**JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2015**

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1. **Summary of highlights**

Although the short-range NWP operational suite is based on HIRLAM, in 2015, most efforts were devoted to the development and operational implementation of a new high-resolution convection-permitting model, the HARMONIE/AROME, in the framework of the collaboration between the HIRLAM and ALADIN NWP Consortia. The new model runs at 2.5 km resolution as a Time Critical application at ECMWF computers and its run in e-suite mode in the new AEMET’s supercomputer system. .

In the area of predictability at the end of 2014 the AEMET multi-model multi-boundaries Short Range Ensemble Prediction System, SREPS was discontinued; the efforts in this field have been focused to contribute to the HIRLAM-ALADIN GLAMEPS System and the development of the HARMONEPS.

Downstream applications based on HIRLAM are the WAM wave model and the MOCAGE Chemistry Transport Model.

1. **Equipment in use**

During 2014, the operational prediction system of AEMET ran on the AEMET CRAY X1E high-performance computer, which was discontinued at the end of 2014 and provisionally replaced by a relatively small Bull System. The definitive Bull System, a Bull DLC B700 acquired in 2014 on a renting base will be installed in two phases in 2015 and 2016.

A new Bull supercomputer system has been installed. The system is based on Intel Xeon 2697 V2 Ivy Bridge processors (12 cores) at 2.7 GHz with 64 GB DDR3 of memory per node. The system has 144 nodes and 3456 cores. During 2016, the system will be enlarged to 324 nodes and 7776 cores, and half of the nodes will increase its memory to 128 GB.

The archiving System started in operation in 2009 served by 4 Altix 350 (SGI) servers, a disk cabinet and an ADIC (QUANTUM) robot. From 2013, this System has been replaced by a cluster of nodes of EMS, and ISILON One FS.

The dust prediction model (NMMB/BSC-Dust) is run at the MareNostrum III supercomputer, where there is a reservation of 260 cores for the operational run. A backup run, at a reduced resolution, is daily performed at the forecast server, also owned by BSC. Product dissemination is performed by the BDFC main server. The three servers mentioned here are located at Barcelona Supercomputing Center (BSC) facilities. BSC is the AEMET partner in dust forecasting.

1. **Data and Products from GTS in use**

The HIRLAM model is coded to accept input observational data in BUFR3. All conventional observation reports in ASCII received by the GTS are pre-processed in order to be assimilated by the NWP operational suite. Data received by GTS in BUFR4 are transformed as needed to BUFR3. VAD and radial wind radar data, GPS Zenith Total Delay, and BUFR ATOVS AMSU-A data are coming into the system from other information sources.

1. **Forecasting system**

AEMET is a partner in the international HIRLAM Programme, which has, as its main goal, the development of a Limited Area Model for its use in operational short and very short-range numerical weather prediction. As a result of the collaboration between HIRLAM and ALADIN consortia, a “ALADIN-HIRLAM Shared System” has been set and it is currently used operationally by many of the Meteorological Services belonging to the consortia.

Spain is a Member State of the ECMWF and uses their output products. They are received in real time from the dissemination system of the European Centre. ECMWF products are: deterministic forecasts up to +240 hours twice per day, the ECMWF ENS (Ensemble Prediction) products twice per day, and the BC products supplying boundary conditions to the HIRLAM and Harmonie models four times per day.

* 1. **System run Schedule and forecast ranges**

The operational short range numerical prediction system is run by AEMET in three different domains, called ONR, HNR and CNN respectively, (see previous NWP reports) each one with a different resolution. All of them run four times per day at 00, 06, 12 y 18 UTC with their own data assimilation cycle.

The ONR model has a horizontal resolution of around 16 km (0.16º in a latitude/longitude grid) and 40 vertical levels. It is run up to +72 hours with two-hour data cut-off time. Boundary conditions are supplied from the ECMWF model, with 3-hourly time resolution.

The HNR model has a horizontal resolution of around 5 km (0.05º in a latitude/longitude grid) and 40 vertical levels. It is run up to +36 hours with a two-hour data cut-off time. Boundary conditions are supplied from the ECMWF model with 3-hourly time resolution. The CNN model has the same features than HNR. HNR is run over the Iberian Peninsula and Balearic Islands and CNN over the Canary Islands.

HARMONIE/AROME with 2.5 km resolution and 65 vertical levels is run 4 times per day over 2 domains (Iberian Peninsula and Canary Islands) up to +48 hours. The model runs as a Time Critical application at ECMWF facilities and is directly nested in the ECMWF forecasts.

* 1. **Medium range forecasting system (4-10 days)**

Medium range forecasts are not produced in AEMET. ECMWF products are used instead.

**4.2.3. Operationally available Numerical Weather Prediction (NWP) products**

Several basic ECMWF products are available on the AEMET Internet web pages and additional ones on the McIDAS workstation. Others like diagnostic convective fields, predefined pseudo soundings of specific points, predefined vertical-cross sections, etc., are displayed on the Intranet system. All of them are obtained from 00 and 12 UTC runs. Maritime and aeronautical outputs are available in different platforms for operational purposes.

**4.2.4. Operational techniques for application of NWP products (MOS, PPM, KF, Expert Systems, etc.,)**

4.2.4.1. In operation

A database of gridded forecasts of sensible weather elements (BDDP) is fed with predictions from HIRLAM, HARMONIE and ECMWF models. From this database many end users products are generated. In principle, HIRLAM and HARMONE are used for the short range and ECMWF for longer ranges but backup procedures exists if some of the models are missing. For some of the parameters as the near surface temperature a post process is applied to remove the model bias.

4.2.4.2. Research performed in this field

The GFE (Graphical Forecast Editor) tool has been extensively tested. It is able to generate automatic text products and graphics. With this tool, the forecaster can modify the model output before generating the end products.

NWP data are ingested into the recently installed meteorological workstations based on the NinJo software.

* 1. **Short-range forecasting system (0-72 hrs)**

Two different systems are used: HIRLAM at 0.16 and 0.05 resolution, and HARMONIE/AROME at 2.5 km resolution up to 48 hours.

The HIRLAM analysis and forecast systems are described in the scientific documentation of HIRLAM-5. (see references).. The main added value of HIRLAM compared with ECMWF is in near surface variables and especially in 2m temperature, wind and wind gust (Navascues et al, 2013). For precipitation, it complements ECMWF output helping to assess predictability of the weather systems. The three HIRLAM runs use the same version for each of the domains. In addition, the same dynamics and physics are used.

The HARMONIE/AROME is based on cycle 38 and it is close to the system described in Seity et al (2011). The verification shows a clear added value compared with HIRLAM and ECMWF forecasts, especially for near surface variables, precipitation and low level clouds.

* + 1. **Data assimilation, objective analysis and initialization**
       - 1. In operation

3D-VAR analysis with HIRLAM HIRVDA version 7.2; initialization by digital filters developed within the HIRLAM project. All the available surface and upper air conventional observations are assimilated. A blending procedure to merge the large-scale component of ECMWF analysis with the HIRLAM fields was introduced to improve the initial atmospheric state. The HIRLAM forecast up to 6 hours is then started from it using the most recent ECMWF fields as boundaries to create the first guess for the next assimilation cycle. HARMONIE/AROME uses an optimal interpolation method for the surface and a 3DVar method for upper air fields.

* + 1. Research performed in this field

Research is focus in the HARMONIE/AROME system. Assimilation of GNNS (Sanchez Arriola, 2016) and ATOVs data have been though roughly tested and it is close to be included in operations.

Radar assimilation is another area of active research. Radial wind and reflectivity from the Spanish C-band radars are assimilated using a Field Alignment technique for correcting position errors. Results are promising although the added value of the radar assimilation is lost after a few hours.

Assimilation of Atmospheric Motion Vectors is under development. A special effort is devoted to the use of the High Resolution Winds software provided by the Nowcasting SAF and to the use of the Cloud Products, which include new microphysics information.

Currently HARMONIE/AROME assimilation is performed at 3-hour cycles but shorter cycles are under investigation.

* + 1. **Model**
    2. In operation

For HIRLAM, the forecast model is the 7.2 version is a grid point model with the following parameterizations: ISBA surface scheme, Kain-Fritsch, RaschKristjanson convection and condensation schemes, CBR TKE turbulence scheme and Savijärvi radiation scheme.

HARMONIE/AROME is based on cycle 38h1.2. A general description of the system can be found in Seity et al. (2011) It is a Non-Hydrostatic, Semi-Implicit spectral model without parameterized deep convection, using a unified approach for the turbulence-shallow convection processes (EDMFM scheme) and an externalized surface parameterization (SURFEX) based on ISBA for nature tiles.

* + 1. Research performed in this field

Research on dynamics has been focus on the introduction of a vertical discretization using finite elements. The method has been successfully implemented in the code although the approach is very sensitive to the definition of the vertical levels

Although HARMONIE/AROME improves significantly low clouds and fog predictions it tends to produce too many false alarms. Most efforts in the physics group have been devoted to understand and try to cure this problem. A new turbulence scheme, HARATU developed by KNMI, has been implemented and has a significant impact on low level clouds, increasing its cloud base and reducing its amount.

HARMONIE is being tested for very fine resolution modelling (km and sub-km resolution). The model is stable either using Predictor-Corrector scheme or using SETTLS and applying an upper boundary condition. The benefit of this runs is under investigation.

* + 1. **Operationally available NWP products**

The HIRLAM model produces file outputs. They contain the following model variables: wind, temperature, specific humidity, cloud water content, and TKE (turbulent kinetic energy) at all model levels; from an argument list, post-processed products are derived such as the aforementioned variables at pressure levels. They also contain surface pressure, and the parameters that describe the ground state as temperature and water content at the different tessels and levels of the soil model; these files also contain climate data like orography, roughness, etc…In addition parameters as 2m temperature, 10m wind, accumulated precipitation, etc are available.

See 4.2.3 and 4.2.4 notes for the same considerations. HIRLAM models are used for short range predictions.

The outputs from HARMONIE/AROME model are available to the forecasters and AEMET internal users. There is an increase use of this model in the operational forecasting process. Research is been carried out about new post processing possibilities of the convection-permitting model for example for hail and lightning.

* + 1. **Operational techniques for application of NWP products**
    2. In operation

Advanced and specific HIRLAM and HARMONIE outputs are being used for aeronautical purposes: identification of turbulence, icing condition, mountain waves, etc., at flight levels, FL. More sophisticated products will be obtained for mountain meteorology in the near future.

Some NWP derived parameters and vertical profiles are obtained from the HIRLAM model output to identify and forecast the most likely convection environments. Other end-user products are delivered automatically from the high resolution model, HNR, at surface level to meet data requirements.

A fog forecasting model based in HIRLAM 1D was developed for its use at some airports. Special products are prepared for specific users and clients.

* + 1. Research performed in this field

Many of the post-process products have been migrated from HIRLAM to HARMONIE. Also HARMONIE forecasts have started to replace HIRLAM forecasts in the BDDP, the Data Base of gridded forecast, from which most end users products are generated,

* + 1. **Ensemble Prediction System AEMET-gSREPS**

During 2015 the new multi-model multi-boundaries System (AEMET/gSREPS) was developed on the ECMWF supercomputing facilities. Four LAMs (HARMONIE-AROME, HARMONIE-ALARO, WRF-ARW and WRF-NMM) were integrated taking as initial and boundaries the global fields from five global models: ECMWF, Arpege from MeteoFrance, GFS (from NCEP), GSM (from JMA) and CMC (from Canada). Therefore, the number of ensemble members is 4x5=20.

* + 1. Daily runs in 2016

The gSREPS System will be run twice a day at 00 and 12h UTC up to 36 hours beginning in Spring 2016. The model resolution is around 2.5 km in the horizontal and 65 levels in the vertical. On December 2016 the gSREPS will be installed and run at AEMET supercomputing facilities in Madrid.

* + 1. Research performed in this field

Work was done to correct bias (difference between mean values of the forecasts and the analyses in the verification areas), and to calibrate the system using different techniques. From a statistical point of view, results were encouraging for surface variables (including precipitation) but there was still an issue with extreme events.

* + 1. Availability of gSREPS products

The AEMET-gSREPS provided two kinds of products. The deterministic products are averages of deterministic outputs of each of the members in the ensemble. They are made available every 1 hour for geopotential, temperature, specific humidity, wind and surface variables. The probabilistic products are obtained from the full set of the individual deterministic forecasts of the ensemble by estimating the probability of occurrence of a meteorological event, such as 6-hour accumulated precipitation higher than 1, 5, 10 and 20 mm; 10m mean wind higher than 10, 15 y 20 m/s; positive or negative variations higher than 2, 6 y 12 ºC of the 24 hours and tendency of the two meter temperature. Spread vs ensemble mean maps are available as well. In addition, there are snow outputs according to thresholds aimed to forecast adverse weather.

**4.3.6. Ensemble Prediction System GLAMEPS**

AEMET is contributing to the development and testing of the Grand Limited Area Model Ensemble Prediction System (GLAMEPS) project developed within the HIRLAM and ALADIN Consortia. This system runs operationally (time critical facility) twice daily at ECMWF platforms. The system is a multi-model (two HIRLAM, one AROME, and for the rest a subset of ECMWF EPS is taken) and uses perturbations (ECMWF EPS is used as ICs and LBCs). It runs at 8 km with 40 vertical levels, over a domain that covers Europe, part of the North Atlantic Ocean, including Canary Islands. GLAMEPS data are transferred from ECMWF to AEMET and then conveniently post-processed. The configuration is operational since mid-September 2014

4.3.6.1 Availability of GLAMEPS products

Probabilistic products: Two runs are available: 06 and 18 UTC. AEMET forecast offices are provided with a convenient set of probability maps, mainly for weather parameters (2mT, wind, precipitation), covering the required meteorological thresholds (more or less the same than for AEMET-SREPS) for early warnings.

* 1. **Nowcasting and Very Short-range Forecasting Systems (0-6 hrs)**

No specific numerical model system is available to this purpose, but some HNR/CNN fields and parameters are used for linear extrapolation in the radar based cell convective identification modules. These applications work at national and regional levels. Other HIRLAM parameters are included into satellite applications for nowcasting, such as identification of convection and detection of icing conditions in real time.

HIRLAM wind fields are used for linear extrapolation when a cluster of lightning is identified and warning messages are sent automatically to aeronautical authorities.

HARMONIE graupel field outputs are used for a lightning probability forecasting product (McCaul et al, 2008).

* 1. **Specialized numerical predictions**

HIRLAM outputs are used as inputs data by the following models:

* Wave models: A wave forecasting system developed by the Spanish holding of harbours (Puertos del Estado) is run by AEMET (Gomez and Carretero, 2005). This system is made-up by two main WAM based applications for the Atlantic Ocean and the Mediterranean Sea that provide boundary conditions to four nested applications: three based on the WAM model (Cantabrian coast, Gulf of Cadiz and Canary Islands) and the fourth on the WW3 model (Strait of Gibraltar). Both (WAM and WW3) are third generation well known models that solve the wave transport equation explicitly without any presumption on the shape of the wave spectrum. Furthermore, the WAM model incorporates a two-way nesting scheme that allows the definition of different grid resolutions in various sub-regions of the model domain. The system is driven with 10 m wind fields from the HIRLAM ONR 0.16º and HIRLAM HNR 0.05º models and it is operated on a twice a day cycle with a 72 hour forecast length. The forecast results are verified on real time using the data from Puertos del Estado buoy network. In the research field, AEMET is partner of the Iberian-Biscay-Irish Monitoring & Forecasting Centre of the Copernicus Marine Environment Monitoring Service (The Copernicus IBI-MFC).
* Trajectory model: FLEXTRA is a Lagrangian trajectory model, well known by the scientific community, which can be used to compute forward or back trajectories. It has nesting capabilities. It has been widely validated and the results can be found in the literature. FLEXTRA model is daily used (with HIRLAM ONR 0.16º fields as input) to calculate the analysed (from H+0 to H-96) and forecasted (from H+36 to H+0) back trajectories, in order to check the coherence of the observations of the Spanish EMEP/GAW air quality, the Brewer (ozone) and the Sun-photometer networks and as a help tool to understand the observed values of the parameters measured by the aforementioned networks.
* Chemical Transport Model: MOCAGE is the CTM used (Josse et al 2004). It has been developed and provided to AEMET by Météo-France. It is run operationally in AEMET for Air Quality and UV forecasting and as an emergency tool in ACCIDENT mode. It allows nesting up to three more domains to the global domain. Now, one global domain with 2º horizontal resolution and a second run with a 0.5º continental domain, covering most Europe and Atlantic area, nested to the 2º global domain are run daily up to H+24. A third domain configuration is run with 0.1º over the Iberian area nested to the continental domain in the chemical mode up to H+24 for Air Quality and UVI forecast. Besides, the accident mode can run with different domains: global, continental, Iberian area and the Canary Islands with different horizontal resolution from 1º for global domain to 0.05º for the smallest areas up to H+24 to calculate the evolution of an accidental nuclear or chemical release. AEMET calculates daily the evolution of a possible accidental release over every nuclear power site in operation in Spain. The global domain meteorological and surface forcings come from the ECMWF and MéteoFrance. The meteorological forcings for the continental and Iberian domain come from the HIRLAM ONR 0.16º and HIRLAM HNR 0.05º suites run operationally in AEMET. In the research field, AEMET is a partner of the MACC-III Project (Monitoring Atmospheric Composition and Climate – Interim Implementation), funded by the 7th Frame Program of the European Union for Research and AEMET contribution mainly consists of investigating air quality modelling in high resolution in Western Mediterranean.

A dust prediction model (NMMB/BSC-Dust) is operationally run at a horizontal resolution of 0.1 x 0.1 degrees with 40 vertical sigma levels for a regional domain covering Northern Africa (north of equator), Middle East and Europe, which is the area of responsibility of the Barcelona Dust Forecast Center. There is a daily run at 12 UTC up to a 72-hour lead time. The resolution of the backup run is 0.33 x 0.33 degrees with 24 vertical levels. By the moment, there is not data assimilation: dust contents is initialised with the 24-hour forecast of the previous day. Initial meteorological conditions come from the NCEP global analysis at a 0.5º latitude x 0.5º longitude resolution and 6-hourly boundary meteorological conditions from the NCEP Global Forecast System at the same resolution. A scheme to assimilate MODIS products is under development.

NMMB/BSC-Dust is operationally run at a horizontal resolution of 0.1 x 0.1 degrees with 40 vertical sigma levels for a regional domain covering Northern Africa (north of equator), Middle East and Europe, which is the area of responsibility of the Barcelona Dust Forecast Center. There is a daily run at 12 UTC up to a 72-hour lead time. NMMB/BSC-Dust is a non-hydrostatic model.

The NMMB/BSC-Dust model solves the mass balance equation for dust taking into account the following processes:

* + Dust generation and uplift by surface wind and turbulence.
  + Horizontal and vertical advection (Janjic et al., 2009).
  + Horizontal diffusion and vertical transport by turbulence and convection (Janjic et al., 2009).
  + Dry deposition and gravitational settling (Zhang et al., 2001).
  + Wet removal including in-cloud and below-cloud scavenging from convective and stratiform clouds (Betts, 1986; Betts and Miller, 1986; Janjic, 1994; Ferrier et al., 2002).

The operationally available products are:

* + Dust surface concentration (dust concentration at the lowest model level) in µg.m-3
  + Dust surface extinction at 550 nm (dust extinction at the lowest model level) in Mm-1
  + Dust load (columnar dust contents) in g.m-2
  + Dust optical depth at 550 nm
  + 3-hour accumulated dust dry deposition in mg.m-2
  + 3-hour accumulated dust wet deposition in mg.m-2

There is a non-operational daily multi-model run involving 11 models. Model outputs are interpolated to a common grid mesh of a 0.5-degree resolution up to a lead-time of 72-hours. Products generated include mean and median to describe centrality and standard deviation and range of variation to describe spread. Involved variables are dust surface concentration and dust optical depth at 550 nm.

* 1. **Extended range forecasts (ERF) (10 days to 30 days)**

Not computed by AEMET. The ECMWF ERF System is used.

* 1. **Long range forecasts (LRF) (30 days up to two years)**

Apart from the application of different downscaling techniques to ECMWF seasonal forecasts already described in previous reports, most of the current activity is pointing to support the Mediterranean Outlook Forum (<http://medcof.aemet.es>) and to calibrate and combine different sources of seasonal information as a tool for operational activities. In addition, studies of predictability over Spain and the Mediterranean region are being developed in support of the operations.

1. **Verification of prognostic products**

HIRLAM, HARMONIE and ECMWF outputs are routinely verified against observations for different European and African observations. Standard scores are computed for all model parameters in the vertical and at surface using the available TEMP and SYNOP data. The common HARMONIE software Monitor is used for this purpose. In case of precipitation, also the observations from AIMET’s climate observation network (around 4000 stations in Spain) are used.

The verification has been enlarged using METAR observations. This allows verifying new model variables such as visibility and cloud base.

A spatial verification method (SAL) for precipitation is also run using observations from the climatic network. This technique is able to compare models with different resolutions in a fair manner showing the added value of the convection permitting HARMONIE runs.

The SAL technique has been extended to the verification of low cloud using the Nowcasting SAF data products (Cloud type). The technique is able to identify model deficiencies (in our case the overestimation of low clouds in certain areas) and it is sensitive enough to distinguish between different model configurations. The drawback is that it needs a significant effort to control the quality and representativeness of the data.

1. **Plans for the future (next 4 years)**
   1. **Developments of the GDPFS**
      1. **Major changes in the operational DPFS which are expected in the short future**

During 2016, HARMONIE suit will be officially declared operational based on the integrations on the new Bull supercomputer and the postprocessing software will be migrated from HIRLAM to HARMONIE. In addition, assimilation of ATOVs and GNNS data will enter in the operational suite.

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

Radar data and AMVs data will be implemented in the assimilation cycle and probably SEVIRI radiances, MODES data and scatterometer data. The assimilation cycle frequency is expected to be 1 hour.

A convection-permitting EPS system based on HARMONIE will be implemented during 2016. The system will be enlarged afterword based on the multi-model, multi-boundaries concept. .

* 1. P**lanned Research Activities in NWP, Nowcasting and Long-range Forecasting**

Research on 4DVar assimilation and ensemble based methods will continue. On the other hand, the RUC assimilation and the convection-permitting EPS will allow to develop new nowcasting products.

Most of our seasonal forecasting activities will be focused on the development of an operational framework to calibrate and combine different sources of seasonal information based on Bayesian methods

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