SPECIAL PROJECT PROGRESS REPORT

Reporting year	2014
Project Title:	Continental winter weather prediction with the AROME ensemble prediction system
Computer Project Account:	spfrbout
Principal Investigator(s):	François Bouttier
Affiliation:	CNRM, Météo-France
Name of ECMWF scientist(s) collaborating to the project:	n/a
Start date of the project:	15 March 2012
Expected end date:	Dec 2014

Computer resources allocated/used for the current year and the previous one

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(MSBU)	5	5	6	2 on 19June14
Data storage capacity	(Gbytes)	4000	5	4000	5

Summary of project objectives

The aim of the project is to improve a convective-scale ensemble prediction system, AROME, for continental winter conditions over Europe. It is planned to run ensemble experiments at 2.5km resolution around France and Hungary during selected episodes that exhibit high-impact low-level phenomena, snow and freezing, as well as cold low-level clouds and fog. Ensemble performance will be assessed using relevant observations. Scientific studies will focus on obtaining the correct level of ensemble spread, and representing model error using stochastic physics and surface perturbations appropriate for the dominant phenomena.

Summary of problems encountered (if any)

None

Summary of results of the current year (from July of previous year to June of current year)

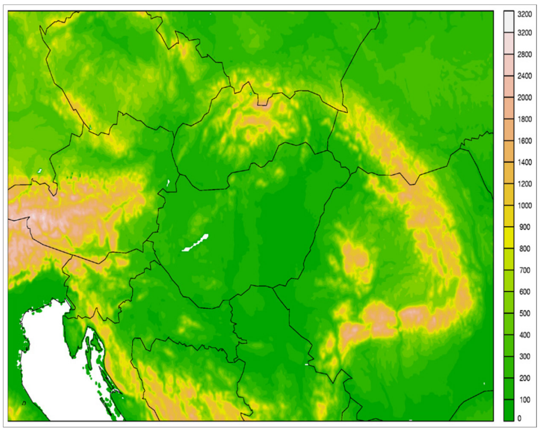
see next pages.

Testbed description

Two AROME-EPS testbeds have been set up for this project, one over France covering January 2013 (with several severe snow events), the other over Hungary in the 26 Dec 2011 - 8 Jan 2012 period (with warm, windy weather and little snow or fog). The ECMWF SBUs have been consumed by this experimentation.

The Hungarian testbed initially used interpolated global analyses as initial conditions, in the spirit of Wang et al (2011). It appeared that short-range model performance was poor (with strong initial biases) and that it was necessary to start from a more balanced AROME initial state. An Hungarian AROME data assimilation system has been set up, which provided much improved deterministic initial conditions, and initial perturbations centered around them were prepared using rescaled PEARP (French ARPEGE EPS) initial perturbations. This vastly improved the short-range ensemble performance. In summary, the AROME-EPS testbeds for this project now have the following characteristics:

- initial conditions: AROME analysis plus rescaled PEARP perturbations
- lateral conditions: PEARP forecasts
- physics perturbations: AROME SPPT
- surface perturbations: developed by this project in 2013/2014(see below)
- AROME model at 2.5km resolution, typically 24-range and 10-12 member forecasts run once a day.
- domains: see below for the Hungarian domain (320x500 gridpoints), on next page for the French one.



Winter weather case studies

Although the bulk of of the work has consisted of month-long impact experiments and verification using objective probabilistic scores, a few case studies have been done to assess the AROME-EPS ability to warn about high-impact winter weather events. Only a fog case in shown here, other studies have been devoted to the forecast of negative surface temperatures, high winds, and the rain/snow transition.

Fog has high impact on the transport sector because of its consequences in terms of visibility. It can also be linked with road or airport runway icing because they are important for nighttime cooling. The 18-h forecasts valid on 18 Jan 2013, 12utc, have been examined and two key probability fields are shown below. The fog probability clearly identifies areas of fog with high (over Spain) or moderate (over SW France) fog probabilities. In this case, is Spanish fog is simply due to clouds intersecting the mountains. In SW France, there is some probability of genuine fog formation on a plain with moist ground (the Landes forest). These fog predictions are possible because the

AROME model contains a detailed land surface model (SURFEX scheme) and a 5-species microphysical scheme (ICE3) that is active in the PBL. This allows full coupling between surface fluxes, turbulence, radiation and microphysics in the moist PBL. It is interesting to see that AROME-EPS can predict fog probabilities although there is no surface perturbation (surface perturbations have been developed at a later stage as described below; the SPPT stochastic physics scheme is not active near the surface either): here, all fog dispersion comes from the ensemble dispersion of upper-level atmospheric parameters. Fog verification has not been attempted yet because of the relatively low accuracy of the forecasts, and the rarity of in situ observations. In a forthcoming AROME version, the vertical resolution (currently no better than 10m near the surface) will be increased, which is expected to significantly improve fog forecasts. Fog and visibility ensemble forecasts will be studied more closely in this framework, with surface perturbations and low-level stochastic physics.

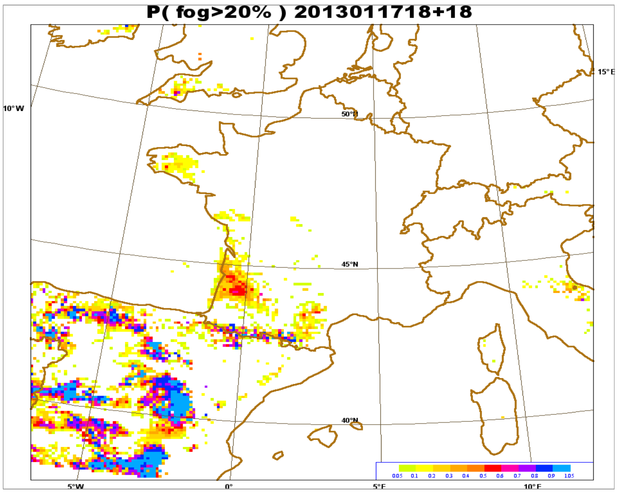


Figure: Probability maps for fog (left) in a winter case, as predicted with the AROME-EPS system.

Impact of surface perturbations

A simple surface perturbation scheme has been developed. The motivation is that previous studies have shown that surface perturbations tend to improve large-ensemble predictions (e.g. Lavaysse et al MWR 2013, with the Canadian regional EPS). (experiment ref: e828/plotscoKfi) As a first step, perturbations have been implemented to a set of surface parameters: vegetation fraction, leaf area index, vegetation thermal coefficient, land surface roughness length, albedo, soil temperature and humidity, snow depth, sea surface temperature and sea fluxes (of heat, moisture and momentum). The perturbations are centered around the operational analysis, and they follow a spatial random pattern (independent for each member) with prescribed horizontal correlation length (200km) and standard deviation (scaled according the assumed uncertainty on each parameter). The perturbations are additive or multiplicative depending on the parameter, and they are clipped in order to stay within physically meaningful limits. They remain constant during the course of each forecast. We have run impact experiments where the ensemble surface perturbations are applied to subsets of these parameters. The conclusion is that, in line with previous warm season studies with other models, the most effective parameters to perturb are the soil moisture and sea surface temperature ('effective' meaning here that (a) substantial spread is obtained with minimal degradation of the ensemble member realism, and (b) that these fields provide the clearest benefit on probabilistic scores). It is interesting to see that the impact of surface perturbations is not confined to the warm season.

The following figures show the impact of perturbing the full set of surface parameters listed above, in a 10-member AROME ensemble run once per day over January 2013. In all runs, the perturbations on lateral boundary conditions, atmospheric initial conditions and the stochastic physics are active. Many more scores have been checked to support our conclusions, only a sample is shown here. The impact of surface perturbations on two-metre temperature and humidity is beneficial and statistically significant. The impact on wind is beneficial, but it cannot be proven for strong winds (the CRPS takes into account all wind speeds, and in this verification dataset the majority of winds is slower than 30km/h); the main parameter that affects wind performance in this study is surface roughness, and ensemble performance is degraded whenever the perturbation amplitude is ramped up to yield a significant impact on the forecasts. It suggests that one should look for other surface or PBL parameters to perturb (e.g. orographic drag or PBL turbulence parameters). Finally, precipitation scores are not significantly affected by the surface perturbations.

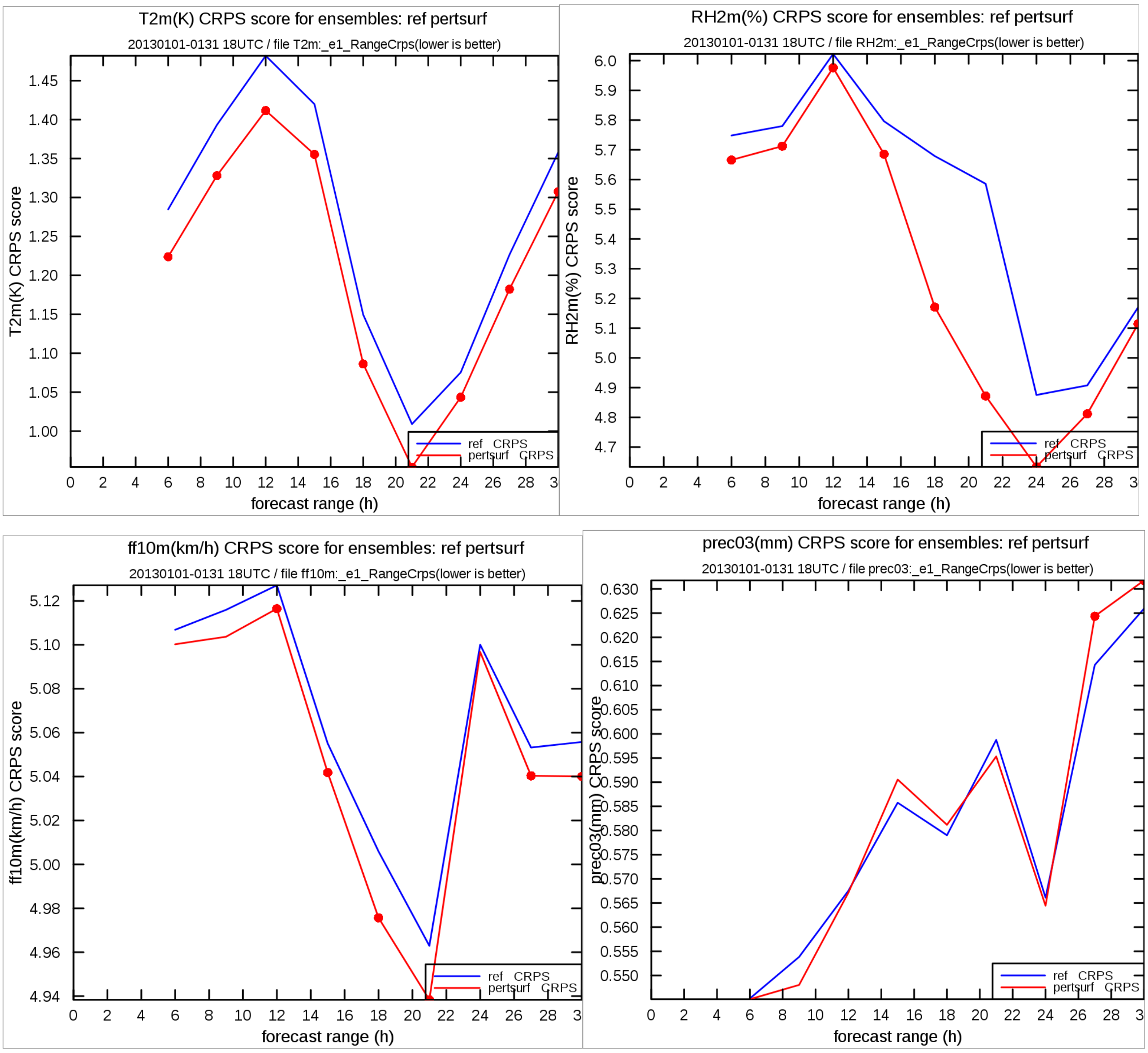


Figure: CRPS (continuous ranked probability score) impact of activating surface perturbations in the AROME ensemble over France in January 2013, as a function of forecast range. Blue is the reference ensemble, Red is the reference plus surface perturbations, Red dots indicate bootstrap 95%-significant differences. Lower is better. This figure shows that surface perturbations have a clear beneficial impact on forecasts of low-level temperature, humidity and wind. The impact on precipitation is non-significant.

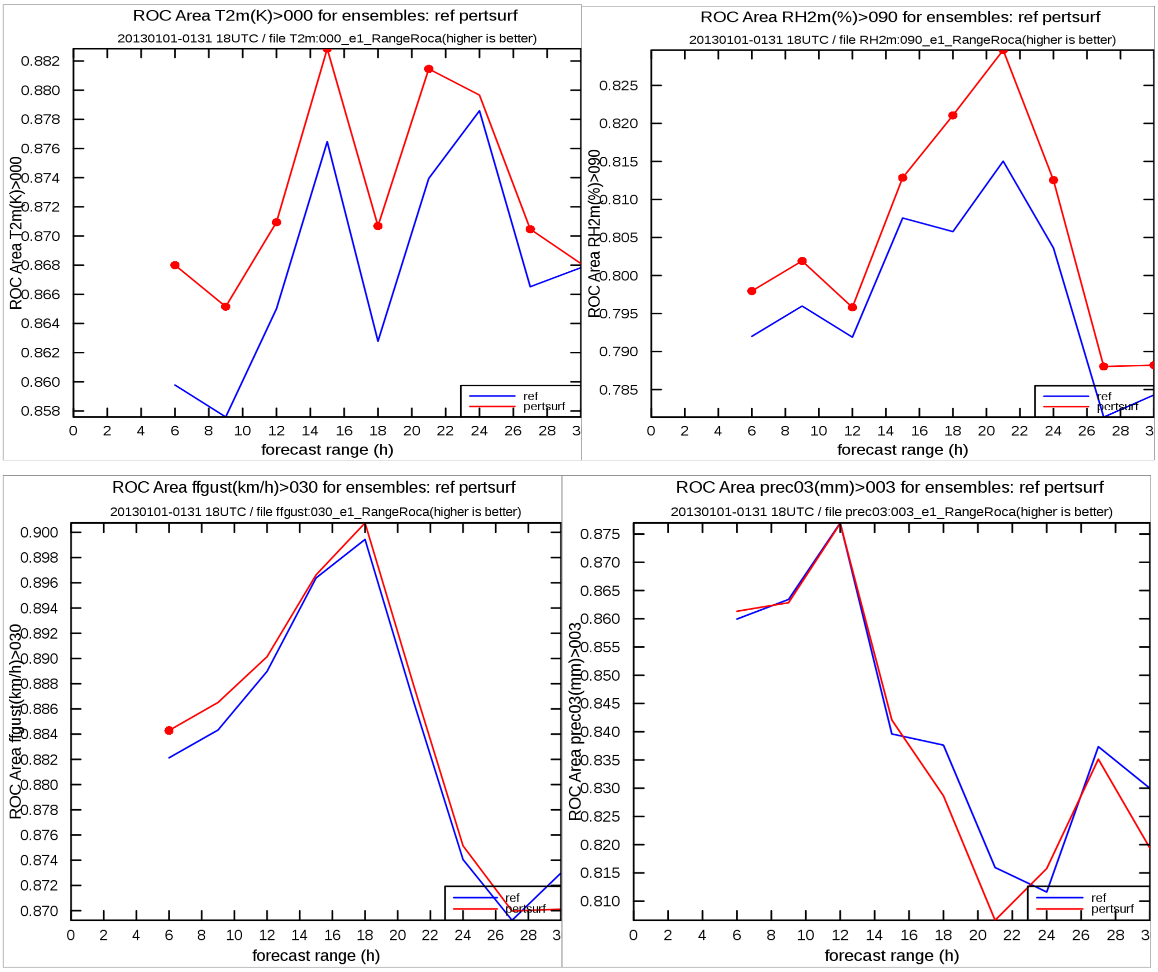


Figure: Same as on previous figure, the score now being the ROCA (Receiver Operating Characteristic Area) for the following events: T2m>0C, HU2m>90%, ff10m>30km/h, rr3h>3mm. The higher the better. These plots show that ensemble surface perturbations significantly increase the value of the ensemble for decision-making with respect to these events, for 2m temperature and humidity. The impact on windspeed and precipitation is not significant.

Impact of using ECMWF high-resolution lateral boundary conditions

The impact of using LBCs from experimental high-resolution EPS runs has been tested on the Hungarian domain, where the French PEARP LBCs cannot be used. Some results have been presented in last years' report. New tests have been performed on wintertime cases, 26 Dec 2011 to 8 Jan 2012. In this experimentation, there was no initial condition perturbation nor representation of model error, and the surface conditions were interpolated from the Hungarian ALADIN analysis. The impact of high- vs low-resolution LBCs from ECMWF EPS was tested in terms of the resulting AROME-EPS performance on Z500, T850, HU700, 925hPa wind speed, T2m, HU2m, ff10m, MSLP. Hungarian SYNOP observations were used for the low-level scores. 00UTC and 12UTC production runs have been compared. The following figure shows a sample of the scores. The conclusion is that high resolution ECMWF EPS LBCs clearly improve the AROME EPS forecasts.

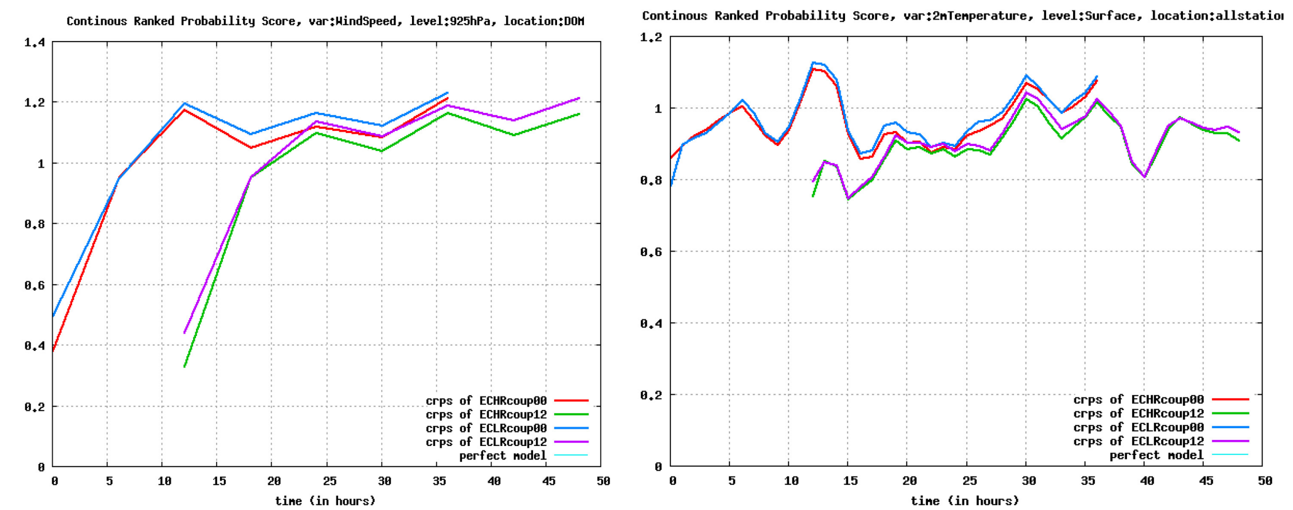


Figure: CRPS scores of 925hPa wind speed and T2m on the Hungarian implementation of AROME EPS. The red and green curves are forecasts driven by the experimental high-resolution ECMWF EPS boundary conditions, their respective references are the blue and purple ones. (lower CRPS is better)

Conclusion and outlook: the AROME-EPS experimentation in winter cases has shown that the high-resolution ensemble provides valuable forecast information. This project showed in previous years that stochastic physics (SPPT scheme) improves forecasts in winter. Now we also show that surface perturbations improve ensemble forecasts too, on selected parameters. We also show that ECMWF high-resolution EPS boundary conditions would be a significant improvement over the current lower-resolution ones, for ALADIN/HIRLAM centres that rely on ECMWF output for their NWP production.

If resources are allocated for a continuation of this project, it is planned to further study the wintertime behaviour of the AROME-EPS ensemble by considering verification against cloud cover and visibility forecasts, by looking more closely at the ensemble performance in windstorm cases, and by improving the ensemble perturbations in the surface and boundary layer.

List of publications/reports from the project with complete references

Bouttier, F., B. Vié, O. Nuissier and L. Raynaud, 2012: Impact of stochastic physics in a convection-permitting ensemble. *Mon. Wea. Rev.*, 140: 3706-3721

Wang Y., M. Bellus, C. Wittmann, M. Steinheimer, F. Weidle, A. Kann, S. Ivatek-Sahdan, W. Tian, X. Ma, E. Bazile, 2011: The Central European limited area ensemble forecasting system: ALADIN-LAEF. *Quart. J. Roy. Meteorol. Soc.*, **137**, 483-502. doi:10.1002/qj.751

Bouttier, F. and Szucs, M.: SPFRBOUT project reports, June 2012 and June 2012 (already sent to ECMWF)

Summary of plans for the continuation of the project

A new project will be requested in order to gain deeper understanding into some issues raised in this project. The computer resources needed will be similar.