and also be applied to the upper boundary conditions.

Experiments at (sub-)km resolutions are continuing in several places (Spain, Ireland, Netherlands, Norway, Finland). Work has initially concentrated on deriving appropriate physiographic databases for these resolutions. The present model orography is based upon the GTOPO30 database (1km resolution globally). Experience has been gained with using more detailed locally available digital elevation maps in the model orography, and generic software has been created for integrating such information in the model reliably. To prevent the model from becoming numerically unstable at these resolutions, a predictor-corrector scheme can be used, but this roughly doubles the cost of the dynamics. As the stability problems mainly occur at or near the model top, instead upper boundary nesting was introduced. By applying this vertical nesting, the encountered stability problems were shown to disappear.

A new physics-dynamics interface is being implemented in the main forecast model steering routine APLPAR, which should be suitable to handle the Arome, Alaro and Arpege physics packages. This is also being used as an opportunity to thoroughly clean up the time step organization code, and to look into its code transparency and efficiency aspects. The radiation team will start in parallel on cleaning the radiation code in the present steering routine for Arome, APLAROME, and attempt to achieve a more consistent treatment therein of microphysics in the cloud, condensation and radiation schemes.

A new version of the surface model Surfex (v8) will become available in autumn 2014. The main new features in v8 will be the MEB snow-over-vegetation scheme, changes in the CROCUS snow and TEB urban schemes, optimization and parallelization of several parts, the introduction of the SODA assimilation and other surface assimilation options, and general code cleaning.

Hirlam surface modeling activities have remained focused on snow and ice. In addition to the final validation and testing activities for MEB, the 3-layer snow scheme CROCUS is undergoing testing. A simple thermodynamic sea ice scheme is being introduced. This will allow the temperatures on the ice surface to evolve through the forecast, thereby hopefully improving the modeling of near-surface temperatures and of the stable boundary layer. The introduction of fractional sea ice cover in Surfex will permit to use ice concentration observations of higher resolution and potentially better quality than is currently achieved from the ECMWF analysis (OSTIA SST). These observations will be introduced in the SODA assimilation system and their impact will be assessed in the course of the summer. A far more sophisticated sea ice scheme

GELATO is under development at Meteo-France, but there are still quite many scientific issues to be settled there.

In Harmonie Cy38, significant differences were seen in meteorological performance with respect to Cy37 due solely to a change in physiographic and soil composition data. The performance of these new databases varied considerably over the various Harmonie domains; for most domains the new databases were an improvement, but for some areas, e.g. Spain, a degradation was seen. Several ways to improve the new Ecoclimap-2 database and remove errors from it have been identified, and these are being addressed in an updated version of Ecoclimap-2.

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## Summary of plans for the continuation of the project

(10 lines max)

The present project is for the final two years of the Hirlam-B programme, and this reporting period represents the first of these two years. In the year 2015, in data assimilation research attention will remain focused on the introduction and optimization of flow-dependent assimilation techniques (4D-Var and hybrid 3- and 4DEnVar) under the OOPS code framework, on the optimization of the impact of high-resolution remote sensing observations, and the study of field alignment and cloud initialization methods. Forecast model developments will continue to focus on sensitivity studies aiming to improve the description of low clouds and fog, cloud microphysics and aerosols, and winter stable boundary layer conditions at present resolutions. Experimentation with the use of the model at sub-km resolutions will be further intensified and extended to more physics-related aspects (grey zone treatment, the possible need for 3D parametrizations).

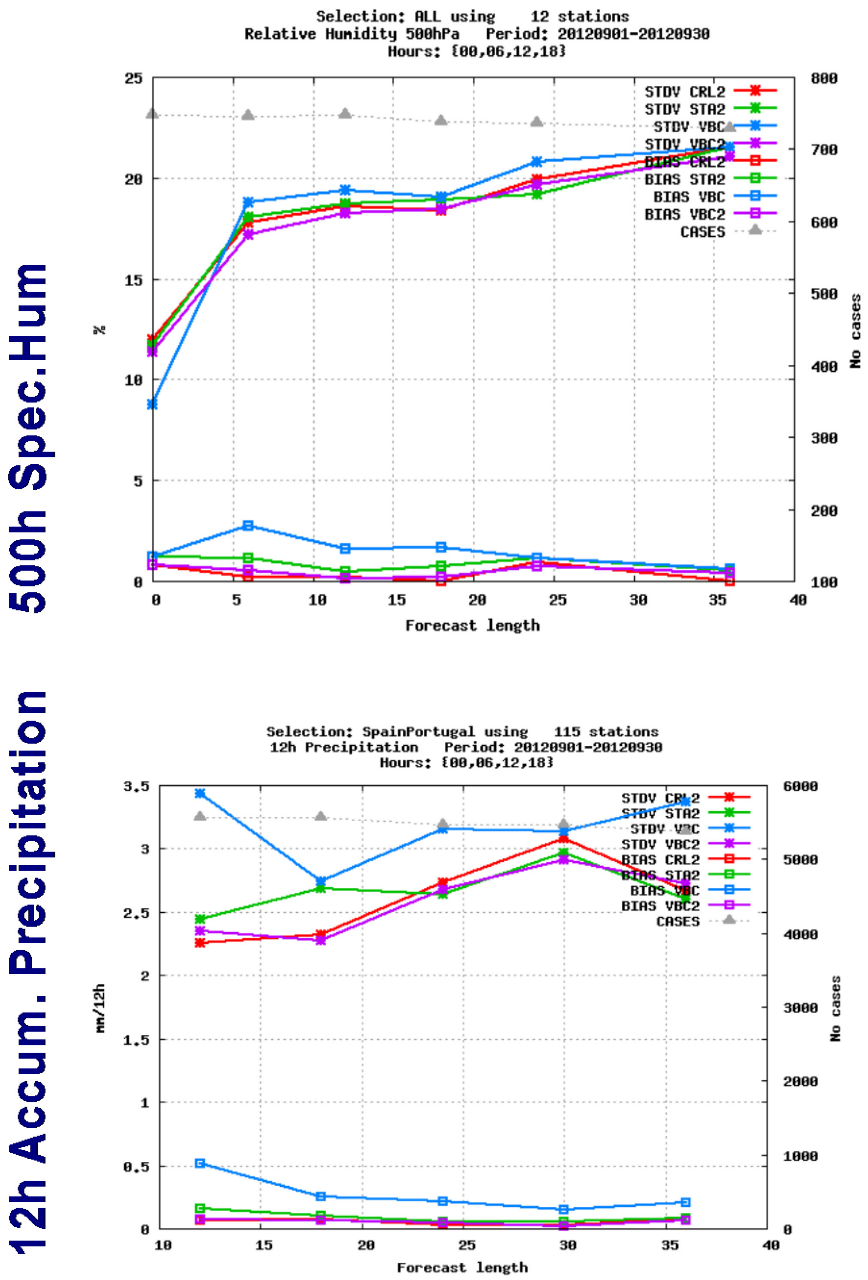


Fig. 1: Impact of GNSS data for a 1-month verification period (September 2012) in the Spanish Harmonie model. A 3h-cycling 3D-Var system was used to assimilate conventional data and GNSS zenith total delay. Shown are the standard deviation and bias of 500 hPa relative humidity (upper panel) and 12h accumulated precipitation (lower panel) for four model runs: the reference 3D-Var run without GNSS data (red), 3D-Var with GNSS ZTD and a static bias correction (green), 3D-Var with GNSS ZTD and variational bias control, with settings which gave relatively large weight to the observations (blue), and 3D-Var with GNSS and much “stiffer” settings for VarBC (pink). A small but consistent positive impact is seen for GNSS data using the “stiff” varBC. A degradation is seen when using varBC with larger weights on the observations. A further analysis has shown that this effect is likely due to a humidity bias in the model.

Fig. 2: Verification scores for 10m wind speed and direction (standard deviation and bias as a function of forecast time) for three Harmonie 3- and 4D-Var setups at KNMI, for a 1-month period (17 January 2014 – 14 February 2014). Shown are the operational KNMI Harmonie run (red, 3D-Var with 3h cycling, conventional data only, and nesting in Hirlam), the 3D-Var 1-hourly RUC run (blue, nested in ECMWF and assimilation of conventional data plus Mode-S observations), and 4D-Var (black, conventional and Mode-S data). Both the 3D-Var RUC and 4D-Var give some improvement in wind speed, while 4D-Var also nearly removes the bias in wind direction.

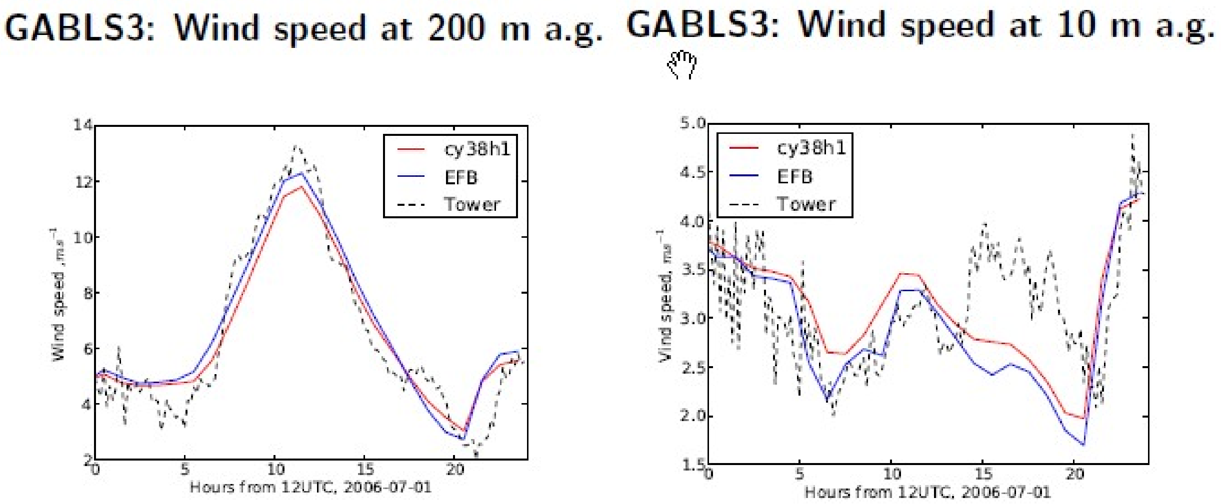


Fig. 3: Example of 1D-testing of the Energy and Flux Budget (EFB) scheme for stable boundary layer conditions. The test case shown here is the GABLS-3 experiment. The figures show the results of the model with the EFB scheme (blue curve) and the default model configuration (red curve), against Cabauw tower observations (black dashed curve). The left plot shows the verification of wind speed at 200m above the ground, the right the wind speed at 10 level. In both cases the EFB scheme gives a slight improvement of the model wind description. Unfortunately, in this case its impact on model temperature appears negligible.