COSMO-CZ-EPS

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1 Introduction

One of the main challenges for numerical weather prediction (NWP) is still recognized as quantitative precipitation forecasting. Therefore, accurate precipitation forecasts are of great social and economic importance. Numerical weather prediction models are capable of simulating the evolution of precipitation fields explicitly. However, their skill is limited by the model configuration (e.g. horizontal resolution, parameterization of subgrid-scale processes) and imperfect data assimilation techniques to derive the initial conditions.

Ensemble techniques applied to weather forecasting have been developed during the last two decades to address the problem of limited predictability and uncertainty in numerical weather prediction (Leutbecher and Palmer, 2008). The ensemble approach consists in generating a set of deterministic forecasts which should represent a sample of the possible future states of the atmosphere. The forecasts then provide an estimate of probability distribution functions for atmospheric state in forecast. Several national and international weather centers, like the European Centre for Medium-Range Weather Forecasts (ECMWF), the Canadian Meteorological Centre (CMC), the National Centres for Environmental Prediction (NCEP) and the UK Meteorological Office, provide valuable operational ensemble prediction at a global scale (Buizza et al., 2008). In addition to them, several weather services are currently running operational convection-parameterizing EPS. These convection-parameterizing models have horizontal grid sizes of 7–32 km, with lead times ranging from 2–16 days (Peralta et al, 2012). The example of these ensembles is e.g. MOGREPS regional ensemble with horizontal resolution about 18km (Buizza et al., 2007) or COSMO-LEPS (Montani et al., 2011), described more in next paragraph. See Bowler et.al. (2008) for more extended list of examples. Nowadays, many limited-area ensemble prediction systems have been recently developed, either in research or in operational mode, so as to address the need of detailing high-impact weather forecasts at higher and higher resolution and to provide more reliable forecasts than achievable with a single deterministic forecast (Iversen et al, 2011). Current areas of research on short-range EPS include the use of high-resolution non-hydrostatic models to describe forecast uncertainty up to a convection-permitting scale, that is 2 or 3 km of horizontal resolution (Wandishin et al., 2010).

The main disadvantage of the regional ensembles with high resolution (2-3 km) is the computational and memory demand. This is a reason, why these ensembles are covering mainly the area of interest of each institution developing this ensemble. Many European states are developing or running their own regional ensemble. German Weather Service is operationally running a COSMO-DE-EPS with horizontal resolution 2.8km. The perturbations in IC+LBC comes from four different global models and perturbed model physics (Gebhardt et al, 2011; Peralta et.al., 2012) Another example is COSMO-E, ensemble with 21 members covering the Alpine area with 2.2km resolution. The IC are from LETKF data assimilation and LBC are from VarEPS (Buizza et al., 2007). Italian COSMO-IT-EPS run with 10 members with 2.8km horizontal resolution, taking the LBC from COSMO-LEPS and IC from KENDA assimilation system.

The COSMO-CZ-EPS is running at Institute of Atmospheric Physics Czech Academy of Sciences in high resolution using lateral, initial and boundary conditions from COSMO-LEPS. The description of the ensemble, its development and comparison with driving COSMO-LEPS is presented in the next paragraphs as follows. In the second paragraph there is an overview of the ensemble and used NWP model. The third paragraph contains a brief description of a selected verification period and verification data. The fourth paragraph describes the results of forecast verification and the fifth paragraph summarizes the results of the paper.

2 Ensemble Setup

The COSMO-CZ-EPS is non-operational regional ensemble computed at Institute of Atmospheric Physics ASCR. The ensemble is designed for research of heavy precipitation forecast and its uncertainty. The ensemble consists of 16 members. The single ensemble runs are computed by COSMO model which is a non-hydrostatic and fully compressible model formulated in advection form (Baldauf et al., 2011). The ensemble is integrated over the area covering the domain of Czech Republic (Fig. 1A), which comprises 281 by 211 grid points with a horizontal resolution of 2.8 km. The model is integrated with 50 vertical levels and time step is 30 s. The parameterization of deep convection is switched off and only the parameterization of shallow convection is included. The forecasts started at 0600 UTC with the lead times up to +42h. The model has same setting as in the COSMO-CZ run (Sokol 2011; Sokol and Zacharov, 2012) which led to the acronym COSMO-CZ-EPS.

The COSMO-CZ-EPS was previously planned to run on initial, lateral and boundary conditions (IC+LBC) from COSMO-SREPS (Marsigli, 2009). The former SREPS was driven by three different global NWP models (GME, GFS and IFS) with perturbed model physics. Unfortunately there was a strong dependence of the SREPS forecasts on the given global model and the dependence of the physical parameterization disturbances was significantly smaller than the dependence of a driving model. This problem was significant also for COSMO-CZ-EPS members. The precipitation totals are strongly dependent on driving global model and the differences among the members with same driving global model are negligible. This problem was also detected by objective spatial verification (e.g. SAL, not shown here) where the results of the verification were grouped into three clusters, depending on driving global model. This was one of the main reasons why the number of the ensemble members was decreased to three members in June 2012 and the COSMO-SREPS was ended in December 2012.

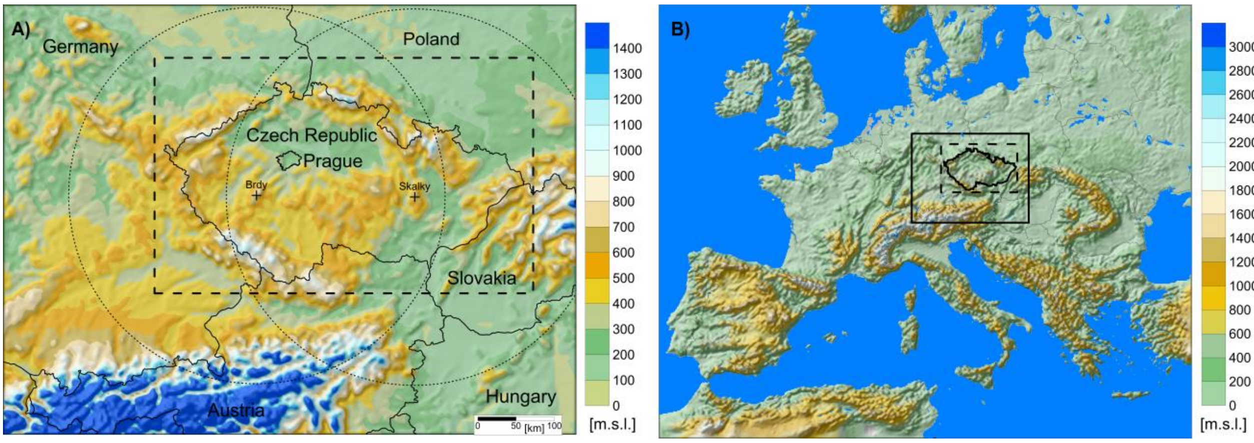

FIG. 1: A) The model domain of COSMO-CZ-EPS with topography above sea level in m (see legend). The positions of the Brdy and Skalky radars (black triangles), the position of Prague (black cross) and the areas covered by the radar data (dotted circles) are marked. The dashed rectangle represents the verification domain. B) The model domain of COSMO-LEPS with topography above sea level in m (see legend). The dashed rectangle shows the verification domain and the solid rectangle represents a position of COSMO-CZ-EPS in COSMO-LEPS domain.

The actual COSMO-CZ-EPS is driven by the COSMO-LEPS which is the mesoscale limited-area ensemble of the COSMO Consortium, developed by ARPA–SIMC. The COSMO-LEPS is running since 2002 (Montani et al., 2011) and it is based on 16 runs of the COSMO model with 7 km horizontal resolution on a domain covering central and southern Europe (see fig. 1B) and 40 levels in the vertical. The ensemble is generated as a downscaling of the global ECMWF EPS. An ensemble reduction technique (Molteni et al., 2001) is applied to select members of the EPS for nesting the COSMO model. The members of EPS runs are grouped into 16 clusters on the basis of the similarity of some mid and lower tropospheric fields. One representative member is selected for each cluster to provide IC+LBCs of the COSMO run creating the COSMO-LEPS.

3 Verification data and methods

The COSMO-CZ-EPS was verified on the period of July 2012. In the first part of this period a heavy precipitation occurred in an area of the Czech Republic. The second part of July was drier with some afternoon showers. To determine the verification rainfall values, we applied the MERGE product (Šálek and Novák, 2008), which adjusts the radar data with gauge measurements, as described e.g. by Sokol and Zacharov (2011). The MERGE is an operative product of Czech Hydrometeorological Institute. The radar data were obtained from the CZRAD network (Novák, 2007). The positions of both radars are shown in Fig. 1A. For the verification purposes, the MERGE data were interpolated into each ensemble grid. We chose to verify the ensembles using their own resolutions because each model forecasts the precipitation structures in different ways and because these differences could be smoothed by interpolation to any other resolution. This approach was used e.g. by Zacharov et al (2013). For verification we used four 3-h precipitation totals for each day of selected period. The totals cover the afternoon period 1200-2400 UTC. The whole number of forecasts for single ensemble is 1984, which comprises 31 days of July 2012, 16 members of each ensemble and 4 lead times.

For the evaluation of the COSMO-CZ-EPS and its comparison with COSMO-LEPS we used traditional and spatial verification methods. The traditional methods comprise a mean error and a Talagrand diagram. The spatial verification is represented by Fraction Skill Score (e.g. Roberts, 2008). The detailed description of selected verification methods, except for Talagrand diagram, with relevant references could be found in Zacharov et al (2013).

The Talagrand diagram, sometimes called Rank histogram, is a valuable tool for quick ensemble evaluation. This method checks where the verifying observation usually falls with respect to the ensemble forecast data arranged in increasing order at each grid point. The histogram permits a quick examination of some qualities of the ensemble. Consistent biases in the ensemble forecast will show up as a sloped rank histogram; a lack of variability in the ensemble will show up as a U-shaped, or concave, population of the ranks (Hamill, 2001).

A problem exists as to whether fixed or varying thresholds should be used in threshold-dependent verification. Fixed thresholds are easier to understand but are not simple to interpret when comparing forecasts with different resolutions or for a long period with different precipitation totals. In contrast, varying thresholds serve better for comparing forecasts, but the interpretation of these results can be complicated. Therefore, we applied fixed thresholds of 0.1, 0.5, 1, 5, 10 and 20 mm/3-h and three varying thresholds. Wernli et al. (2009) used the varying threshold *Th*, which is defined as *Th* = 1/15 * R95, where R95 denotes the 95th percentile of all grid-point values equal and larger than 0.1 mm/3-h. This precipitation threshold is often a low value; therefore, we extended the definition to *Th(X)* = 1/X * R95, where X = 1, 5 or 15, which yields three varying thresholds (also in Zacharov et al, 2013). Another advantage of using varying thresholds is a detection of more objects even for high thresholds, e.g. *Th(1)* = 1/1 * R95. This is valuable mainly for verification of forecasts over a long period, because days with heavy precipitation can be alternated with days with light precipitation.

4 Verification

The ensembles were verified on the period covering July 2012. First, we used a traditional verification approach. Both ensembles slightly underestimate the precipitation, the mean error of all forecasts over July 2012 is -0.16 mm/3h for COSMO-CZ-EPS and -0.21 mm/3h for COSMO-LEPS. Both ensembles have also very similar distribution of mean errors for single forecasts. The Talagrand diagram enables us to look into distribution of the ensemble precipitation values and their spread. The diagrams on fig. 2 were constructed from 3h precipitation totals on the whole verification period. The diagrams also show a little underforecasting for both ensembles. Higher columns in a Talagrand diagram for COSMO-CZ-EPS are caused by a greater number of grid points in the verification domain of this ensemble caused by higher resolution.

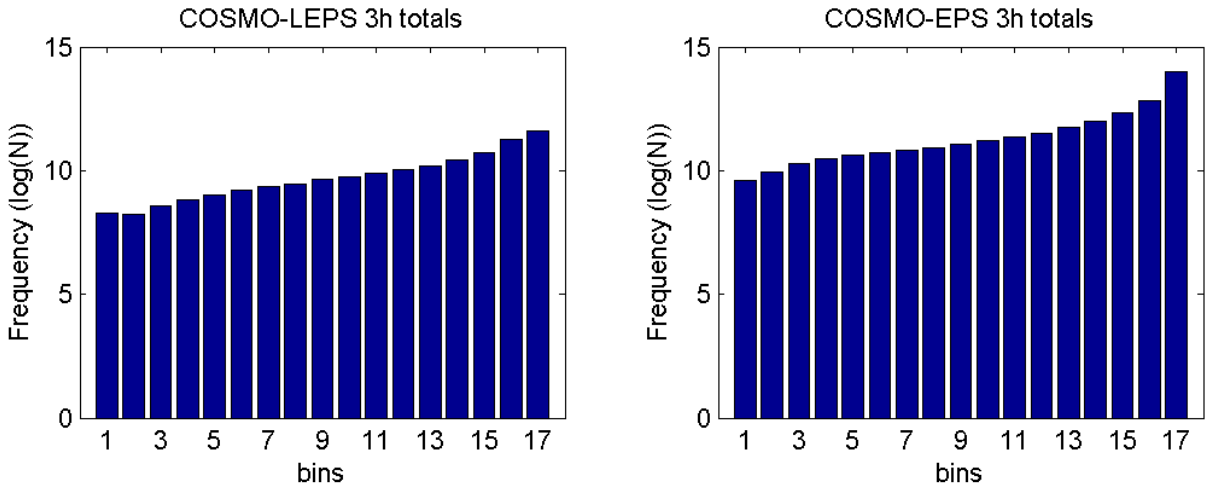

FIG. 2: The Talagrand diagram for COSMO-LEPS (left) and COSMO-CZ-EPS (right).

If we compare the mean and maximal values of both ensemble systems with MERGE data, we get better results for COSMO-CZ-EPS. The improvement can be seen on figure 3, both for maximal and mean values over the verification domain. The COSMO-LEPS didn't reach the maximal precipitation values and most of the points in the figure 3a lies under the diagonal. The COSMO-CZ-EPS proves a better correlation between measured and forecasted maximal values (figure 3b). The strange structures looking like vertical lines in all subpanels of figure 3 are caused by different mean/maximal values from one ensemble forecast (16 members) assigned to one measurement. The outliers on a figure 4b (measured maximal value 163.6 mm/3h) are caused by heavy precipitation lying across the borders of the Czech Republic near a border of verification domain. This structure was not forecasted by the ensembles, but there was no other significant precipitation over the Czech Republic forecasted and measured as well. It is also important that 65% of measured maximal precipitation lie between the COSMO-LEPS maximal values of given forecast (figure 3a). For COSMO-CZ-EPS lie 75% of forecasts between maximal forecasted values (figure 3b). For mean values there are 82% of measured mean values between the forecasted values for both ensembles, but the COSMO-CZ-EPS has a better correlation between the forecasts and measurements (figure 3d). The better results of COSMO-CZ-EPS are markable also in correlation coefficients between forecast and measured data (see Table 1). In general, COSMO-CZ-EPS predicts better than COSMO-LEPS the mean and also maximal precipitation over the verification domain.

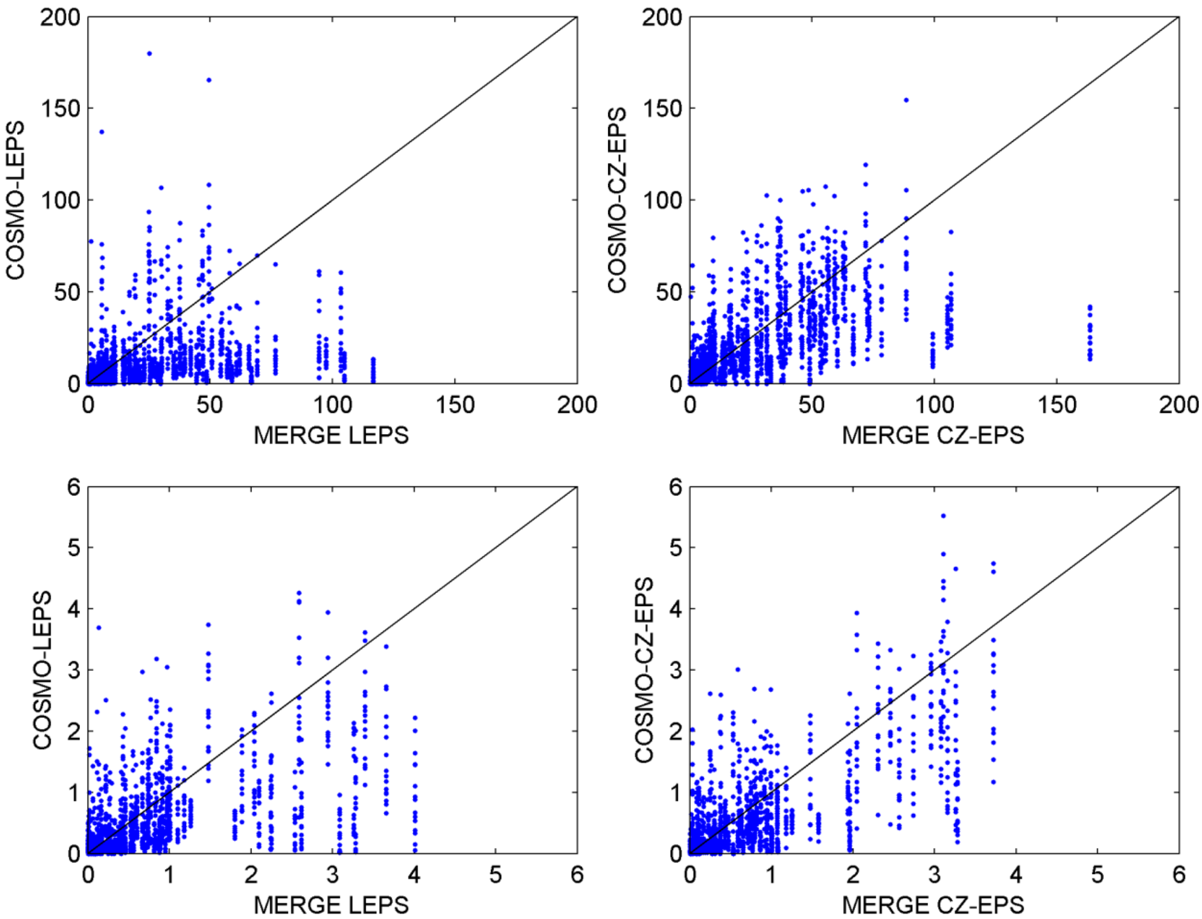

FIG. 3: The scatterplots of maximal (first row) and mean (second row) precipitation values over the verification domain for COSMO-LEPS (first column) and COSMO-CZ-EPS (second column). The horizontal axis represents the MERGE and the vertical axis represents a given ensemble. Maximal and mean values are computed for each forecast of both ensembles.

Table 1: Correlation coefficients between ensemble forecasts and MERGE data (mean and maximal values) for both ensembles COSMO-LEPS and COSMO-CZ-EPS.

	COSMO-LEPS	COSMO-CZ-EPS
maximal value	0.32	0.57
mean value	0.59	0.75

The spatial verification technique Fraction Skill Score compares the fractional coverage of some given elementary area with measured and forecasted precipitation over given threshold (Roberts, 2008; Zacharov et al., 2013). For evaluation of a large number of forecasts by FSS we used a method applied in Zacharov et al. (2013). This method evaluates for each single forecast elementary area (*EAuniform*), where the FSS of given forecast exceeds a uniform forecast (*FSSuniform*). The *FSSuniform* is defined as a mean between perfect forecast (FSS = 1) and random forecast (FSS = f_0). This forecast is marked on given EA as a useful forecast. The forecasts of both ensembles are for given precipitation threshold compared by a fraction of useful forecasts for each EA size. See the Zacharov et al. (2013) for larger explanation. This method allows us to compare a large number of COSMO-CZ-EPS and COSMO-LEPS forecasts together.

From the FSS perspective the COSMO-CZ-EPS forecasts better the precipitation over high thresholds (20, 10 and 5 mm/3h) than COSMO-LEPS, which is better for small thresholds (0.1, 0.5 and 1 mm/3h). This feature can be clearly seen also for varying thresholds (see fig. 4). The FSS verification confirms the better representation of high precipitation amounts for COSMO-CZ-EPS than for COSMO-LEPS.

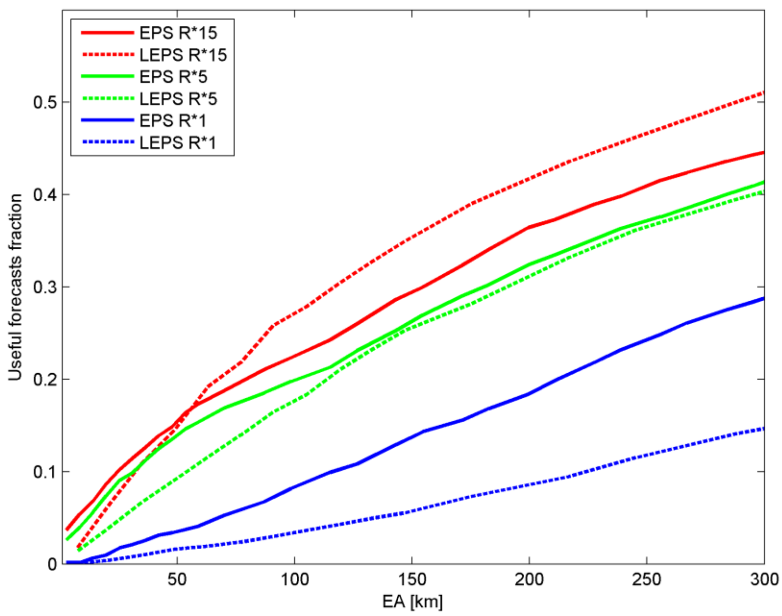

FIG. 4: A dependency of an useful forecasts fractions on elementary area sizes (EA) for COSMO-CZ-EPS (solid lines) and COSMO-LEPS (dotted lines) and three varying thresholds (see a legend). See the text for explanation.

5 Results and Outlook

The COSMO-CZ-EPS was formerly planned to run on IC+LBC from COSMO-SREPS. Unfortunately, the number of COSMO-SREPS members was decreased and in December 2012 it was stopped at all. The actual ensemble uses an IC+LBC from COSMO-SREPS and has 16 members. The forecasts start at 06UTC and the lead time ends at 42h of forecast.

The article shows a comparison of COSMO-CZ-EPS with parent COSMO-LEPS. The verification was made on July 2012. This episode was challenging for precipitation forecasts because there was a few episodes with heavy convective precipitation and the end of July was significantly drier. Both ensembles show a small dry bias. It is possible, that the bias of COSMO-CZ-EPS can be affected also by the start of the forecasts at 0600 UTC; the tests performing the forecasts from 0000 UTC should be done.

The verification results show better forecasts of COSMO-CZ-EPS than COSMO-LEPS for events with heavy precipitation. These events are of high interest and the comparison confirms that the use of COSMO-CZ-EPS is reasonable for simulation of high precipitation events.

In the next work the spread of the ensemble will be studied. It will include main characteristics as geopotential and temperature at standard pressure levels (850hPa, 500hPa). The spread and skill of the precipitation forecasts and a spread-skill relationship will be studied by appropriate spatial verification techniques.

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