01 – Met Éireann High Resolution Reanalysis for Ireland

Eoin Whelan[1] and Emily Gleeson[1]
[1]*Met Éireann, Glasnevin Hill, Dublin*

Abstract
Met Éireann is currently running a 35-year very high resolution climate reanalysis for Ireland, called MÉRA, using the HARMONIE-AROME numerical weather prediction model. This dataset is the first of its kind in Ireland that will be publically available and will have uses in industry and academia. This paper provides an overview of the MÉRA project, its outputs and uses as well as preliminary validation of some of the surface parameters and analysis of one year of rainfall data.

1. INTRODUCTION

Reanalysis is a scientific method for developing a record of how weather and climate are changing over time and provides more information than current observation networks. It is carried out using a consistent version of a numerical weather prediction (NWP) system or model for the entire reanalysis period, with available observations being ingested into the model at regular intervals (every 3 hours in the case of MÉRA (Met Éireann ReAnalysis). Climate reanalyses are thus an important source of information for monitoring climate as well as for the validation and calibration of NWP models.

The MÉRA reanalysis project being undertaken by Met Éireann staff will span a 35-year period from 1981 to 2015. The HARMONIE-AROME configuration of the HIRLAM-ALADIN NWP system is being used to produce a high resolution gridded dataset of atmospheric, near surface and surface meteorological parameters for the reanalysis period. The data assimilation component of HARMONIE-AROME is described in Brousseau et al. (2011) and the forecast component is described in Bengtsson *et al*. (2016) with updates included in Seity et al. (2010). HARMONIE-AROME uses the SURFEX externalised surface scheme (Masson *et al.*, 2013) for surface data assimilation and the modelling of surface processes. The MÉRA dataset will extend the knowledge gained from observations as the model grid is much finer than observational coverage over Ireland and will include many parameters that are not routinely observed. It will be completed in spring 2017 with data being made available soon after. This article provides an overview of the MÉRA project and preliminary analysis of hydrological-related parameters such as soil moisture and precipitation.

2. MÉRA DETAILS

This section summarises the HARMONIE-AROME configuration used for MÉRA and the production implementation. A brief summary of the MÉRA outputs is also provided.

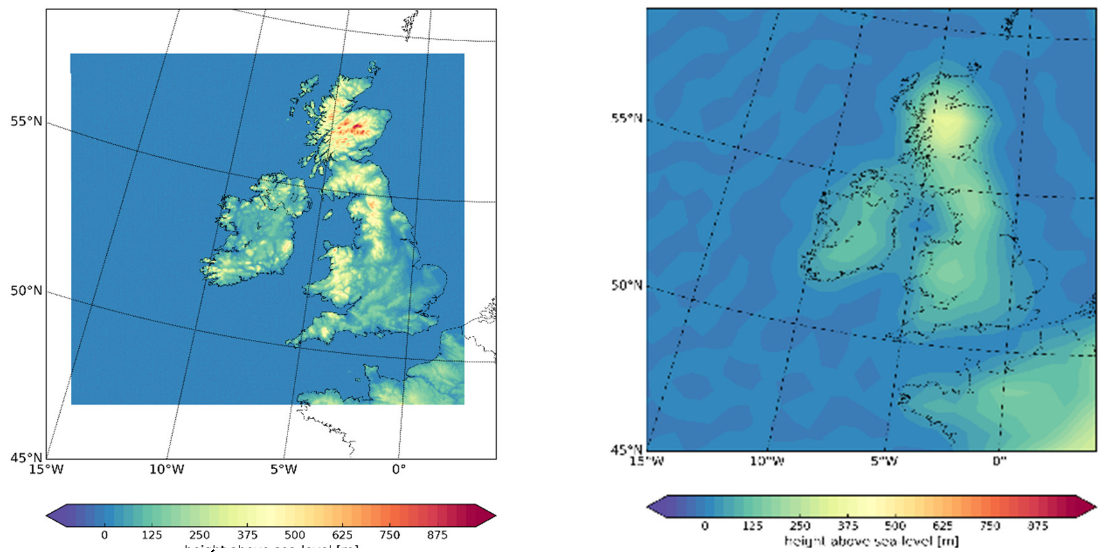

Figure 1: MÉRA (2.5km grid spacing) and ERA-Interim (79km grid spacing) orographies

2.1 Model Configuration

HARMONIE-AROME is configured to run on a horizontal grid of 2.5km, using 65 vertical levels and a model top of 10hPa. The model domain is centred over the Island of Ireland and covers Ireland, the United Kingdom and an area of northern France, see Figure 1. The extra topographical information gained by using the 2.5km grid is clear to see when compared with the ERA-Interim grid (~79km). The domain is the same as has been used operationally by Met Éireann since 2011. Conventional observations (i.e. from synoptic stations, ships, buoys, radiosonde ascents and aircraft) are assimilated. These observations are the same as those used by the European Centre for Medium Range Weather Forecasts' (ECMWF) ERA-Interim reanalysis. MÉRA uses a three-hour forecast cycle with surface and upper-air data assimilation. The assimilation of observations is described in more detail in Section 3. Three-hour forecasts are produced for each cycle except midnight (00 Z) when a 33-hour forecast is produced. This provides a long forecast each day and is used for the purpose of rainfall forecast evaluation. A summary of the model details is presented in Table 1.

Table 1: HARMONIE-AROME configuration used for MÉRA

Model version	HARMONIE-AROME 38h1.2
Domain	540 x 500 grid points (Δx=2.5km)
Vertical levels	65 levels up to 10hPa, first level at 12m
Forecast cycle	3-hours
Data assimilation	Optimal interpolation for surface parameters 3D variational assimilation for upper air parameters
Observations	Pressure from synoptic stations, ships and buoy observations Temperature and winds from aircraft observations Temperature, winds and humidity from radiosondes
Forecast	3 hour forecasts, but a 33-hour forecast at 00 Z

2.2 Simulation Details

Seven separate simulations were set up to run for five years at a time, with a one year spin-up period for each simulation. A spin-up period of 1 year was deemed necessary to allow deep soil parameters reach an equilibrium. Each simulation is running on ECMWF's Cray XC30 system. The MÉRA project will produce approximately 150 TB of forecast and observation feedback data. The forecast data are being stored as GRIB (gridded binary) files and the observation feedback as ODB2 (observation database) files. Three-hourly analysis output is available. Forecast model output is available for each forecast hour up to 33-hours for the 00 Z forecast and to three hours otherwise. A small subset of the surface model (SURFEX) output is available at analysis times and for each three hour forecast. Upper-air data is available on pressure levels as well as a selection of near surface levels. The analysis and forecast output data are summarised in Table 2.

Table 2: MÉRA output data summary

Level type	Parameters	Levels
Pressure	Temperature, wind, cloud, relative humidity, geopotential	100, 200, 300, 400, 500, 600, 700, 800, 850, 900, 925, 950, 1000hPa
Height	Temperature, wind, relative humidity	30, 50, 60, 70, 80, 90, 100, 125 150, 200, 300, 400m
Sub-surface	Temperature, moisture, ice	0, 20, 300cm (below the surface)
Surface	Radiative and non-radiative fluxes	Surface
Top of atmosphere	Radiative and non-radiative fluxes	Nominal top of atmosphere
Surface	Precipitation parameters	Surface
Diagnostic	Screen level parameters	2m for temperatures, 10m for winds
Diagnostic	Other model diagnostic parameters	Various levels

3. DATA ASSIMILATION

Data assimilation is used to estimate the initial conditions of the surface and the atmosphere for the HARMONIE-AROME forecast model using meteorological observations and a background field provided by short-range forecasts (3-hours). The surface data assimilation produces an analysis (i.e. the most likely initial state of the surface) using optimum interpolation (OI), a weighted least squares fit to observations and a background field, (Taillefer, 2002). Three dimensional variational data assimilation (3DVAR) is used to produce the most likely state of the atmosphere, i.e. the analysis. 3DVAR minimises a cost function ($J = J_o + J_b$), the sum of deviations of the analysis from observations (J_o) and deviations of the analysis from the background field (J_b) weighted by respective errors, (Brousseau *et al.*, 2011). The process of atmospheric analysis and forecast is illustrated in Figure 2.

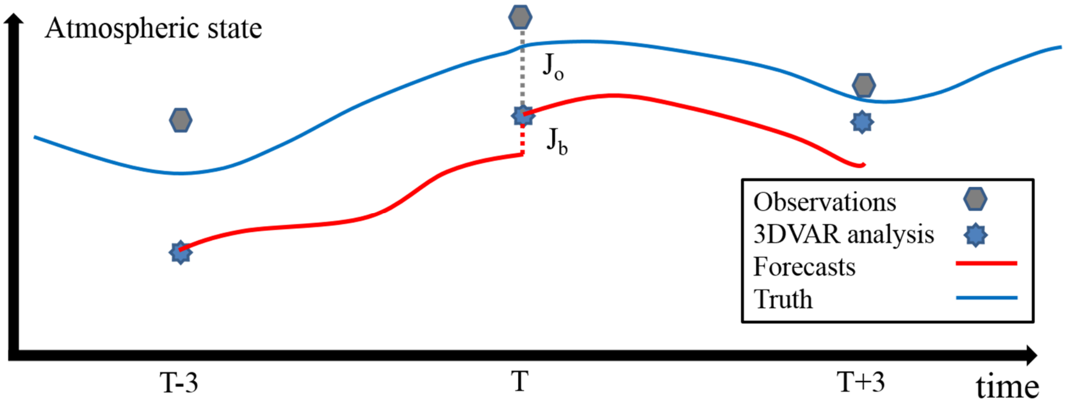

Figure 2: Schematic diagram of the cycle of atmospheric forecast and analysis. Grey hexagons represent the observations used to analyse the atmosphere at time T. The (3DVAR) analysis is produced using information from these observations and the previous forecast weighted by their respective errors. The analysis is the result of minimizing the cost function $J = J_o + J_b$.

3.1 MÉRA assimilation implementation

Conventional observations (listed in Table 1) are assimilated using the HARMONIE-AROME 3DVAR data assimilation system. A three-hour observation window centred at the assimilation time defines the observations assimilated by the 3DVAR system. 3DVAR produces the most likely state of the atmosphere by balancing observation and forecast errors.

Figure 3 shows data counts of the number of surface pressure observations and upper-air temperature observations used by 3DVAR for the years 2005 up to the end of 2014.

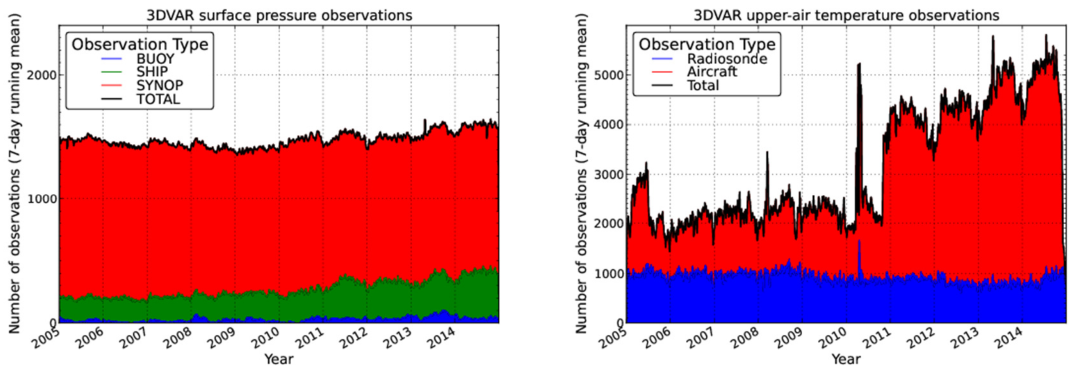

Figure 3: Time-series of the number of surface pressure and upper-air temperature observations used

During this period there is a notable increase in the number of aircraft observations available. The 3DVAR minimization process produces an analysis which is closer to the observations than the model background. An improvement in the average upper-air temperature departures is noticeable from 2011 onwards due to the significant increase in the number of aircraft observations available for assimilation.

4. FORECAST MODEL

This section summarises an initial validation of MÉRA output with an emphasis on parameters important to the hydrological cycle such as soil moisture and precipitation.

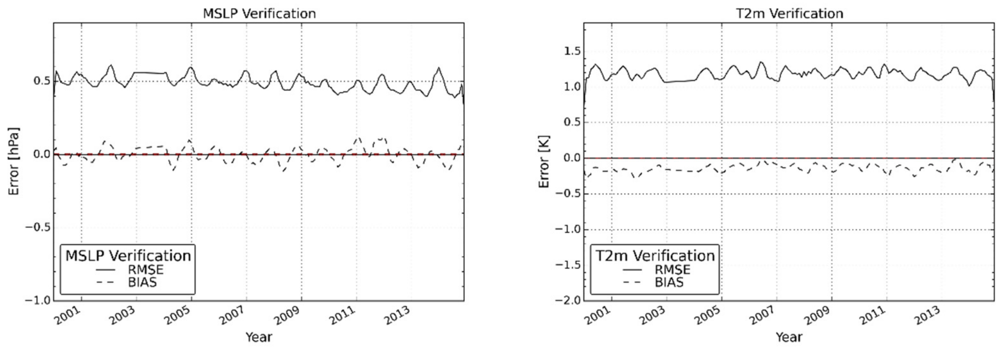

Figure 4: Time-series (2005-2014) of monthly verification scores of 3-hour forecasts of mean sea level pressure (MSLP) and temperatures at 2m compared with synoptic observations. A 3-month running average is applied to the data. The average error, or bias, is plotted using dashes and the root mean square error (RMSE) is plotted using a solid line.

4.1 Forecast Verification Using Surface Observations

The forecast model performance is validated by comparing observed surface parameters and MÉRA output. MÉRA 3-hour forecasts were compared with synoptic observations. All of the synoptic observations available in the MÉRA domain were used in the forecast validation. Figure 4 shows verification results for the years 2005-2014. The results for mean sea level pressure and 2m temperature indicate consistent model performance for the time period. This validation has also identified a slight negative bias in forecasts of 2m temperature.

4.2 Soil Moisture and Model Spin-up

As described in Section 2 a spin-up period of 1 year was deemed necessary to allow deep soil parameters reach an equilibrium. A year-long period, 2010, of model spin-up and production soil moisture below the surface are compared. Production output is treated as truth. It is estimated that it takes approximately three months for soil moisture at 20cm below the surface (SOILMOIST801) and nearly an entire year for soil moisture at 300cm below the surface (SOILMOIST802) to reach equilibrium, as shown in Figure 5.

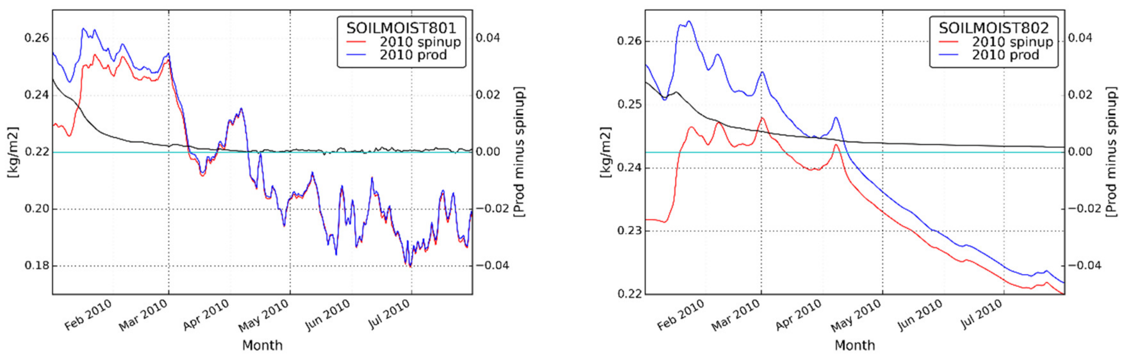

Figure 5: Spin-up soil moisture (red) compared with production soil moisture (blue) for 20cm below the surface (left) and 300cm below the surface (right). The comparison is for the year 2010.

4.3 Verification of precipitation forecasts

Precipitation forecasts produced by MÉRA are compared with observations of 24-hour accumulations of precipitation recorded by Met Éireann's voluntary rainfall network (09Z to 09Z). There is a paucity of higher frequency precipitation point observations preventing a thorough verification of shorter forecast intervals.

In order to identify precipitation forecast errors, mean daily biases during winter (DJF: December, January, February) and summer (JJA: June, July, August) are calculated using 13-years of data (Figure 6). In DJF mean daily biases are mostly positive and within 1 mm. The larger negative biases over mountains are because the 2.5km grid spacing in HARMONIE-AROME cannot account for mountain peaks contained within a grid box. The biases in JJA are slightly larger, mostly within 2mm, and are thought to be as a result of convective rainfall magnitude and positional errors.

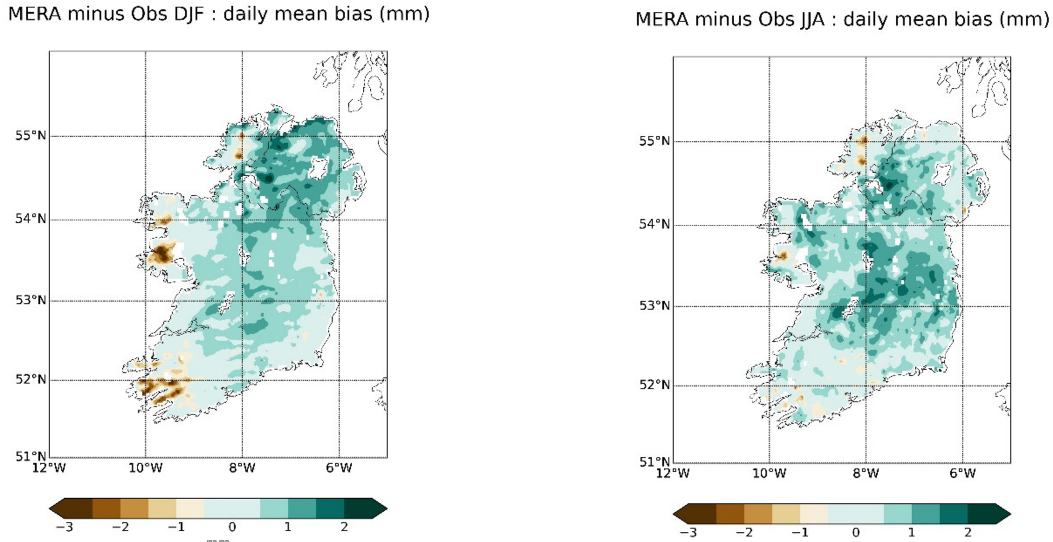

Figure 6: Daily mean biases of precipitation accumulations for winter (left) and summer (right)

Figure 7 shows a year-long (2004) time-series and frequency distribution of 24-hour (09Z -09Z) precipitation accumulations comparing Met Éireann observations to MÉRA forecast data interpolated to observation locations. Over 400 locations were used to carry out this initial statistical validation. The statistics shown are averaged over the all of the comparison locations. The overall trends, peaks and troughs, are very well represented by MÉRA. The frequency distribution shown sheds further light on the positive biases shown by the time-series. This shows the relative frequency distribution of 24-hour rainfall accumulations during 2004 (MÉRA and observed) for accumulations less than 1 mm, 1-2mm, 2-5mm, 5-10mm, 10-25mm and 25-50mm. MÉRA overestimates rainfall less than 5mm but underestimates the extremes – mainly due to the orographic reasons already mentioned.

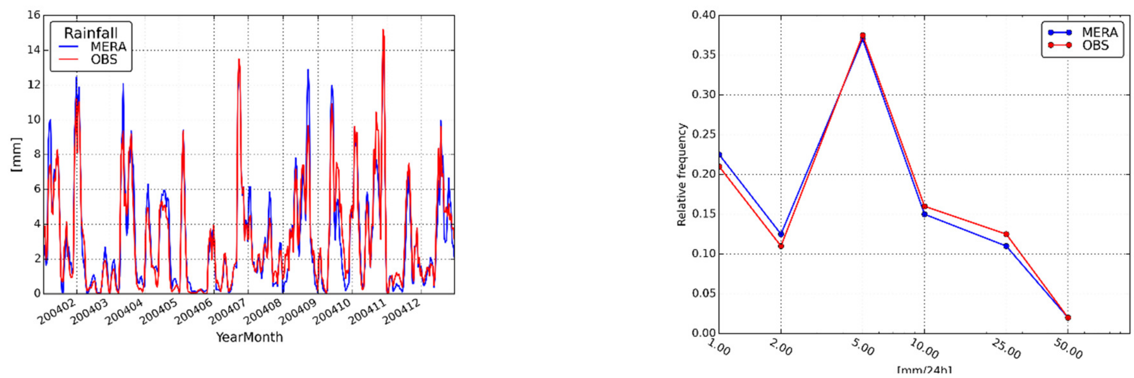

Figure 7: time-series of 24-hour precipitation accumulation observations (red), MÉRA forecasts (blue) and observed (red), MÉRA (blue) 24-hour precipitation accumulation frequency distribution

6. OUTLOOK

The preliminary validation of MÉRA and, in particular, precipitation datasets looks promising. A thorough validation of precipitation and all other parameters is underway, with the aim of quantifying all biases in the dataset. This will enable improvements to be made to Met Éireann's operational NWP suite and will also help in the design of a proposed high resolution ensemble forecasting system. This dataset will be the highest resolution, freely available reanalysis dataset covering Ireland and will have uses in research, food and agriculture, renewable energy, ecology, planning, economics and hydrology.

Future reanalyses should be run on a larger domain, cover a longer time period, make better use of observations and be run in ensemble-mode.

7. REFERENCES

Bengtsson et al., 2016. The HARMONIE-AROME model configuration in the ALADIN-HIRLAM system. In preparation.

Brousseau, P., Berre, L., Bouttier, F., Desroziers, G., 2011. Background-error covariances for a convective-scale data-assimilation system: AROME–France 3D-Var. Q. J. R. Meteorol. Soc. 137, 409–422. doi:10.1002/qj.750

Masson, V., Le Moigne, P., Martin, E., Faroux, S., Alias, A., Alkama, R., Belamari, S., Barbu, A., Boone, A., Bouyssel, F., Brousseau, P., Brun, E., Calvet, J.-C., Carrer, D., Decharme, B., Delire, C., Donier, S., Essaouini, K., Gibelin, A.-L., Giordani, H., Habets, F., Jidane, M., Kerdraon, G., Kourzeneva, E., Lafaysse, M., Lafont, S., Lebeaupin Brossier, C., Lemonsu, A., Mahfouf, J.-F., Marguinaud, P., Mokhtari, M., Morin, S., Pigeon, G., Salgado, R., Seity, Y., Taillefer, F., Tanguy, G., Tulet, P., Vincendon, B., Vionnet, V., Voldoire, A., 2013. The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes. Geosci Model Dev 6, 929–960. doi:10.5194/gmd-6-929-2013

Seity, Y., Brousseau, P., Malardel, S., Hello, G., Bénard, P., Bouttier, F., Lac, C., Masson, V., 2010. The AROME-France Convective-Scale Operational Model. Mon. Weather Rev. 139, 976–991. doi:10.1175/2010MWR3425.1

Taillefer, F., 2002. Canari : code description - algorithms and data flow (presentation, 2002). URL http://www.cnrm-game-meteo.fr/gmapdoc//spip.php?article6 (accessed 10.14.16).