# JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2017


**SMHI**

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## 1. Summary of highlights

The Finnish meteorological institute (FMI) joined as a full partner in the operational NWP cooperation MetCoOp.

A new, larger geographical domain was introduced for the MetCoOp Ensemble Prediction System (MEPS).

Most runs with the HIRLAM model was decommissioned during 2017.

## 2. Equipment in use at the Centre

SMHI operational forecasts are run at computers at NSC (National Supercomputer Centre at the University of Linköping, Sweden) and at NTNU (Norwegian University of Science and Technology of Trondheim, Norway).

SMHI operational forecasting system (HIRLAM weather forecasting and the oceanographic HIROMB and NemoNordic models) is run on 2 separate computer systems, for redundancy.

The most recent HPC “Bifrost” was delivered to NSC in late 2014 and was made operational during the first quarter of 2015. Bifrost is a 10600 core Linux cluster, based on Intel Xeon E5 eight-core processors and Intel Truescale Infiniband QDR.

During 2017, the backup HPC system was shifted from the “Vilje” cluster at NTNU in Trondheim, Norway, to the “Alvin” cluster, procured by MET Norway, and situated at NSC.

The backup system at MET Norway is at the same time run at “Bifrost” at NSC, Linköping, Sweden.

The pre-processing of observational and boundary input to the models are run on Linux servers.

The output of the models are stored on a file-server and also put into SMHI operational database.

## 3. Data and Products from GTS in use

SYNOP, SYNOP SHIP, TEMP, PILOT, BUOY, AIREP, AMDAR and, over sea, AMSU-A.

HARMONIE-Arome (including MEPS) and HIRLAM accepts observational input in BUFR format.

SMHI uses a pre-processing software that processes observational BUFR-messages on GTS and converts it to BUFR-reports that are readable from the NWP systems.

## 4. Forecasting system

SMHI is part of the international HIRLAM project which has a goal to produce a Limited Area Model for operational use for short-range Numerical Weather Prediction in the participating National Meteorological Institutes. SMHI runs the HIRLAM analysis and forecast model for national use for forecasts up to +48 or +72 hours.

SMHI is also a member of ECMWF, European Centre for Medium-Range Weather Forecasts and uses the operational output, which is received in real time from ECMWF dissemination system. The products from ECMWF are mainly a +240 hours deterministic forecast twice a day and products from ECMWF EPS, Ensemble Prediction System and also products from the BC-project to provide horizontal boundaries for NWP 4 times a day.

The HIRLAM Programme has a co-operation with the ALADIN consortium particularly for the purpose of meso-scale modelling. The resulting HARMONIE model system with AROME configurations are available and used both operationally as well as for research and evaluation.

### 4.1 System run schedule and forecast ranges

At SMHI the operational short-range NWP system are run using the HARMONIE and HIRLAM models on several different domains:

- HARMONIE EPS with AROME physics has a horizontal resolution of 2.5km (Lambert grid), 65 vertical levels, and 10 EPS members. The lateral boundaries come from ECMWF. The forecast length is +66 hours for control members and +54 hours for perturbed members
- HIRLAM C11 with a horizontal resolution of about 11 km (0.10 degree on the rotated lat/long grid) and 40 vertical hybrid levels is run to +60 hours with a +2 hour data cut-off time. Lateral boundaries come from the ECMWF BC project with a 3 hour time resolution. The BC (Boundary Condition) project is run 4 times a day and provides 6 hour old boundaries. Use of HIRLAM C11 forecast data was restricted during 2017 (due to SMHI:s long-term purpose of decommissioning the HIRLAM model completely). The only remaining user of HIRLAM C11 products is another Swedish government agency.
- HIRLAM E05 has a horizontal resolution of 5.5 km (0.05 degrees on the rotated grid) and 65 vertical levels. It is run to +48 hours with a data cut-off of 1 hour 15 minutes. The lateral boundaries come from the ECMWF BC project. HIRLAM E05 was permanently decommissioned during 2017.

### 4.2 Medium range forecasting system (4-10 days)

No medium range forecasts are run at SMHI. Products from ECMWF are used.

### 4.3 Short-range forecasting system (0-72 hrs)

The HIRLAM analysis and forecast system are described in HIRLAM-5 Scientific Documentation (Undén, P. et al. 2002). The HARMONIE(Hirlam Aladin Regional/Mesoscale Operational NWP in Europe)-AROME (Application of Research to Operations at Mesoscale) system is part of the joint ALADIN-HIRLAM system and it is described in Bengtsson et al. (2017).

#### 4.3.1 Data assimilation, objective analysis and initialization

##### 4.3.1.1 In operation

The analysis is 4DVAR on the HIRLAM C11 domain. For HARMONIE-AROME/MEPS a 3DVAR-RUC (Rapid Update Cycling) with 3 hourly updating is used.

Initialization is done with Incremental DFI, Digital Filter Initialization, developed within the HIRLAM project.

4.3.1.2 Research performed in this field

The research focuses on the HARMONIE-AROME system and on the ALADIN model that is used for regional reanalysis. The main tasks are:

1) the development of a flow-dependent background error descriptionthe assimilation of high-resolution observations
2) surface data assimilation

For HARMONIE-AROME, a 4DVAR-scheme is now working and was used in different research projects, e.g. DNICast (http://www.dnicast-project.net/). Hybrid ensemble methods are planned to be included in HARMONIE-AROME within the framework of the OOPS design of ECMWF IFS system.

On the algorithmic side, efforts have continued to assess and improve various aspects of the performance of 3D-Var. The main aims are to increase and prolong the impact of observations, and to improve performance in the nowcasting range. Activities include the inter-comparison of various methods for generating structure functions in terms of impact, spin-up and the noisiness of increments; experiments with EDA on small scales in combination with several methods of accounting for the large scale; testing the impact of different methods for estimating optimal thinning distances.

Currently, we assimilate the following observations in operations:

- Conventional: SYNOP, AIRCRAFT,TEMP, SHIP, DRIBU
- Satellite radiances: AMSU-A, AMSUB, MHS, IASI
- ASCAT satellite winds
- Radar reflectivities from Sweden, Norway, Denmark, Finland, and Estonia
- GNSS total zenit delay

T2M, RH2M, SNOW for surface assimilation

#### 4.3.2 Model

##### 4.3.2.1 In operation

The MEPS system is based on HARMONIE-AROME cycle 40.

The forecast model used for HIRLAM C11 is a somewhat modified HIRLAM version 7.1.2 with the following characteristics:

ISBA surface scheme
Kain-Fritsch convection scheme
Rasch-Kristjansson large scale scheme
CBR turbulence scheme
Savijärvi radiation scheme

For the E05 run a newer HIRLAM reference version 7.3 has been introduced. It includes an interactive snow surface scheme and a meso-scale orography parameterisation.

#### 4.3.2.2 Research performed in this field

Continued testing has been done for the so-called 2-patch option in HARMONIE-AROME Cy40h1.2 (introducing the use of two patches (for forest and open land), rather than one, in the calculation of fluxes for the nature tile). This 2-patch adaptation has been shown to address the problem of excessive latent heat flux in the model due to snow cover over open land. In combination with the removal of the CANOPY scheme it has also proven beneficial more in general for reducing T2m biases on several domains, but it has also been seen to give a slight deterioration in u10 in some cases.

Several projects were conducted with horizontal resolution between 500m and 1km in order to assess the model performance at these scales. It was necessary to update the physiography data by using high-resolution products, such as the Urban Atlas. The high resolution reduces the physical size of the domain given limited computing resources. Here, spin-up problems caused issues with precipitation especially during strongly forced winter conditions. More research is needed in order to address this issue.

A stability proof for the weak constraint approach to boundary conditions in the vertical discretization was provided in a toy model. It is now studied to extended this approach to full model dynamics.

### 4.3.3 Operationally available NWP products

Both the MEPS and HIRLAM models produces output on files containing the model parameters like wind, temperature, specific humidity, cloud water and TKE (Turbulent Kinetic Energy) on all model levels as well as parameters that describe the state of the ground like temperature and available water on the different land tiles in the model and on the soil levels. The model files also contain physiographic data like orography and roughness.
In addition to the model files, the output can also, by namelist arguments, produce post-processed files for parameters on pressure levels and parameters like 2 m temp and 10 m wind.
Output from both MEPS HIRLAM is written with 1 hour time resolution to disk and is also written to SMHI database.

### 4.3.4 Operational techniques for application of NWP products

#### 4.3.4.1 In operation

Forecast products from different models, MEPS, HIRLAM C11, E05, HARMONIE/AROME and ECMWF, are selected to create a forecast database, PMP. This database can also be manually edited. This database is then used to produce, automatically, different customer products. Other applications, like other models, can then also use this database for their meteorological input. For HARMONIE/AROME a neighbourhood technique is employed in order to take into account the unpredictability of the smallest spatial scales.

4.3.4.2 Research performed in this field

**The usefulness of the neighbourhood technique was examined for wind energy forecasts, looking at different option for vertical and horizontal neighbourhoods.4.3.5 Ensemble Prediction System**

#### 4.3.5.1 In operation

The MetCoOp Ensemble Prediction System (MEPS) MEPS is based on HARMONIE and uses identical domain and resolution as the previously operational HARMONIE-AROME system. MEPS has 10 members and utilizes the SLAF method to perturbate boundaries.

#### 4.3.5.2 Research performed in this field

Further tests were conducted to compare the optimal number of ensemble members. The usage of ECMWF EPS instead of the SLAF method was also revisited including the test of selecting ensemble members according to a clustering algorithm kindly provided by the COSMO consortium.

Surface perturbations concerning SST, soil moisture and LAI are further examined. Generally, an improved spread for 2-metre temperature and relative humidity can be seen.

#### 4.3.5.3 Operationally available EPS Products

EPS products from ECMWF and HIRLAM/GLAMEPS are available and used.

## 4.4 Nowcasting and Very Short-range Forecasting Systems (0-12 hrs)

### 4.4.1 Nowcasting system

#### 4.4.1.1 In operation

An analysis model, MESAN, for analysis of weather parameters not normally analysed by meteorological models such as fresh snow-cover, visibility and 10 meter winds.

MESAN is used for diagnostic and now-casting purposes and uses an Optimum Interpolation technique.

#### 4.4.1.2 Research performed in this field

The MESCAN horizontal spatialization is still under investigation. Improvements in the surface analysis have been achieved but are rather small.

Car measurements were analysed in order to assess the potential impact that such measurements can have on a nowcasting system. Despite the low accuracy of the measurements, the large number can provide interesting information to road nowcasting.

Lightning nowcasting was examined, especially addressing the user requirements for large industrial complexes. A fast updated prototype with a clear visualization was developed for the operators.

### 4.4.2 Models for Very Short-range Forecasting Systems

#### 4.4.2.1 In operation

No Very-short range Forecasts is run operationally at SMHI.

#### 4.4.2.2 Research performed in this field

A pre-operational model set-up for very short-range forecasting was developed.

Further work was conducted on the assimilation of Nowcasting SAF cloud masks addressing the too dense cloud cover that resulted from first experiments.

Surface data assimilation of soil moisture data from ASCAT was introduced in order to improve very short-range precipitation forecasts. First results are promising.

## 4.5 Specialized numerical predictions

MEPS and/or HIRLAM output is used as input data for a number of other models:

HIROMB. An oceanographic forecast model for temp, salinity, currents, ice cover and water-level.
NemoNordic. A novel oceanographic forecast model for temp, salinity, currents, ice cover and water-level.
SWAN. A wave model.
MATCH. A Transport, Dispersion and Atmospheric Chemistry model.
HBV model. A hydrological run-off model for different catchment areas.

### 4.5.1 Assimilation of specific data, analysis and initialization (where applicable)

#### 4.5.1.1 In operation

Assimilation of scatterometer data (ASCAT) were introduced in the HARMONIE-AROME/MEPS model during 2016

#### 4.5.1.2 Research performed in this field

Surface data assimilation received more focus, especially assimilation of surface radiances and of ASCAT data for better soil moisture initialisation. In the experiments, we also introduce a (simplified) extended

Kalman Filter with preliminary beneficial results. Occasionally, the Jacobians show noisy behaviour which needs further research.
For radar data, improved settins for the superobbing were developed.
On the algorithmic side, flow-dependent assimilation methods are underdevelopment addressing especially the challenges for convective-scale NWP (Gustafsson et al. 2018). Development includes 4D-VAR, LETKF, hybrid ensemble VAR, as well as 3D- and 4D-EnVar.

### 4.5.2 Specific Models (as appropriate related to 4.5)

#### 4.5.2.1 In operation

N/A

#### 4.5.2.2 Research performed in this field

N/A

### 4.5.3 Specific products operationally available

N/A

### 4.5.4 Operational techniques for application of specialized numerical prediction products *(MOS, PPM, KF, Expert Systems, etc..)* (as appropriate related to 4.5)

#### 4.5.4.1 In operation

A Kalman filtered temperature forecast is available.

#### 4.5.4.2 Research performed in this field

Applications for wind and solar energy forecasting are continuously improved.

### 4.5.5 Probabilistic predictions (where applicable)

#### 4.5.5.1 In operation

N/A

#### 4.5.5.2 Research performed in this field

The improved usage of probabilistic forecast data for wind power forecasts in cold climate was examined (Söderman et al. 2017).

#### 4.5.5.3 Operationally available probabilistic prediction products

N/A

## 4.6 Extended range forecasts (ERF) *(10 days to 30 days)*

### 4.6.1 In operation

No extended range forecasts are operational at SMHI.

### 4.6.2 Research performed in this field

N/A

### 4.6.2 Operationally available products

N/A

## 4.7 Long range forecasts (LRF) *(30 days up to two years)*

### 4.7.1 In operation

No long range forecasts are made at SMHI

### 4.7.2 Research performed in this field

The skill of seasonal forecast for hydrological application is examined.
In the project ARCPATH, the potential predictability on the decadal time scale is examined especially for the Arctic. In the project EUCP, different exisiting decadal prediction systems are analysed.

#### 4.7.3 Operationally available products

N/A

## 5. Verification of prognostic products

HIRLAM and MEPS output is continually verified using the EWGLAM (European Working Group on Limited Area Models) verification scheme to verify model output against observations in well specified station lists.

The forecasts are also verified to see its possibility to forecast specified events, like e.g. winds above a certain limit.

Verification results are published at the SMHI internal Website and on hirlam.org for our partners within the HIRLAM-consortium.

### 5.1 Annual verification summary

### 5.2 Research performed in this field

SMHI is contributing to the development of the HARP (HIRLAM-ALADIN R-package) verification tool.

## 6. Plans for the future *(next 4 years)*

### 6.1 Development of the GDPFS

#### 6.1.1 Major changes in the operational DPFS which are expected in the next year

Migration of the entire model production chain will be migrated to a new HPC platform during 2018.

#### 6.1.2 Major changes in the operational DPFS which are envisaged within the next 4 years

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### 6.2 Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

"[Summary of planned research and development efforts in NWP, Nowcasting, LRF and Specialized Numerical Predictions for the next 4 years]"
The HIRLAM-C programme is ongoing in close collaboration with ALADIN . At SMHI, the research will focus on high-resolution very short to short-range NWP and related applications. For data assimilation, efficient methods for mesoscale systems have to be developed. For the initialisation, high-resolution observations have to be assimilated, such as radiances from SEVIRI and IASI, AMV, Mode-S EHS winds and temperature, GNSS atmospheric humidity, scatterometer winds, etc. Some of these new observations such as Mode-S and AMVs might prove to be useful input to Nowcasting of clouds and precipitation. Furthermore, more research focus will lie on the surface data assimilation using remote sensing data. For model physics, development in cloud physics, boundary layer turbulence interaction with the surface, land surface modelling and coupling to the ocean are foreseen. Development for specialized numerical predictions will be done within the fields of solar energy forecasting, wind energy forecasting, and road weather. An important aspect will be the development of probabilistic forecasts with a mesoscale EPS. For the long-range forecasting, seasonal and decadal predictions will be further examined.

#### 6.2.1 Planned Research Activities in NWP

Development of ensemble-based data assimilation schemes for upper air and surface are planned.

New observations have to be established in HARMONIE-AROME, such as Aeolus winds and more.

The spread-skill relationship in the mesoscale EPS will be improved.

A coupling between ocean surface waves and the atmosphere is planned to be included in HARMONIE-AROME.

#### 6.2.2 Planned Research Activities in Nowcasting

Development of a nowcasting system based on the HARMONIE-AROME system is planned.

#### 6.2.3 Planned Research Activities in Long-range Forecasting

The potential predictability for decadal predictions will be further examined with the EC-EARTH model. Seasonal forecasting especially for hydrology will be further investigated.

#### 6.2.4 Planned Research Activities in Specialized Numerical Predictions

Specialized predications will be continuously developed for solar energy, wind energy with a focus on the icing on wind turbines, and road weather.

More research activity is planned for urban meteorology using HARMONIE-AROME on 1km-scale and additional downscaling with radiative and fluid-dynamical models down to meter-scale.

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