

# DTC VISITOR PROJECT

## IMPLEMENTATION AND VALIDATION OF WRF MODEL AS ENSEMBLE MEMBER OF A PROBABILISTIC PREDICTION SYSTEM OVER EUROPE

### FINAL REPORT

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#### 1. Objectives

The probabilistic forecasts widely used in operational Meteorology and Climatology in the major meteorological centers, are routinely produced by means ensemble predictions. The Ensemble Prediction Systems (EPS) are an optimal tool to analyze the predictability of extreme phenomena. The Spanish Agency of Meteorology (AEMET) is using a Short-Range EPS (SREPS) to study the predictability of severe phenomena in the Atlantic area (Garcia-Moya et al, 2009). Moreover, special attention is paid to the Spanish area. A set of probability density functions are generated by means of the integration of limited area models. In AEMET, a SREPS has been developed, initializing different limited area models by several operational analysis data.

The objectives of the DTC visitor project were summarized as follow: the implementation of WRF model as a SREPS member, the SREPS deterministic and probabilistic verification and calibration against observational data, and finally, the SREPS implementation and application to operational AEMET suite and studies of different extreme atmospheric situations.

The general objective was to investigate the predictability of severe phenomena in the Atlantic area. Furthermore, Spanish area was analyzed in more detail.

The inclusion of WRF model as member of the SREPS was the main task of this project.

The quality of each new WRF members was insured by a deterministic comparison with the rest of the models outputs and by means a daily verification against observations over the post-processing area.

This work has been developed following these specific objectives:

#### ***TASK 1 WRF members implementation.***

- 1.1. Installation and compilation of WRF codes.*
- 1.2. Preprocessing adaptations for running with different global models.*
- 1.3. Post processing adaptations for comparison with other models.*

#### ***TASK 2 WRF members quality studies.***

- 2.1. Integrations during a test period.*
- 2.2. WRF models benchmark.*
- 2.3 Deterministic inter comparison with the rest of the models in SREPS.*

#### ***TASK 3 Verification and calibration of the SREPS.***

- 3.1. Objective verification against observational data.*
- 3.2. Bayesian calibration and bias correction.*
- 3.3. Objective verification of the calibrated SREPS.*

#### ***TASK 4 Operational SREPS. Applications.***

- 4.1. New definition of the operational AEMET SREPS.*
- 4.2. Application to severe weather events*

## 2. Scientific and technical description of the results

The Task 1 presents some requirements to be compared with the rest of AEMET SREPS members. Due to extension of the integration area, which covers Northern latitudes, the members should run on rotated latitude longitude areas (Figure 1). Other requirement was obtain the outputs on regular latitude-longitude areas written on GRIB format to verify the WRF models with the same tools that we ordinary manage to verify the SREPS. All the WRF models were installed and run on the NCAR's Bluefire Supercomputer.

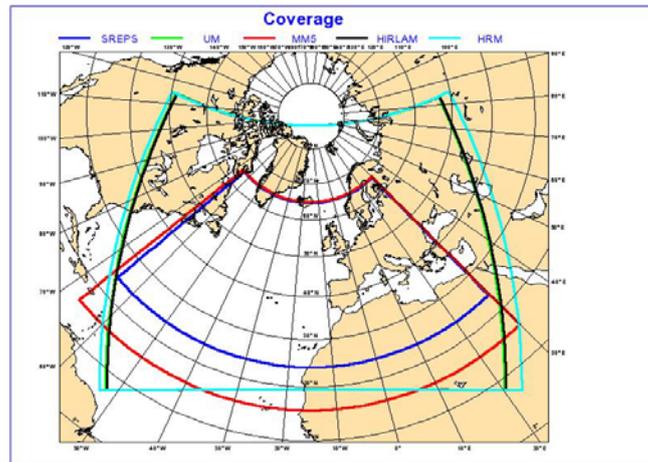
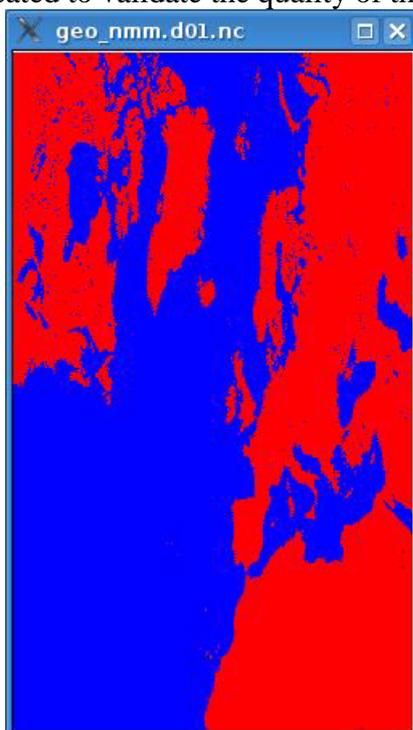


Figure 1: Coverage of AMET SREPS members and common postprocessing area

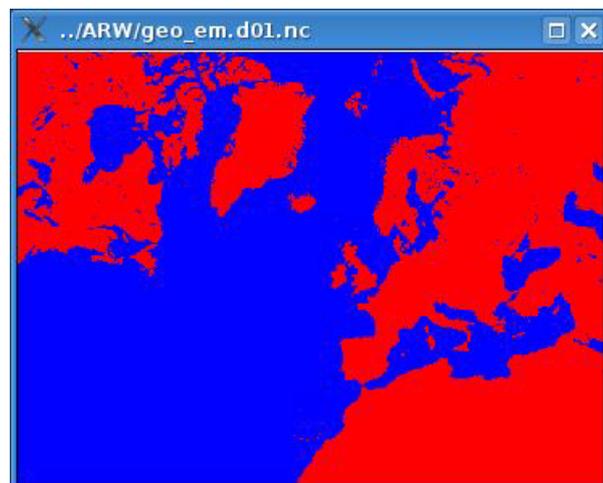
The results of task 1.1. for NMM and ARW cores are the following:

- WRF-NMM members:

After several tests to determine the correct model domain configuration in order to allow the comparison with the rest of the models of the system, the model has been run on a rotated latitude longitude grid with 250 x 426 points and 40 vertical levels. The grid points distances were  $dx = 0.191683$  and  $dy = 0.162951$  and the time step was 60 seg. (Figure 2a). 72-hour forecasts have been created to validate the quality of the model.



(a)



(b)

Figure 2 WRF-NMM (a) and WRF-ARW (b) models integration domain.

- WRF-ARW members:

The final configuration ran on the Bluefire was 366 x 272 grid points and 40 vertical levels. The grid points distances were  $dx = dy = 27794.37$  (Figure 2b) and the time step was 180 s.

The adaptations for preprocessing codes have been done to complete the Task 1.2. New Vtables have been created for the different global models. Modifications have been carried out allowing some changes of the GRIB headers. All the global model data can be preprocessed successfully for both cores. The postprocessing codes (task 1.3) generated problems to obtain regular latitude longitude GRIB outputs. The WPP had problems to postprocess the NMM outputs generating a shifting of the fields (Figure 3). Thanks Jamie Wolff and Hui-Ya Chuang that had made some changes on INITPOST\_NMM.f to fix it.

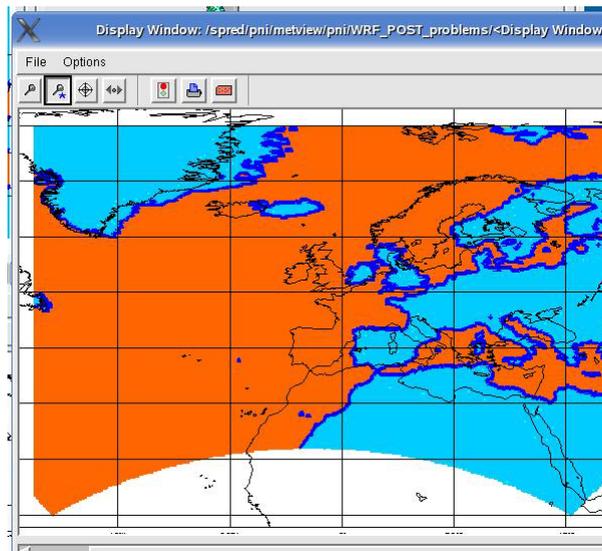


Figure 3 WRF-NMM land-water mask shifting before fixing this problem on INITPOST\_NMM.f code.

The vertical interpolation of the global models data from hybrid coordinates to pressure levels is done using AEMET software. Some changes on the codes have been performed to obtain all the fields needed to run WRF models.

The WPP can not post-process the rotated ARW outputs. To write directly the outputs on GRIB or GRIB2 does not work. Tool to convert directly the rotated netCDF to GRIB is under test.

As conclusion of the task 1, the WRF models successfully run over rotated latitude longitude areas. The NMM core can be post-processed using WPP to obtain regular latitude longitude outputs. The ARW outputs could not be verified and compared with the rest of AMET-SREPS models due to the WPP limitations.

February 2009 has been the integration period selected to complete the Task 2. The WRF-NMM models using GFS data (WNAV) and ECMWF data (WNEC) have been run during February 2009. The integrations using the Unified Model (UM) from UK Met Office and GME from Deutsche Wetterdienst global models fail after few integration time steps. The model reports "PSEUDO HYDROSTATIC IMBALANCE AT THE NORTHERN BOUNDARY". Some tests have been performed to check the possibility of the imbalance was caused by the proximity of the northern boundary of the domain to the North Pole reducing the integration domain. The instability persists in those tests and seems to be the noise associated to the horizontal and vertical interpolations of the boundaries is creating the imbalance. These

instability could be solved with some correction on the model boundary condition treatments.

The WRF integration time on the Bluefire using 8 processors and creating 72-hour forecast took 180 minutes for ARW core and 80 minutes for NMM core. The same configurations took 4 times more on AEMET Cray X1E using vector or scalar processors. The optimization of the codes over CrayX1E is needed to in operational way on AEMET run WRF, this is an ongoing work with the Cray analysts.

To evaluate the WRF model quality over this area a verification exercise was done. The deterministic comparison between WRF-NMM members: WNAV and WNEC and MM5 members, using the same global model as initial and boundary conditions, were performed for February 2009 month to complete Task 2.3. Several meteorological parameters have been verified against observations, showing a similar RMSE and BIAS between WRF and MM5 models (Santos-Muñoz et al., 2009) but a clear BIAS reduction is exhibited 2-meter temperature forecasts (Figure 4).

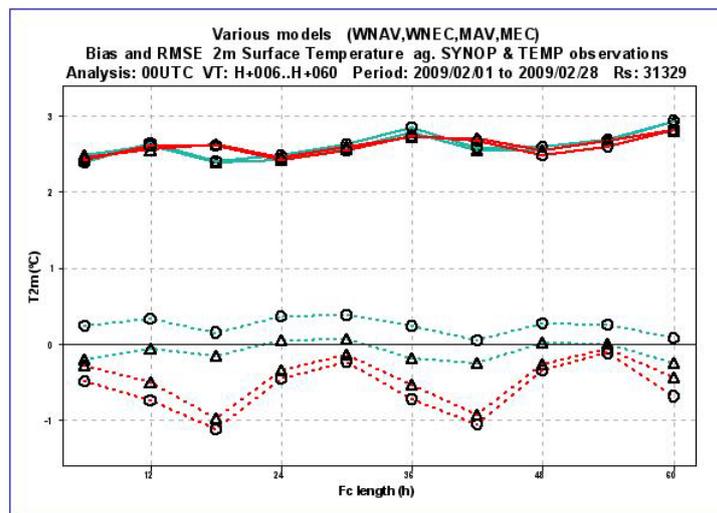


Figure 4: Bias (dashed lines) and RMSE (solid lines) of 2-meter temperature of WNAV (light blue line with triangle points), WNEC (light blue with circle points), MAV (red line with triangle points), MEC (red line with circle points) during February 2009. The number of observations is 31329.

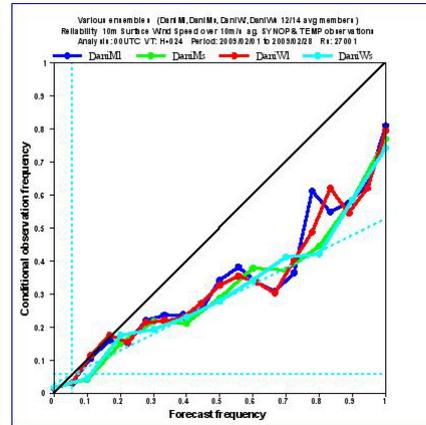
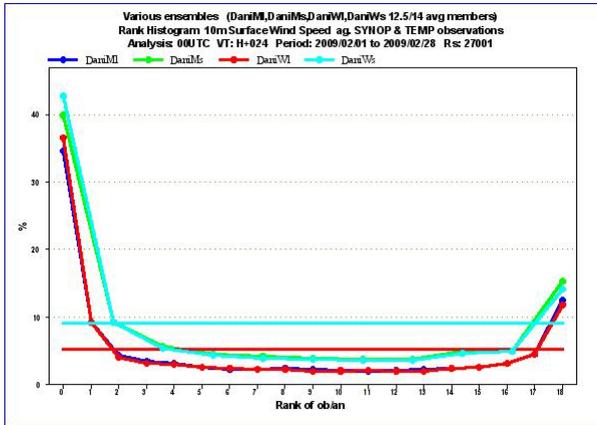
To summarize the Task 2 results, the WNAV and WNEC have been integrated during February 2009, showing a little improvement compared to MAV and MEC models. An improvement is needed in the computer performance to run operationally on AEMET CrayX1E. Also, a different boundary condition treatment is needed to complete the integrations using other global models.

A probabilistic verification has been made (Task 3) generating four different ensemble prediction systems (Table 1). Each of the ensemble systems only showed clear improvements related to the number of ensemble members involved on the verification exercise. Figure 5 shows the verification results of the event probability of 10-metre wind speed over 10 ms<sup>-1</sup>. The rank histogram (Figure 5a), the attribute diagram (Figure 5b), the ROC curves (Figure 5c) and relative value curves (Figure 5d) exhibit a similar performance of the ensembles. The differences on the rank histograms obviously are due to the number of members used in the computation, but a similar shape was obtained indicating a similar calibration of the systems.

The calibration and bias correction (Task 3.2) and posterior verification of the calibrated ensembles have not been carried out because the system has not been completed yet. The Task 4 has been also postponed up to obtain a final version of the system.

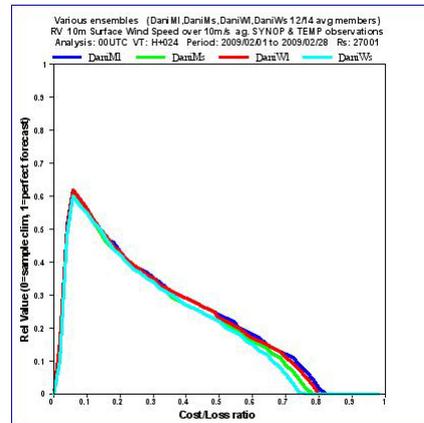
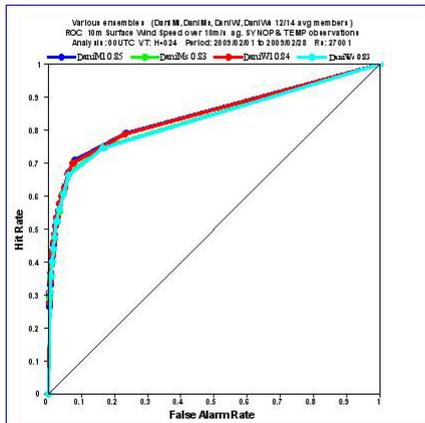
	Limited Area Models	Global Models	Number of members
EnsWLarge	HRM Hirllam Lokal Model WRF-NMM Unified Model	GFS ECMWF GME UKMO	18 (WNGM,WNUK are not included)
EnsMLarge	HRM Hirllam Lokal Model MM5 Unified Model	GFS ECMWF GME UKMO	18 (MGM,MUK are not included)
EnsWShort	HRM Hirllam Lokal Model WRF-NMM Unified Model	GFS ECMWF GME UKMO	10
EnsMShort	HRM Hirllam Lokal Model MM5 Unified Model	GFS ECMWF GME UKMO	10

Table 1: Different ensemble prediction systems created combining limited area models with initial an boundary conditions from global models. Some models has been removed on large ensembles (EnsWLarge and EnsMLarge) to allow a fear comparison between the systems.



(a)

(b)



(c)

(d)

Figure 5 Verification results of the event probability of 10-metre wind speed over 10 ms<sup>-1</sup>. The rank histogram (a), the attribute diagram (b), the ROC curves (c) and relative value curves (d) of the EnsW Large (red line), EnsMLarge (blue line), EnsWShort (light blue line) and EnsMShort (green line).

### 3. Summary and conclusions

WRF model can be used as member of a short range ensemble prediction system due to the similar performance to other limited area models currently operationally running in AEMET.

Some problems related with pre-processing and post-processing codes have created delays on the project execution. Some of these problems have been solved successfully, but the use of the GME and UKMO global model data as initial and boundary conditions is still an unsolved question. Moreover, the possibility of obtain un rotated GRIB outputs of ARWs have limited the verification exercise to the NMM core.

The capability of WRF model to run using other global models could be interesting for the community and a new tool to interpolate vertically these global models and a more complex boundary condition treatment could be helpful to avoid the instabilities in the integrations.

The huge amount of data transferred between UCAR and AEMET computers, has generated delays on the tests and results.

Future works could be performed to complete the eight ensemble members, to verify the full system and to increase the verification period avoiding under-sampling effects.

### 4. Acknowledgments

I would like to thank the DTC visitor program the funds to develop this project.  
Thanks for the collaboration, suggestions and technical help of Jamie Wolff and Louisa Nance.  
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Thanks to the rest of the colleges of AEMET Applications Group: José Antonio García-Moya, Carlos Santos, Alfons Callado, Juan Simarro and Pau Escriba who have created, supported and maintained the AEMET-SREPS.

### 5. References

García-Moya, J., Callado, A., Santos, C., Santos-Muñoz, D., and Simarro, J. (2009). Predictability of short-range forecasting: a multi-model approach. *Nota Técnica AEMET, NT-SPPE-1, ISBN: 978-84-7837-073-3*, 30pp.

Santos-Muñoz, D., Wolff, J., Santos, C., García-Moya, J.A., and Nance, L.(2009). Implementation and validation of WRF model as ensemble member of a probabilistic prediction system over Europe. 10th Annual WRF Users' Workshop 23-26 June 2009 in Boulder, CO