SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Probabilistic forecasts for short range in Europe
Computer Project Account:	spnogeps
Start Year - End Year :	2015 - 2017
Principal Investigator(s)	Inger-Lise Frogner
Affiliation/Address:	Norwegian Meteorological Institute
Other Researchers (Name/Affiliation):	Kai Sattler/DMI, Alex Deckmyn/RMI, Sibbo van der Veen/KNMI, Xiaohua Yang/DMI, Andrew Singleton/MET Norway, Bjorn Stensen/SMHI, Ulf Andrae/SMHI

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The objectives of this project was developing and maintaining probabilistic forecasts for short range in Europe, in the cooperation of two European consortia for short-range NWP: HIRLAM and ALADIN. It consisted of two main activities: Activity 1: maintaining and developing The Grand Limited Area Modelling Ensemble Prediction System (GLAMEPS), which runs at ECMWF as Time-Critical facility Option 2 (TCF_2) and Activity 2: Experimenting scientifically and technically with ensembles of nonhydrostatic modelling with convection-permitting resolution (HarmonEPS) for the very short range in sub-European domains.

Summary of problems encountered

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

Nothing to report.

Experience with the Special Project framework

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

I would like to have the reporting aligned with the years you get SBUs for. The progress reports should be from July of previous year to June of current year, while the SBUs are allocated for calendar years. This means that the first progress report will only cover the first six months, and in total for a project of duration of 3 years this means that you have to submit three reports + a final report. The final report will then be a summary of the three first report plus the last 6 months of the project, *a total of four reports for 3 years*. Especially for this project, were all resources were spent and reported last year, it feels unnecessary to write yet another report. A scientific paper is under preparation, but not yet ready to replace this final report. If the reporting followed the calendar year, two progress reports and a final report would be enough, which will save time for all involved, both for us writing the reports and for those evaluating them.

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.)

Activity 1: GLAMEPS

GLAMEPS is a pan-European multi-model ensemble prediction system run as a cooperation between HIRLAM institutes and Belgian Meteorological Institute. It has been operational since 2011. The daily running of GLAMEPS (version 2) uses SBUs from national resource. SBUs from this special project were used for test runs and parallel runs for a new version of GLAMEPS (version 3).

The SBUs were manly used on 3 different aspects of GLAMEPS:

1. <u>Introducing, testing and tuning the inflation of the initial perturbations (reported in progress report 1)</u>

An inflation factor was introduced to the initial perturbation in HIRLAM part of GLAMEPS:

X (I)= X_(HIRLAM control-analysis) + X_(ECMWF EPS control forecast - ECMWF perturbed forecast nr J) * K

Where X is the model state, I stands for the "I"th perturbed HIRLAM member, J the "Jth" perturbed ECMWF ENS perturbed forecast, K the inflation factor (used to be 1). K=1.5 gave good results. Results are largely as expected with a general improvement on scores, the biggest gain on spread, see figure 1.

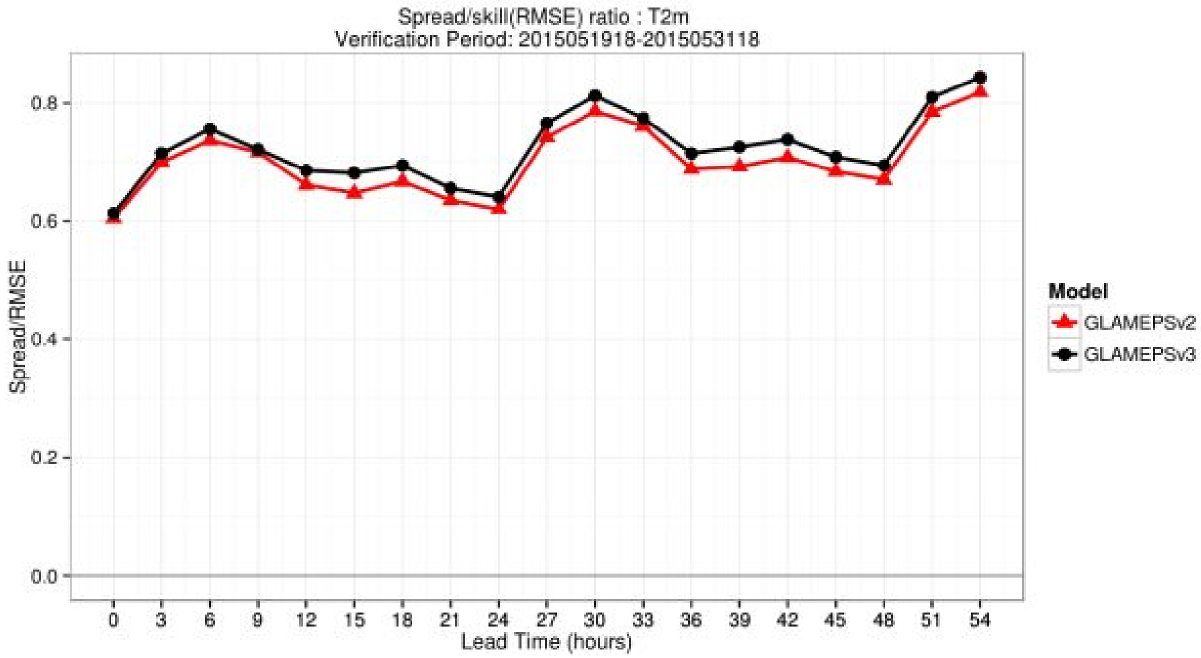

Figure 1: Spread-skill ratio for two meter temperature for 14 days in May 2015. GLAMEPSv2 is the current, operational GLAMEPS. GLAMEPSv3 is the same as v2, but with an inflation factor of 1.5 for the initial perturbations coming from IFS ENS.

2. Increased resolution, increased output frequency, implementation and testing of CAPE-SVs (reported in progress report 2 and 3)

CAPE-SVs were successfully implemented and tested in version 3. The first tests with increased resolution and output frequency revealed a significant drop in computer performance, so it became necessary to reconfigure parallelization geometry, and especially also to configure separate tasks for i/o work. As an example, figure 2 shows runtime/SBU performance for different domain decomposition of Hirlam forecast runs. The black entries showing results from GLAMEPS version 2 comparison runs, and the colored entries showing performance/cost of the GLAMEPS version 3 runs. The two groups of entries from GLAMEPS version 3 runs represent the slower (large runtime) but cheaper (less SBUs) runs utilizing hyperthreading, and the faster (smaller runtime) but more expensive (more SBUs) runs without hyperthreading. The indicated line represents approximately what would be expected by just taking the new grid geometry of the version 3 domain into account.

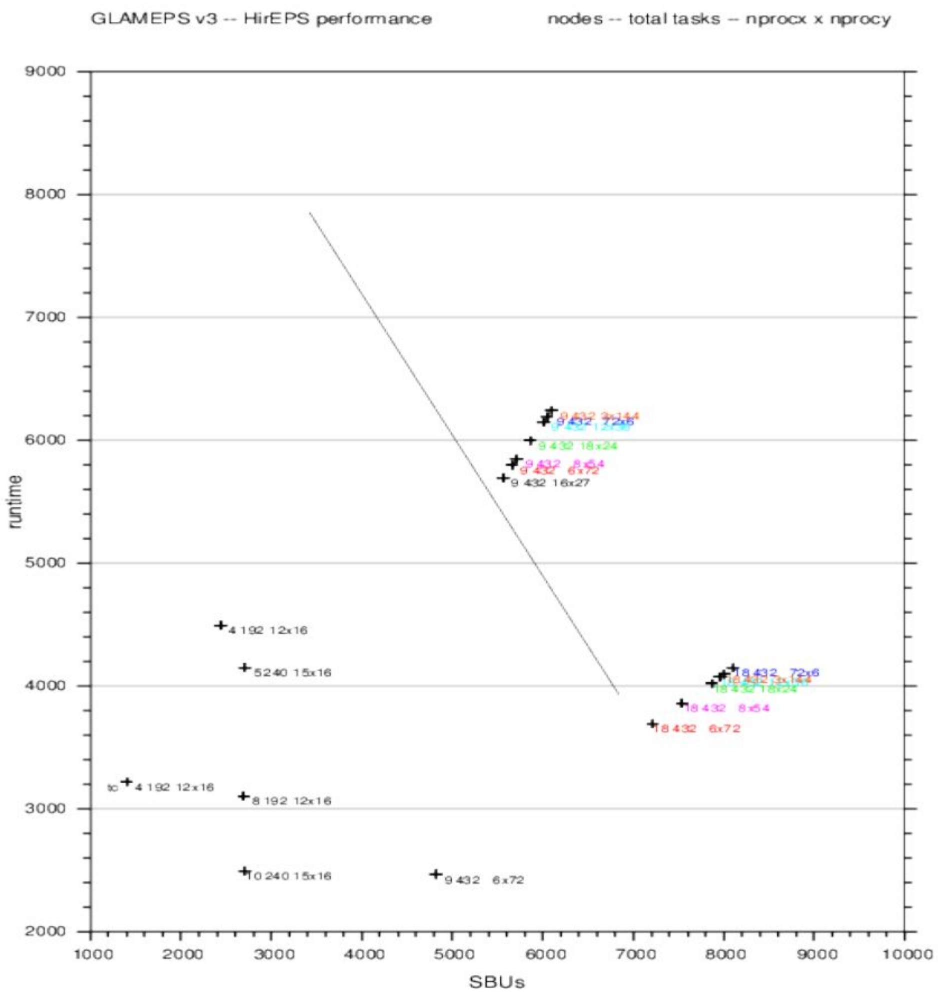

Figure 2: Runtime/SBU performance for different domain decomposition of Hirlam forecast runs. Expantation in the text.

3. New model versions and parallel run (reported in progress report 3)

Due to many technical challenges the testing and parallel run for version 3 went on for a much longer period than expected. When looking at the individual sub-ensembles that GLAMEPS consists off, we saw problems that did not show up when looking at the ensemble as a whole. We also experienced stability issues with version 3. On its meeting 22 June 2017 the HIRLAM Council decided to stop any further development of GLAMEPS due to lack of personnel resources. GLAMEPS version 2 will continue to run until June 2019.

Activity 2: HarmonEPS

HarmonEPS (Frogner et al. 2016) is an ensemble prediction system for the short range (~48h) based on the non-hydrostatic HARMONIE-AROME model configuration (Bengtsson et al., 2017) in the ALADIN-HIRLAM NWP system (Termonia et al., 2018). HarmonEPS is a flexible system and includes a range of possibilities to describe uncertainties in different parts of the system.

Several institutes run implementations of HarmonEPS. Presently all systems run with 2.5 km horizontal resolution and 65 vertical levels. At the time of writing two systems are operational and four have preoperational status. The first system to become operational in November 2016 was MEPS (The MetCoOp Ensemble Prediction system). MEPS is operated jointly by the national meteorological institutes of Finland, Norway and Sweden within the MetCoOp cooperation. Both MEPS and other systems have benefited from the developments of perturbation methods done with SBUs in this project.

The SBUs from this project has been used to study initial uncertainty (EDA), model uncertainty (multi physics and parameter perturbations) and initial surface uncertainty (surface perturbations).

1. Surface perturbations (reported in progress report 2)

Surface is an important source of the uncertainty in convection-permitting ensemble systems like HarmonEPS. The surface perturbation scheme developed Bouttier et al. (2015) is implemented in HarmonEPS. The SBUs from this project were used to do initial experiments with perturbations of surface parameters (e.g. soil moisture, albedo, SST, LAI and soil temperature). Two periods were chosen for the experiments, one summer (20150720-20150810) and one winter period (20151230-20160119). We ran HarmonEPS with 8+1 members, one experiment when only surface was perturbed, and one where also boundaries and initial conditions were perturbed in the default HarmonEPS way (that is using perturbations from the nesting model. In this case differences from the high resolution forecast from ECMWF valid at the same time but with different forecast length, the so called SLAF method). We compared against a control run of HarmonEPS.

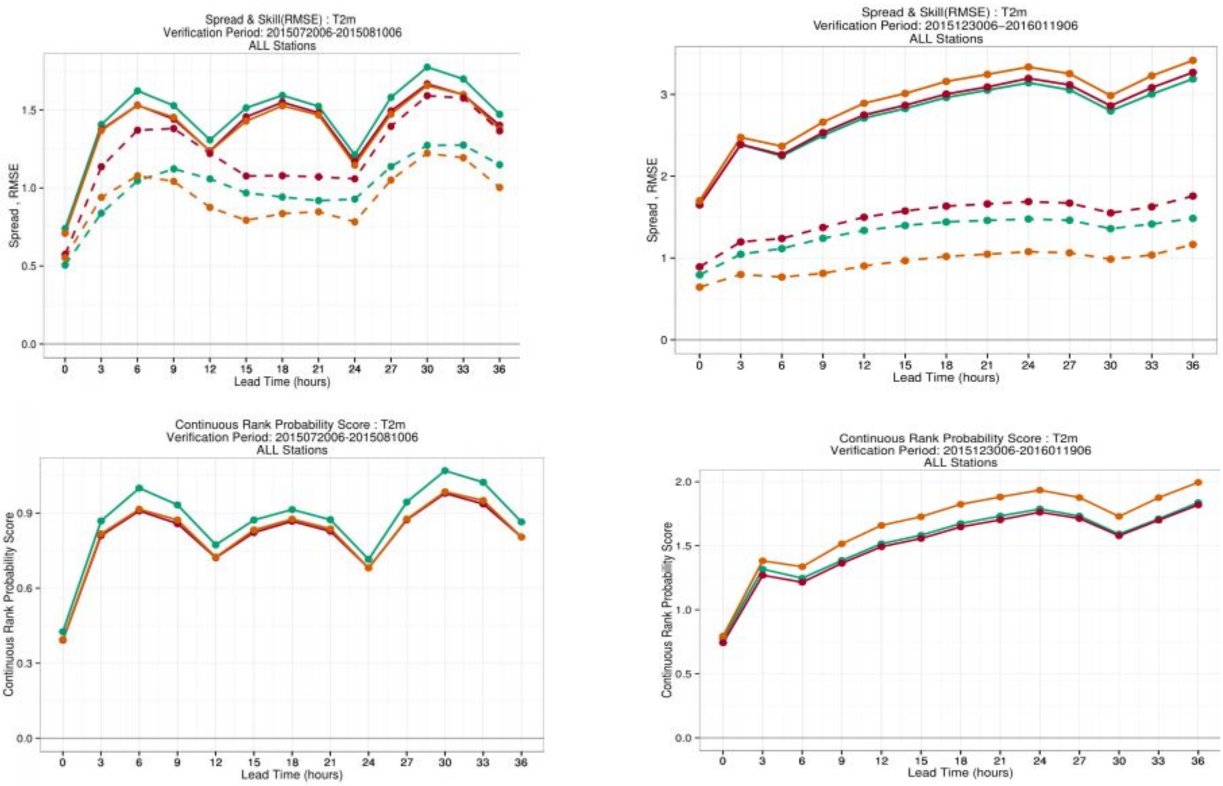

Figure 3: For T2m. Upper left is spread and skill for the summer period, upper right is spread and skill for the winter period. Lower left is CRPS for the summer period, lower right is CRPS for the winter period. The HarmonEPS reference run in orange, HarmonEPS with only surface perturbations in green and with surface perturbations and standard boundary and initial condition perturbations in red.

In Figure 3 spread and skill is shown (top row) and CRPS (bottom row) for the two experiments and the HarmonEPS control run, for both summer (left) and winter (right). It is striking to see that the experiment with only perturbing the surface, and no perturbations to lateral boundaries or initial conditions, actually gives larger spread than the control run of HarmonEPS. However, the best spread and skill relationship is obtained when we have a combination of perturbations to the boundaries, initial conditions and surface (red curve in Figure 3). For CRPS we seen an improvement in including surface perturbations for winter, but not for summer. The results are similar for relative humidity at 2 meters (not shown). For other parameters the impact of the surface perturbations are small (not shown).

After this initial study with surface perturbations, extensive testing has been done, but using other resources for SBUs. The surface perturbation code is now default in HarmonEPS and used operationally eg in MEPS

2. <u>Ensemble of Data Assimilations (EDA) (reported in progress report 1 and 2)</u>

The ensemble of data assimilation (EDA) for HarmonEPS uses perturbed observations. In the upper-air part of the data assimilation, the observations are perturbed with observation error size with randomly uncorrelated quantities similar to what is described in Isaksen et al. (2007). For the surface data assimilation, the perturbation of 2 meter temperature and 2 meter humidity is done separately but using the same technique. The first experiments with EDA that was reported in progress report 2 of this project, only used conventional observations. In a later test the use of conventional observations (Synop, Ship, Buoy, Radiosonde (Temp), Profilers) as well as radiances (AMSU-A, AMSU-B/MHS, IASI) was tested. An error in the initial EDA experiments gave spurious high level humidity. Results from the new EDA experiments with fix for this problem and more observations are briefly reported here, instead of repeating what is in report 2.

Here we present a comparison of the reference HarmonEPS setup and different EDA approaches, all with 10 + 1 members. The test period was 17 days in spring 2016. The reference run (REF) used a standard HarmonEPS setup. EDA was set up to run one analysis with perturbed observation per member in our ensemble, and at the same resolution. In experiment EDA_surfobs we use the same setup as for REF, except that we do not include the surface perturbation scheme (see above), but instead perturb the observations also for the surface assimilation (EDA for the surface), for each member. Experiment EDA_surfpert is as EDA_surfobs experiment, but instead of perturbing the observations in the surface analysis, we use the surface perturbation scheme, as in REF.
In figure 4 spread and skill are shown for REF, EDA_surfobs and EDA_surfpert for T2m, S10m, Pmsl and low clouds (LC). The RMSE is not changed much between the experiments, but there is a small tendency for EDA_surfobs to be less skillful than REF and EDA_surfpert, and for Pmsl both EDA experiments have larger RMSE than REF. It is clear that EDA_surfobs increases the initial spread, and gives a better spread-skill relationship, but only for first few hours. EDA_surfpert has the best spread-skill relationship throughout the forecast range, due to increased spread, except that the spread is too large initially for Pmsl. CRPS is in figure 5. EDA_surfpert is better or as good as REF for T2m and Pmsl, while it is better for S10m and low clouds (LC), and this holds throughout the forecast range. Clearly EDA_surfobs does not have the same skill as EDA_surfpert. The perturbations in EDA_surfpert are initially larger than in EDA_surfobs (not shown) and also EDA_surfpert has perturbations to more surface parameters than EDA_surfobs, which can explain the differences in quality. This is currently under investigation.

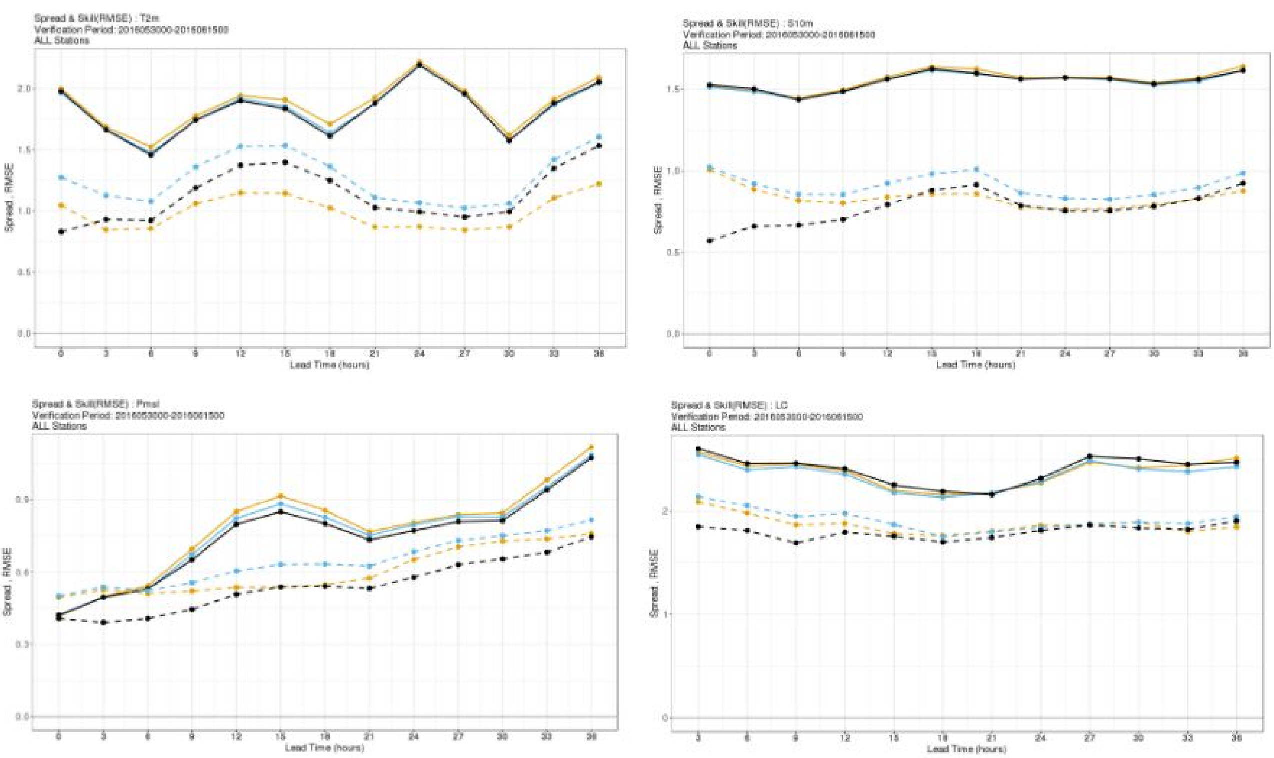

Figure 4: Spread (dashed) and skill (solid), for REF (black), EDA_surfobs (orange) and EDA_surfpert (blue). T2m (upper left), S10m (upper right), Pmsl (bottom left) and LC (bottom right).

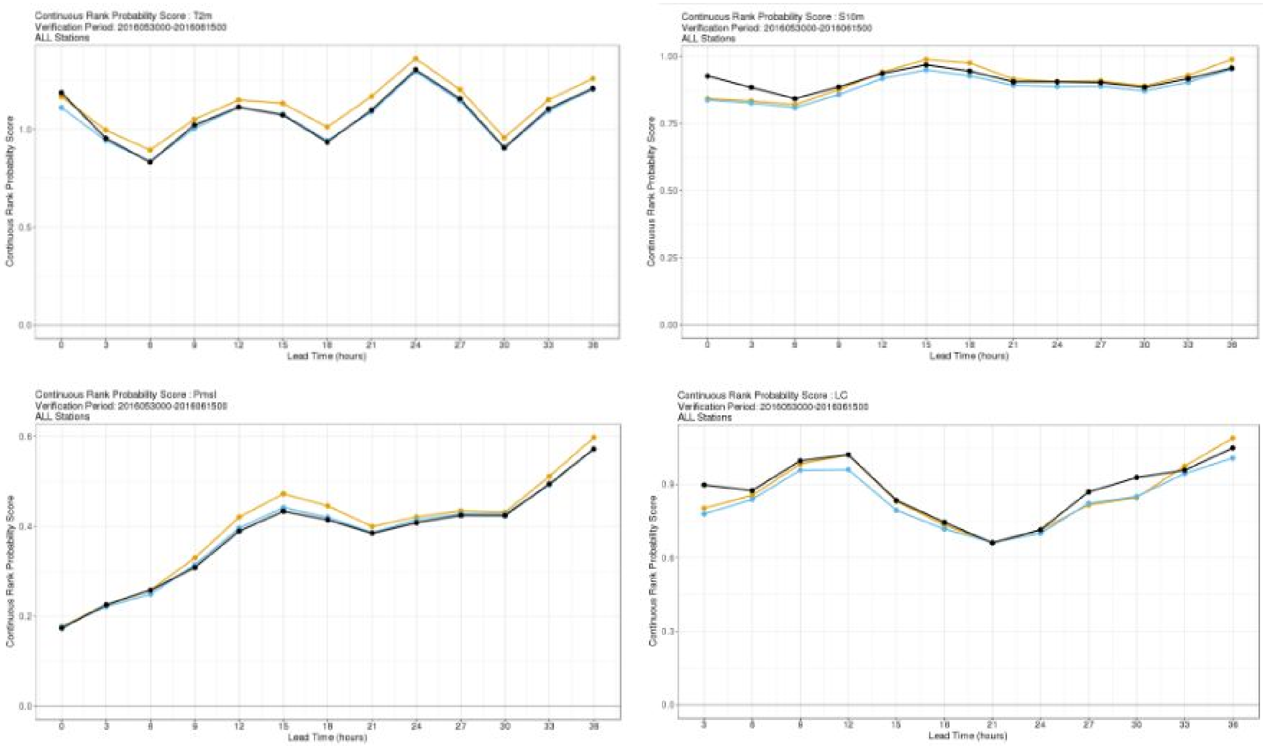

Figure 5: Figure EDA3: CRPS for REF (black), EDA_surfobs (orange) and EDA_surfpert (blue). T2m (upper left), S10m (upper right), Pmsl (bottom left) and LC (bottom right).

3. <u>Multi Physics (reported in progress report 2)</u>

Multi-physics (MP) can be used as one possibility to account for model error, by using different schemes for micro-physics, turbulence and radiation parametrizations, as we have several available in HarmonEPS. A three week period in summer 2015 was run (20150720-20150810) and compared to a reference with the basic setup of HarmonEPS and the same boundary conditions and initial conditions. In Figure 6 the CRPS is shown for T2m, S10m, Pmsl and 12h accumulated precipitation (AccPcp12h). We see a small, but positive effect of multi-physics. Also the spread is slightly larger for multi-physics experiment (not shown). Multi-physics most likely result in different members of the ensemble with different characteristics, or biases. As expected this is the case for HarmonEPS with multi-physic (figure 7), with one clear outlier (member 3) and two members with different evolution with forecast length (members 1 and 8). This is not seen for the reference experiment where the members have the same characteristics.

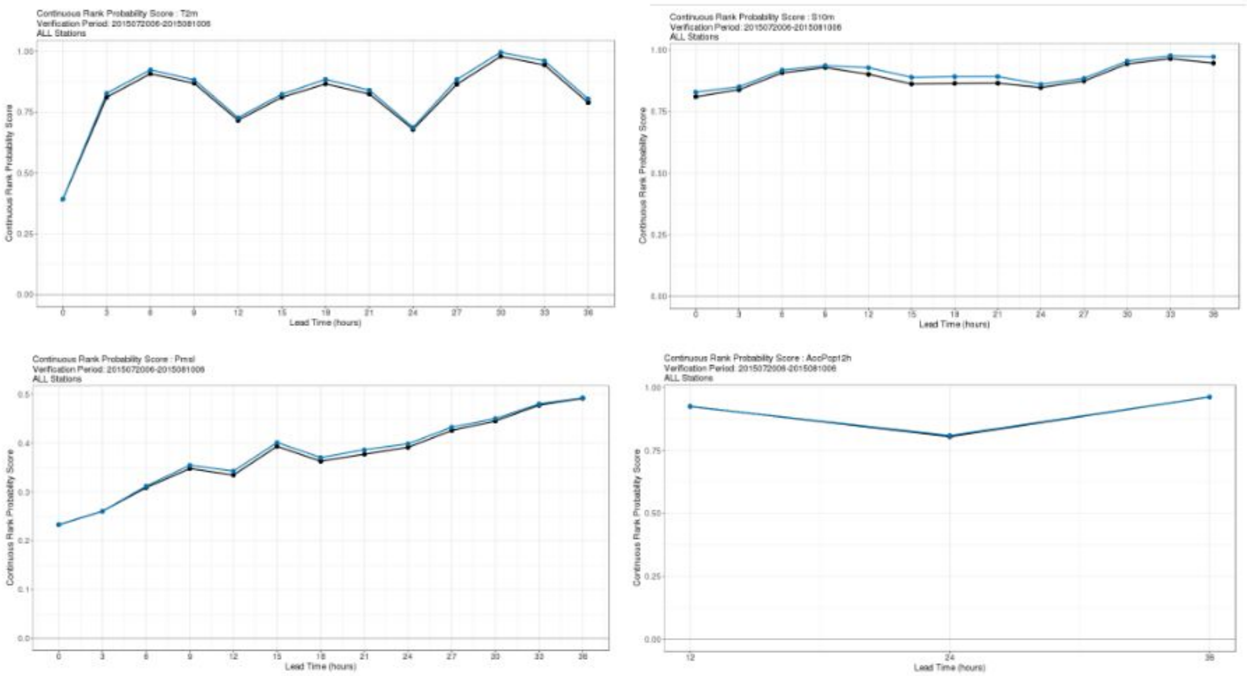

Figure 6: CRPS for T2m (upper left), S10m (upper right), Pmsl (lower left) and AccPcp12h (lower right). Experiment REF in blue, experiment MP in black.

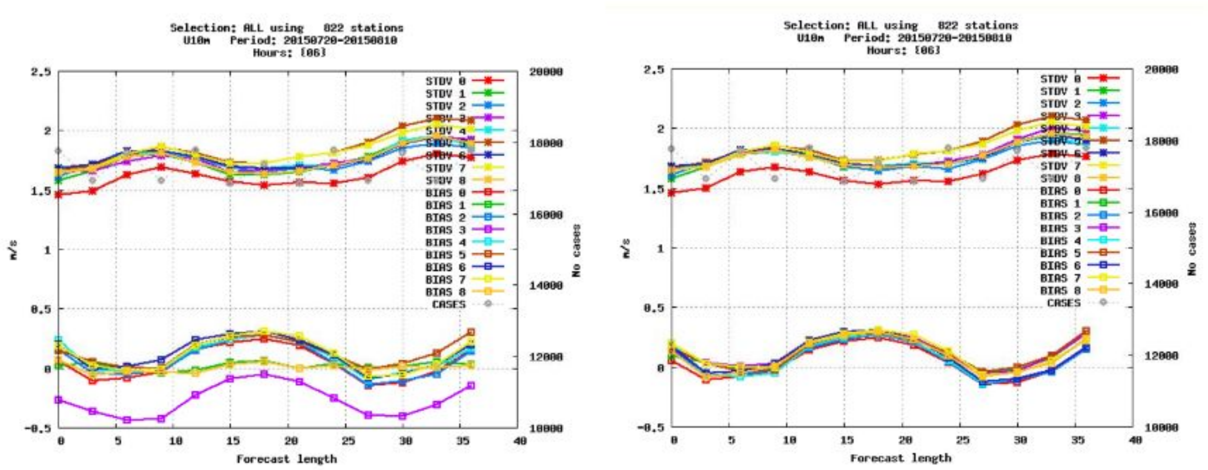

Figure 7: MAE and bias for all members of the MP experiment (left) and the REF experiment (right), for 10 m wind speed.

4. <u>Parameter perturbations (reported in progress report 3)</u>

A relatively simple way of introducing stochasticity is application of Random Perturbed Parameters (RPP), where an uncertain parameter in a parameterization scheme is randomly chosen for each member and cycle, but kept constant during the forecast. This was the first approach we used for a parameter that influences the level of relative humidity required for (low) clouds to form. This parameter was chosen based on advice from physics experts, with the expectation that perturbing this parameter could enhance the spread in HarmonEPS and possibly also improve the mean state. However, one should not expect too much from perturbing just one parameter. A two and a half week period in May-June 2016 was run with 10+1 members perturbing this parameter, and it was compared to a reference experiment without this perturbation, but otherwise identical. In figure 8 CRPS is shown for T2m, total cloud cover (CCtot), Cloud base height (CH) and Low clouds (LC). We see a small improvement for low clouds, on other scores the impact is negligible.

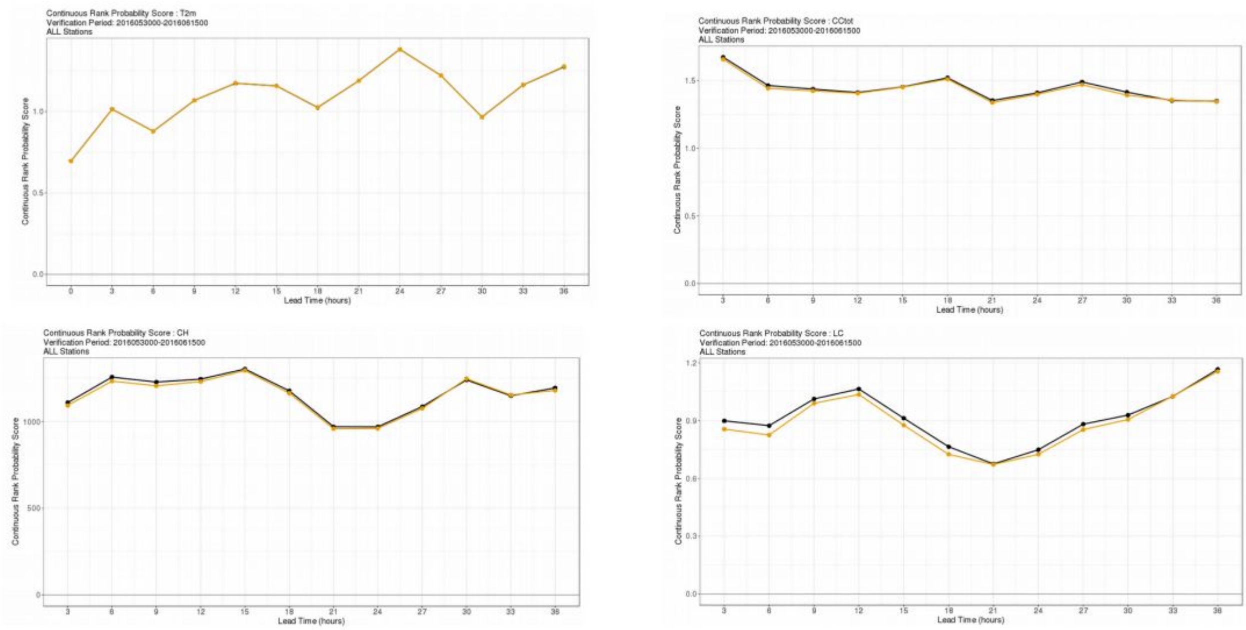

Figure 8: CRPS for HarmonEPS with perturbation of humidity parameter (orange) and reference run without (black) for T2m (upper left), Total cloud cover (upper right), cloud base height (lower left) and low clouds (lower right).

A more sophisticated way is to randomly and gradually change the parameter during the forecast, depending on space and time. Such a procedure is a Stochastically Perturbed Parameterisations (SPP) method. This work has progressed since the finishing of the SBUs from this project, and the IFS framework for SPP is now implemented in HarmonEPS and tests with other parameters have been performed, as well as testing different spatio-temporal patterns and their characteristics. This work will be published at a later stage.

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List of publications/reports from the project with complete references

HarmonEPS paper in preparation

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.)

Following the advice from ECMWF we do not ask for a continuation project for HIRLAM EPS development, but instead this is now, as requested, in a joint application from Jeanette Onvlee that covers HIRLAM-C research plan, both deterministic and probabilistic.