Hungary's use of ECMWF ensemble boundary conditions

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Forecasters at the Hungarian Meteorological Service (OMSZ) make extensive use of ECMWF's high-resolution (HRES) and ensemble forecasts (ENS) in their daily work. In addition, like most other European national meteorological services, OMSZ also runs limited-area models (LAM) to provide improved forecast information at even higher resolution. OMSZ, which is part of the ALADIN consortium, uses the ALADIN and AROME models. Running these LAMs requires not only initial conditions (ICs) but also lateral boundary conditions (LBCs). Their availability has been ensured through ECMWF's Optional Boundary Condition (BC) Programme.

OMSZ's limited-area ensemble activity started almost a decade ago. Météo-France's global ensemble system (Prévision d'Ensemble ARPEGE, or PEARP) has been used to produce boundary conditions since our first system became operational in 2008. OMSZ has also been interested in ECMWF's ENS boundary conditions (ENS-BCs) from the beginning. While tests confirmed this interest, some technical issues have in the past imposed severe limitations on the operational use of ENS-BCs. The extension of ECMWF's Optional BC Project in July 2015 made ENS-BCs available in a similar way to HRES-BCs.

In recent experiments, the current ENS-coupled version of our limited-area ensemble system (ALEPS-ENS) produced forecasts that were significantly different from those produced by the operational version (ALEPS-PEARP). Single members were more accurate for most variables, so the root-mean-square error (RMSE) of the ensemble mean was lower. At the same time, the system was less dispersive. Neither ALEPS-ENS nor ALEPS-PEARP outperformed ECMWF ensemble forecasts in terms of standard scores, but they provided crucial added value when an extreme weather event occurred over Hungary.

Operational LAM ensemble

In OMSZ's operational system (ALEPS-PEARP), we integrate 11 ensemble members using boundary conditions derived by simple dynamical downscaling of the first 11 members of PEARP (*Descamps et. al.*, 2014). Model runs start at 18 UTC every day and cover the next 60 hours.

For the integrations we use the ALADIN model in hydrostatic mode with 8 km horizontal resolution and 49 model levels. Our domain covers most of continental Europe (Figure 1). Parametrized processes are described by the ALARO physics package. OMSZ's long-term plans include the development of a convection-permitting ensemble prediction system (EPS) based on the AROME model with 2.5 km horizontal resolution (*Szintai et. al.*, 2015).

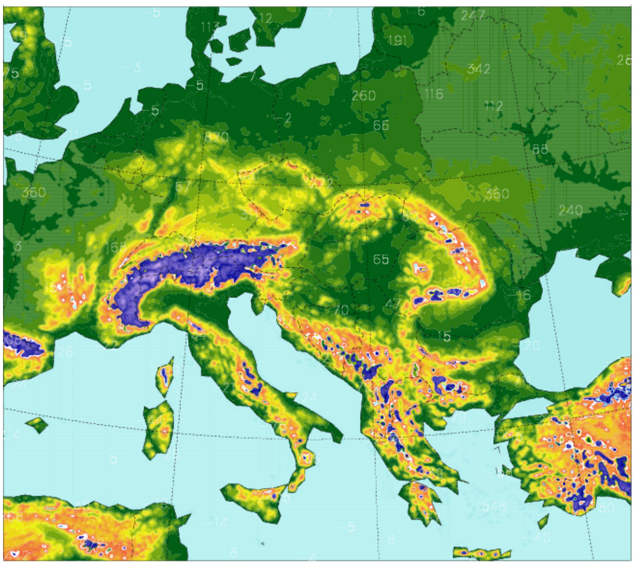


Figure 1 The ALADIN domain of ALEPS forecasts at 8 km horizontal resolution.

Atmospheric perturbations are derived from interpolated global ICs and LBCs while surface fields are identical for all ensemble members at the beginning of the model runs. Coupling is realised every six hours based on the outputs of the 18 UTC PEARP run. In order to use local observations and improve the representation of initial condition uncertainty, we have investigated using the Ensemble of Data Assimilations (EDA) method in both the ALEPS and the AROME-EPS frameworks (*Horányi et. al.*, 2011, *Szintai et. al.*, 2015). For model error representation we have tested the Stochastically Perturbed Parametrized Tendencies (SPPT) scheme (*Szintai et. al.*, 2015).

ENS-coupled LAM ensemble

The downscaling of an ECMWF global forecast to obtain the ALADIN model BCs consists of three major steps. The first is the file retrieval from the MARS database, separated into atmospheric spherical and grid-point fields and surface grid-point fields. The second step is the file conversion between the GRIB and FA data formats (ALADIN 901 configuration). Finally, global fields are interpolated to limited-area ones (ALADIN e927 configuration) with 15 km resolution.

In the case of HRES-BCs, this process has been run by ECMWF for many years as part of the Optional BC Programme. In the case of ENS-BCs, ECMWF Member States may run a similar process or even a whole ensemble prediction system (*Weidle et al.*, 2015) on ECMWF's supercomputer using a national quota of system billing units (SBU). While Hungary is a Co-operating State without its own SBU, this option became available after the extension of the BC Programme in the summer of 2015. OMSZ then prepared related tasks on ECMWF's supercomputer, which were implemented in ECMWF's operational suite in November 2015 with the assistance of ECMWF.

Once this had been done, OMSZ began to routinely download ENS-BCs via ECMWF's dissemination system to OMSZ's supercomputer. Following a second interpolation step to 8 km horizontal resolution, we run an ensemble of forecasts (ALEPS-ENS). Like the operational ensemble system, ALEPS-ENS comprises 11 members, the first of which is coupled to the ENS control and the others to the first 10 of the 50 perturbed members. Model runs start at 18 UTC every day and cover the next 60 hours. The coupling frequency was improved to 3 hours compared to 6 hours in the operational system. In addition, we get ENS-BCs for 12-hour periods from the other three ENS production times (00, 06 and 12 UTC). These can support our future plans for maintaining an ensemble of data assimilation cycles.

The surface processes in ECMWF's Integrated Forecasting System (IFS) are quite different from those in the ARPEGE and ALADIN models, where the ISBA parametrization scheme is used. As a result, it is not feasible to initialise surface fields directly from the IFS at the beginning of an ALADIN run. Since there is no surface data assimilation in OMSZ's ALEPS, the issue can simply be resolved by obtaining surface fields from an interpolated ARPEGE file. However, if such a procedure were to be used for all members, it would lead to the elimination of the surface field perturbations in ENS. Since we would like to preserve such perturbations, we decided to add them to the surface fields obtained from the PEARP control member. This step and the whole process are visualised in Figure 2.

Verification results

We have examined the impact of ENS-BCs on forecasts up to 60 hours ahead produced during a 52-day winter

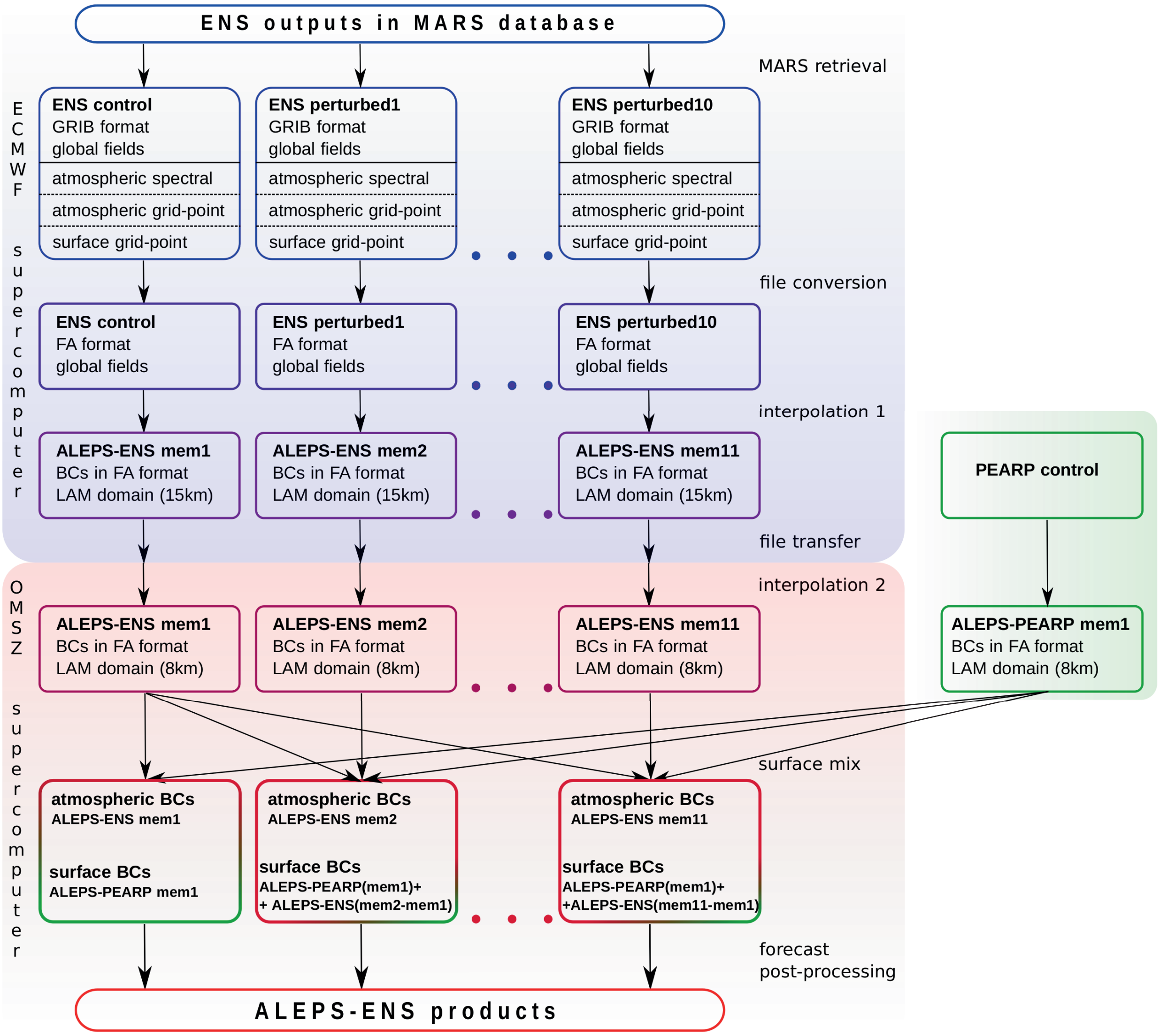


Figure 2 Chart of dataflow for ALEPS-ENS dynamical downscaling. Eight-km-resolution BCs are generated on OMSZ's supercomputer from the 15-km-resolution BCs generated on ECMWF's supercomputer. As a final step before the model integration, surface fields are taken from the ALEPS-PEARP control because of the inconsistency of the surface schemes used in ECMWF's global model on the one hand and in the ALADIN model on the other. To preserve surface perturbations, we simply add the difference between the downscaled ENS perturbed members and the ENS control member to the ALEPS-PEARP control surface fields.

period, between 11 December 2015 and 31 January 2016. ALEPS-ENS ran every day at 18 UTC during this period. The results were compared with the operational system (ALEPS-PEARP) and also with the ENS. To avoid any effects stemming from inconsistencies in the number of ensemble members, in this comparison we verified only the first 10 perturbed members and the control member of the ENS.

We verified upper-air variables against radiosonde measurements over the whole model domain (on average 37 measurements at 00 UTC and 43 measurements at 12 UTC). We found the RMSE of the ensemble mean to be generally smaller for ALEPS-ENS compared to ALEPS-PEARP. At the same time, the spread of ALEPS-ENS forecasts was also smaller than that of ALEPS-PEARP forecasts. ECMWF ENS had preferable features in terms of RMSE and the spread–error relationship compared to the ALEPS forecasts (Figure 3).

We calculated the RMSE and the spread for near-surface parameters against 30 SYNOP stations located in Hungary (Figure 4). For the two versions of ALEPS, the results are similar to those obtained for upper-air parameters. The quality of the ensemble mean is slightly better in ALEPS-ENS, except for 10-metre wind speed, but at the same time the system is less dispersive than ALEPS-PEARP. ALEPS-ENS was able to outperform ECMWF ENS only for 2-metre relative humidity.

Winter case study

On 6 and 7 January 2016, a high amount of precipitation occurred in Hungary in various forms (rain, freezing rain, wet snow, snow). This weather event caused a lot of damage to power transmission lines, especially in southern and central parts of the country, where mixed-phase precipitation occurred.

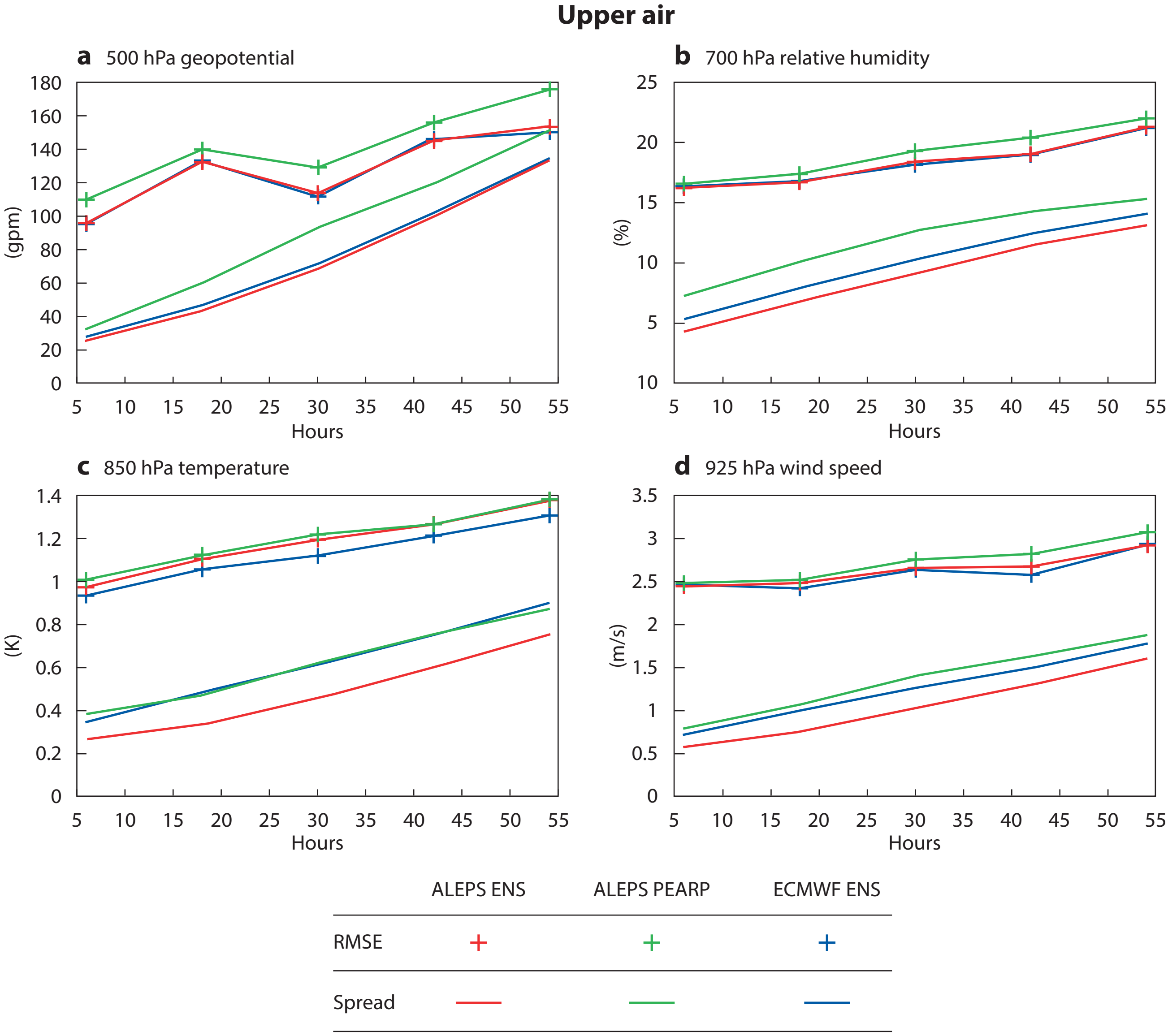


Figure 3 RMSE of the ensemble mean and spread around the ensemble mean of forecasts up to 60 hours ahead run at 18 UTC every day between 11 December 2015 and 31 January 2016 for (a) 500 hPa geopotential, (b) 700 hPa relative humidity, (c) 850 hPa temperature, and (d) 925 hPa wind speed.

The probability of high amounts of precipitation was much lower in the ENS than in the limited-area ensembles run by OMSZ. Due to their higher resolution, ALEPS forecasts seem to capture high-impact weather better than global model runs. In addition, ALEPS-ENS provided good probabilistic guidance for mixed-phase precipitation in the form of freezing rain and wet snow.

Synoptic description

On 6 January, a cyclone developed over the Adriatic Sea and propagated toward the Balkan Peninsula and the Black Sea (Figure 5). At upper tropospheric levels (500 hPa), a trough started to deepen over Central Europe and moved eastward. Consequently, the region of Hungary was at the northern flank of a well-defined baroclinic zone accompanied by significant horizontal and vertical wind shear. In the afternoon and evening of 6 January, there was mostly a northerly-northeasterly flow of cold air at the surface, while at 925 and 850 hPa levels the wind turned to an easterly, southeasterly direction, bringing back warmer air (Figure 6). Hence, there was a potential for falling precipitation to pass the 0°C isotherm several times, causing snowflakes to melt and refreeze in some places.

Precipitation

Although in such winter cases large-scale motions dominate over local effects, there is a strong sensitivity to lower atmospheric features, which can be the main source of forecast uncertainty. It can be important to estimate this uncertainty with a high-resolution ensemble system whose members are able to capture the bigger precipitation events. To see how well ALEPS-PEARP, ALEPS-ENS and the ENS were able to do this, we compared their probability maps. We note that in this case study we used

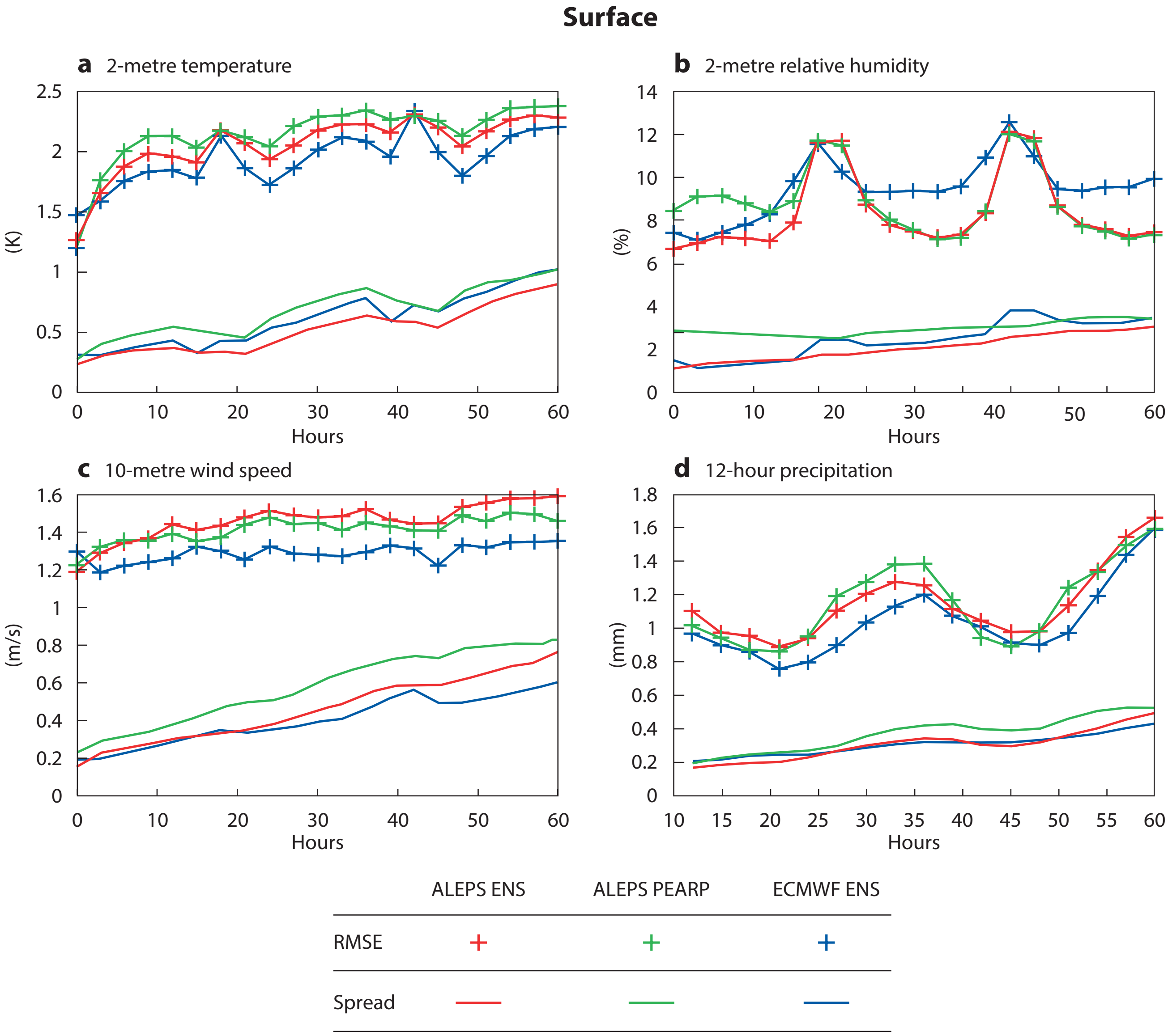


Figure 4 RMSE of the ensemble mean and spread around the ensemble mean of forecasts up to 60 hours ahead run at 18 UTC every day between 11 December 2015 and 31 January 2016 for (a) 2-metre temperature, (b) 2-metre relative humidity, (c) 10-metre wind speed, and (d) 12-hour precipitation.

all the 50 perturbed and the control member of ENS. The probability maps show that all three ensembles gave a similar likelihood for 24-hour precipitation to be over 10 mm in the southern and the middle part of Hungary (Figure 7c–e). There are differences in structure, with the ENS looking much smoother than the ALEPS versions. This is not surprising because of the difference in horizontal resolution and the number of members. If we focus on the 20 mm threshold, the outcome is quite different (Figure 7f–h). Limited-area ensembles predicted much higher probabilities for such a level of precipitation. The areas of the highest probabilities were in relatively good accordance with the area of the observed occurrence of the event. In the Hungarian weather alarm system, 20 mm is the first warning level for rain and approximately the second warning level for snow.

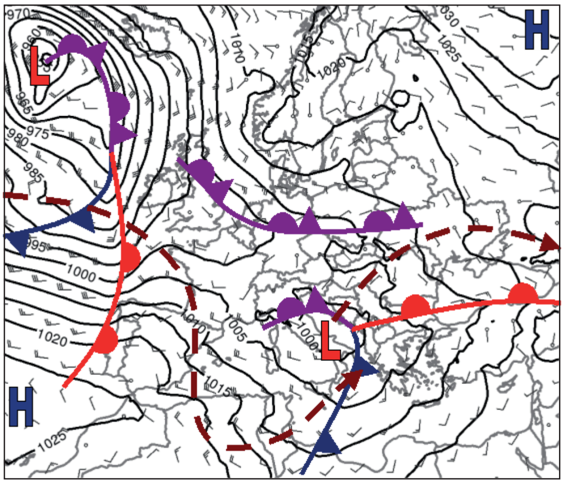


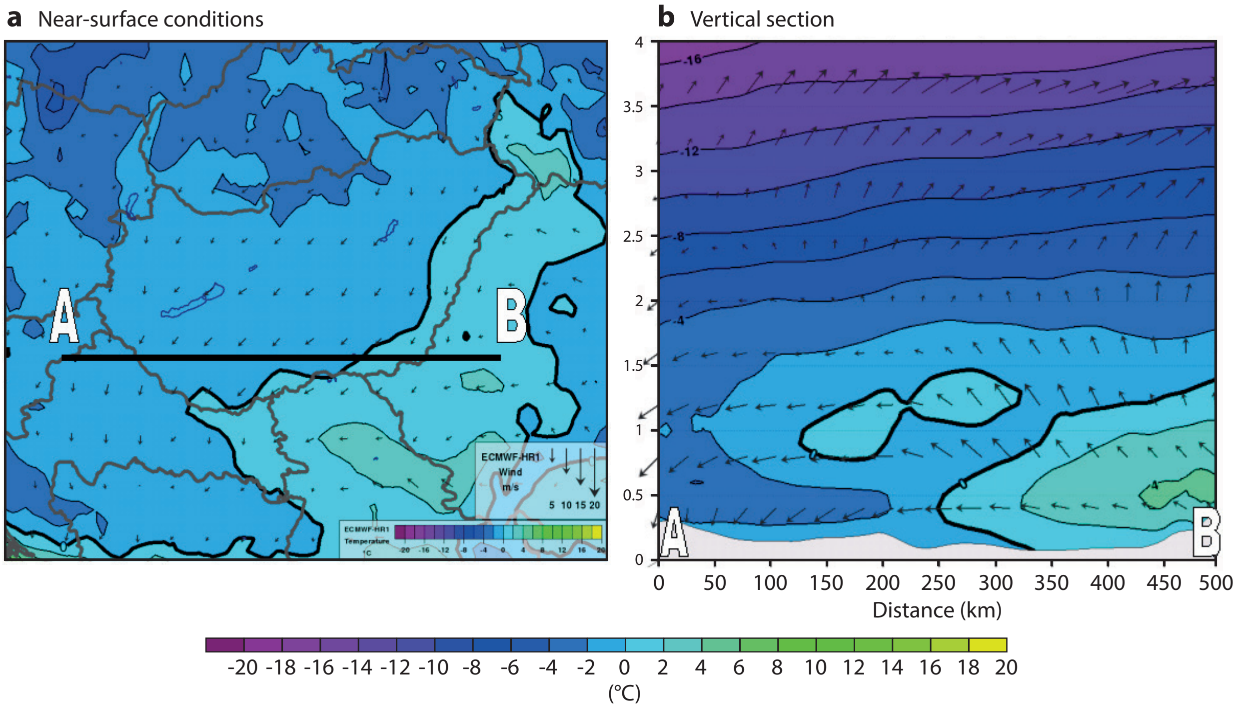
Figure 5 Synoptic chart based on the HRES analysis of mean sea level pressure (contours, in hPa) and 10-metre wind (barbs) valid at 12 UTC on 6 January 2016. The dashed line marks the position of the 300 hPa wind speed maximum (nearly the axis of the upper tropospheric jet).

Freezing rain and wet snow

As mentioned above, mixed-phase precipitation caused the greatest damage during the high-impact weather event on 6 and 7 January 2016. We have used quite simple methods to visualise the probability of severe weather such as freezing rain and wet snow in the ALEPS-ENS. We assumed that snow will be wet during snowfall in temperatures between 0 and 3°C. We note that the sticking efficiency further depends on the liquid water content, which is mostly between 5 and 40%, and wind speed, but the exact determination of these factors is currently rather problematic (*Somfalvi et al.*, 2015). In the case of freezing rain, we simply added up the amount of rain if the temperature was below 0°C.

We then produced probability maps for 36-hour accumulated freezing rain (Figure 8). We examined 1 mm and 5 mm thresholds, which correspond to the second and third warning level in the Hungarian alert system, respectively. ALEPS-ENS provided good guidance on which areas of the country were at risk and highlighted the most threatened counties.

A similar probability map was produced for wet snow with a 5 mm threshold (Figure 9a). Although there is no specific warning level for wet snow, large amounts can cause serious damage, especially to the electricity grid. According to reports by Hungarian disaster management


a Near-surface conditions

b Vertical section

Figure 6 Three-hour HRES forecast of (a) 2-metre temperature (shading) and 10-metre wind (arrows) valid at 15 UTC on 6 January 2016, and (b) the same as (a) but in vertical cross section along the line AB up to a height of 4 km. The 0°C isotherm is depicted by a thicker line.

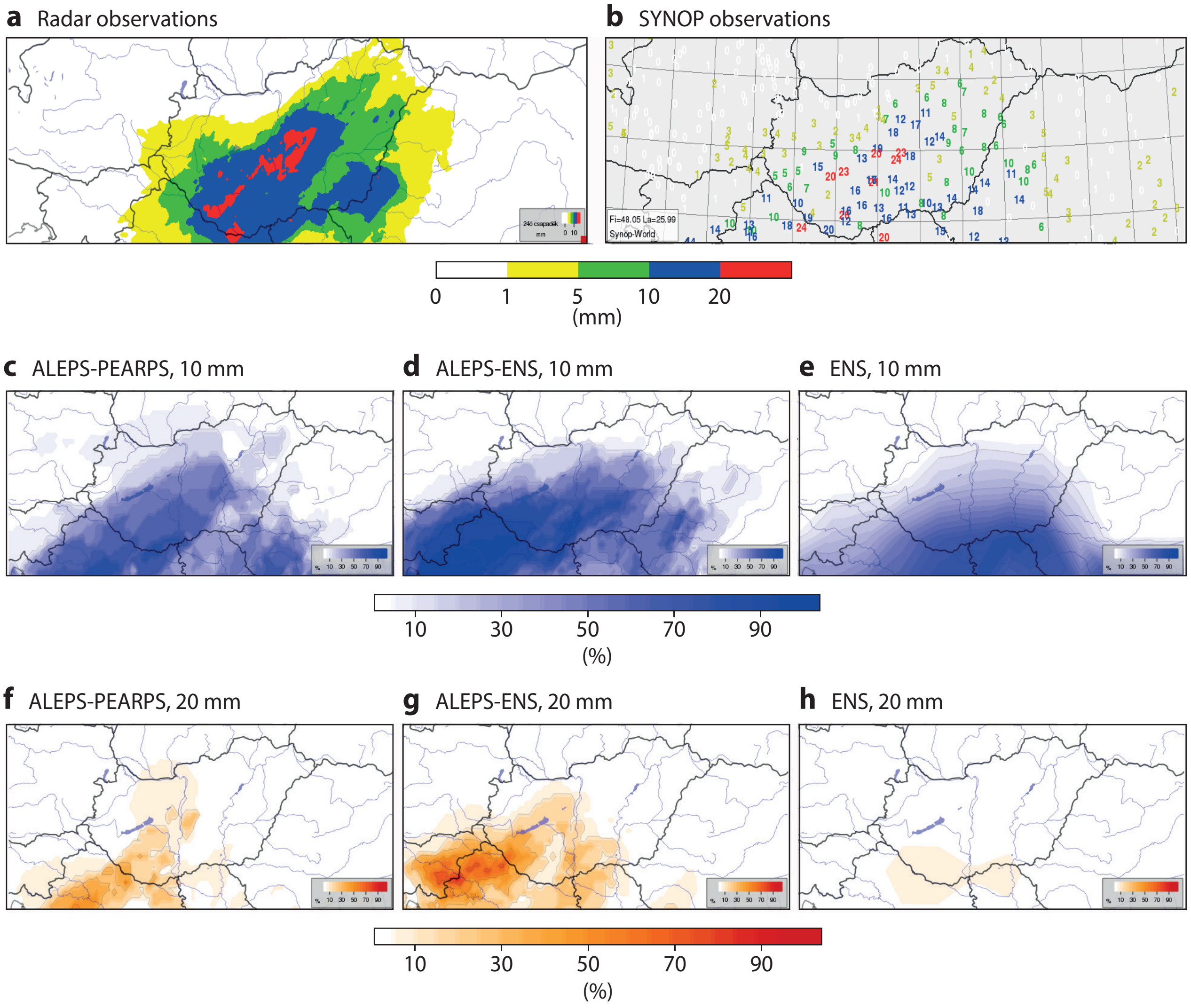


Figure 7 Precipitation in the 24 hours ending at 06 UTC on 7 January 2016 according to (a) estimates based on radar measurements, (b) SYNOP observations, (c)–(e) 36-hour forecasts of the probability of reaching 10 mm, produced by ALEPS-PEARPS, ALEPS-ENS and ENS, respectively, and (f)–(h) 36-hour forecasts of the probability of reaching 20 mm, produced by ALEPS-PEARPS, ALEPS-ENS and ENS, respectively.

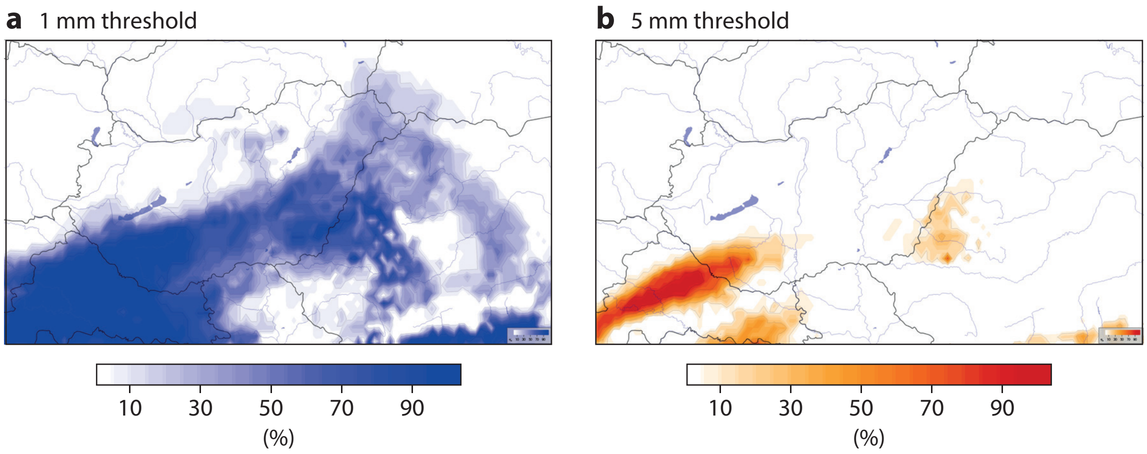


Figure 8 ALEPS-ENS forecast valid at 06 UTC on 7 January 2016 of the probability of 36-hour accumulated freezing rain to be (a) over 1 mm and (b) over 5 mm.

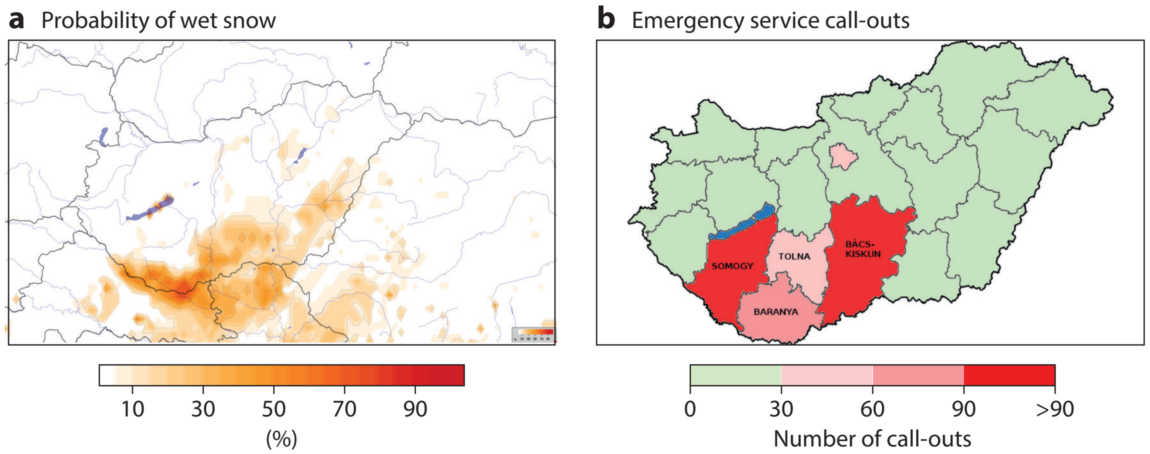


Figure 9 The charts show (a) the probability of 36-hour accumulated wet snow to be over 5 mm from the ALEPS-ENS forecast valid at 06 UTC on 7 January 2016 and (b) the number of call-outs reported by Hungarian disaster management bodies on 6 and 7 January 2016.

bodies, there were temporary power cuts in approximately 40,000 households in Somogy, Bács-Kiskun and Baranya counties. On 6 and 7 January, fire brigades were alerted about three times more often than on average days and most call-outs were in the above-mentioned southern areas (Figure 9b). These statistics correspond well to the ALEPS-ENS predictions, which identified those same counties as the ones most at risk.

Summary and outlook

After the ensemble forecasting extension of the Optional BC Programme, OMSZ was able to run extended tests with an ENS-coupled limited-area ensemble. This system has different characteristics than the operational one: broadly speaking, ALEPS-ENS members are more accurate but the system is less dispersive. Although limited-area ensembles can usually not beat the ENS in scores, they add great value when it comes to forecasting high-impact weather events.

Finally, we would like to underline that ENS-BCs can support our plans to run a local EDA. First, BCs are available with higher frequency and from more production times (four times per day) than in the currently operational version. Second, this setup of LBC generation can ensure that the members of a possible EDA system would be identical with the ones coupled to HRES. It makes the technical maintenance easier and the EDA can correctly describe the uncertainty of our deterministic run as well.

These considerations have led us to prepare further tests with an ENS-coupled EDA system. The results of these experiments will eventually determine the precise role of ENS-BCs in our operational system.

FURTHER READING

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