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Frame approach in coupling – REPORT

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1. Introduction

The report presents methodology and results of experiments on the subject of frame approach in coupling. The objective was to test whether a compression of LBC files, which are needed to run a LAM model, is possible. The task was a part of the RC-LACE Workplan for Dynamics and Coupling and was completed during a stay in CHMI in Prague in November 2021.

At present, LBC files for LAM models operating in the LACE telekom domain come from a forecast of the ARPEGE model and are produced in Météo-France. Alternatively, LBC files produced at ECMWF from the run of IFS model are available, but we did not work with them. ARPEGE runs on approximately 5km horizontal resolution over the Central Europe (stretched grid) and the results are then downscaled to 8km horizontal resolution for transfer. Moreover, for the LBC files produced from ARPEGE run, the linear truncation is downscaled to the quadratic one in the files prepared for transfer. The number of vertical levels is being kept from the original run and it is 105. The files are sent to national weather centers and then processed to a final domain and resolution. Therefore, any reduction of a size of the LBC files would speed up transferring of the files as well as their processing at national weather centers. Furthermore, it may also allow some upgrade in the coupling process (e.g. increasing coupling frequency to 1h).

The idea of compression of LBC files is not new, though. The current work was based on findings of colleagues from Météo-France (authored by Philipp Marginaux) who tackled the problem a couple of years ago. Basically, we intended to check whether it is possible to reproduce the experiments and to verify the results more thoroughly. We adopted their methodology, however in practice it turned out that not everything works and therefore we often had to do something differently.

Experiments were conducted on coupling between ARPEGE and ALARO (2,3km horizontal resolution, 87 vertical levels) run in the Czech operational domain (Fig. 1). The forecast length was 72 hours. Only the morning run (00 UTC) was considered.

Figure 1: Czech operational domain used at CHMI. Its basic dimensions are:
NDLON =1080,NDGL =864, NDLUX =1069, NDGUX =853, NBZONL =16, NBZONG=16.

2. Methodology

Following the report of Meteo-France, two alternative approaches were examined:

- hollow coupling (grid-point representation)
- core coupling (spectral representation)

For every approach, forecasts were produced based on modified LBC files and then compared with reference (these are forecasts from unmodified LBC files in grid point and spectral representation, respectively). Coupling frequency was set to 1h. For evaluative purposes, we used a dedicated piece of software called VERAL. Verification spans a period from 1st to 14th November 2021 (14 days of dynamical adaptation). The period was chosen since it involves a low passing through the central part of the domain on the 4th November. Forecasts were evaluated against observations using objective scores (e.g. bias, RMSE, standard deviation). Finally, an estimate of possible compression in size of LBC files was made.

3. Hollow coupling

In an operational mode, LBCs are used only in an outside frame of a domain (so called extension and intermediate zone). In our case, the width of these zones are equal to 11 and 16 grid-points, respectively. In the rest part of the domain (so called central zone) LBCs are not used directly. The idea is to check how removing the values in the central zone of LBCs will affect the model performance. Initially, we have used the modification made in MF introducing the possibility to read grid-point represented model variables. This modification is under the key LSUSPECA_GP=T in NAMCT0. Since the code is not sensitive on the namelist parameters meant for deciding which model variables will be grid-point and which will be spectral (TFP_X%LLGP in NAMAFN), only the change in all the fields (T, U, V, PD, VD, SP, SURFGEOPOTENT) is possible. Moreover, we were not able to apply several namelist parameters (in NAMAFN) which master the process of hollowing a file. Therefore, we resigned from the method and used an external tool to prepare hollow files instead. It turned out however that simple replacing a defined rectangular with zero or with an average value of a field does not work. Hence, we replaced the inner part of the field with an inverse distance-weighted interpolated values from its edges (Fig. 2). This was inspired by the solution used in the routine *fadcpl.F90* within the model code. Several fortran-based tools were used to prepare grid-point represented LBC files, namely fa_sp2gp (to transform model variables including surface geopotential), facalc (to create new field SURFGEOPOTENTIEL) and farecdel (to remove redundant SPECSURFGEOPOTEN). Some modifications of the size of the hole were tested by changing a parameter ICPLSIZE (where ICPLSIZE=0 means the biggest hole possible, see Fig. 3). Only upper air fields were hollowed since they are the subject of coupling. The other fields which are needed for physics, surface scheme or other purposes as orography, roughness etc. are kept unchanged.

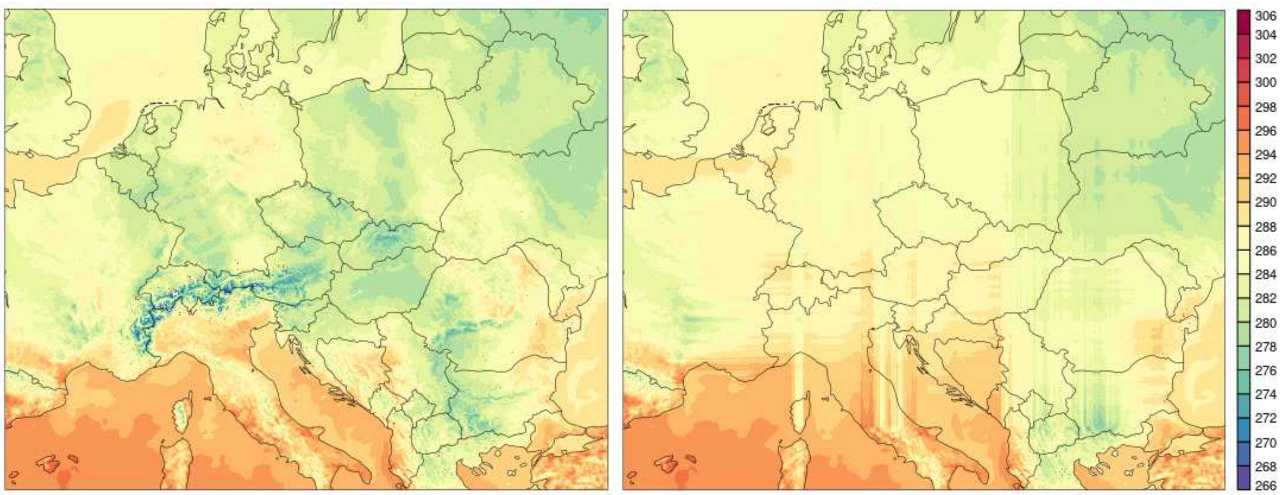


Figure 2: Comparison of surface temperature in full (left)) and hollow (right) LBC file (ICPLSIZE=100).

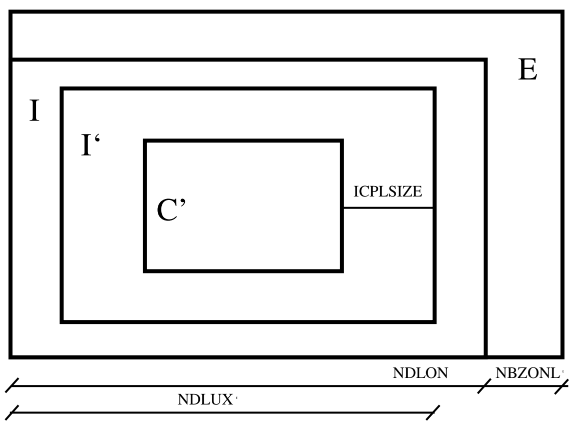


Figure 3: Scheme of coupling zones and sizes.

Final performance assessment was done for ICPLSIZE equal to 1 and 10 (Fig. 4 and Fig. 5). Vertical – time cross section of the difference of RMSE between the experiment and the reference is shown for temperature and wind speed (Fig. 6).

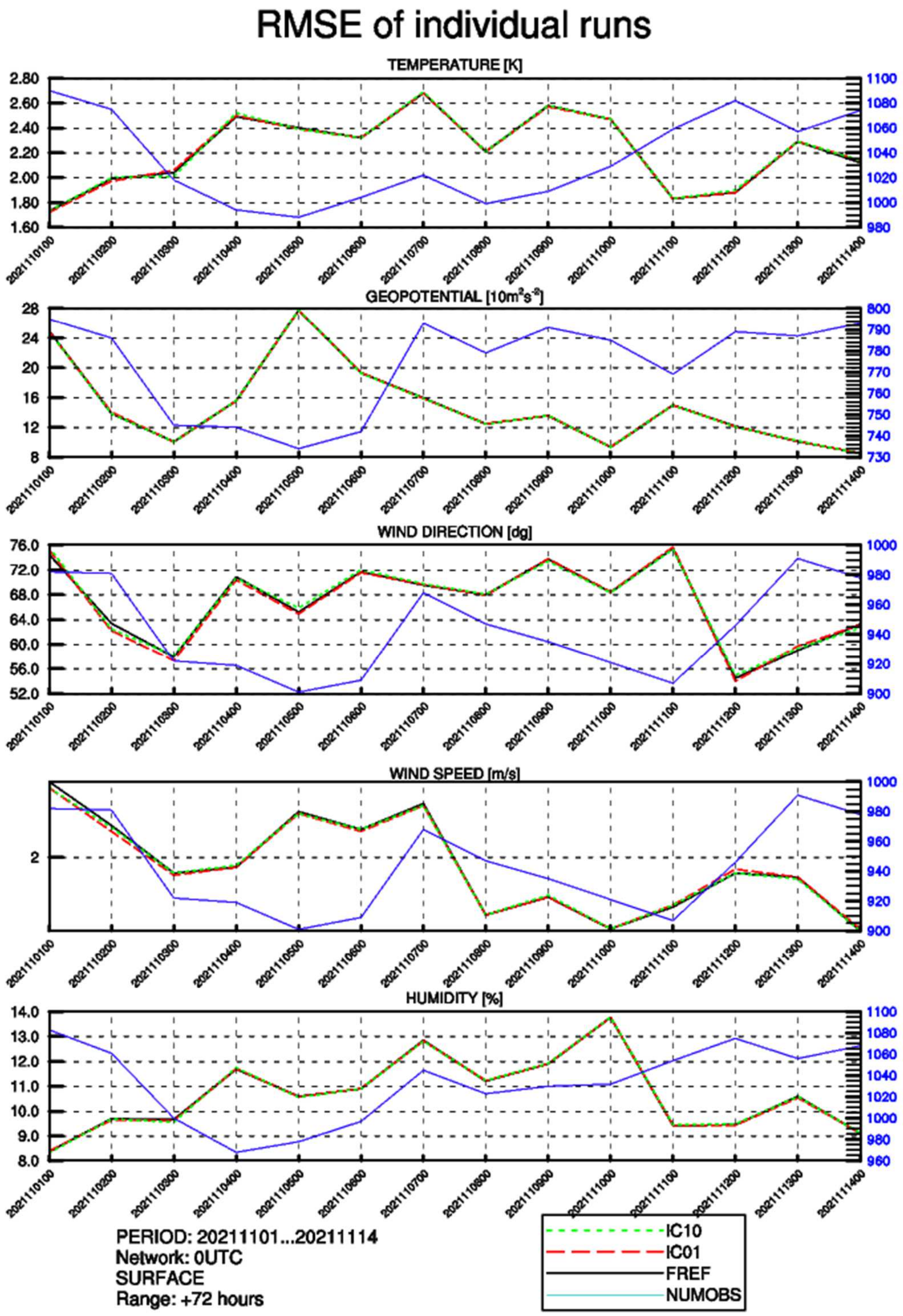


Figure 4: RMSE of the reference forecast (FREF), a forecast produced from hollow LBC files with ICPLSIZE=1 (IC01) and 10 (IC10) for 72h leadtime.

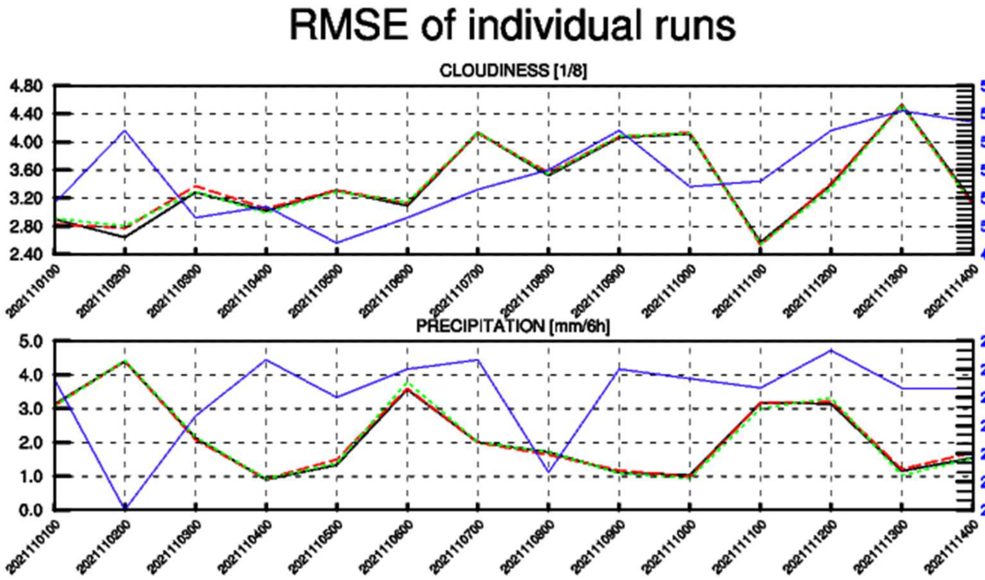


Figure 5: Same as Fig. 4 but for cloudiness and precipitation.

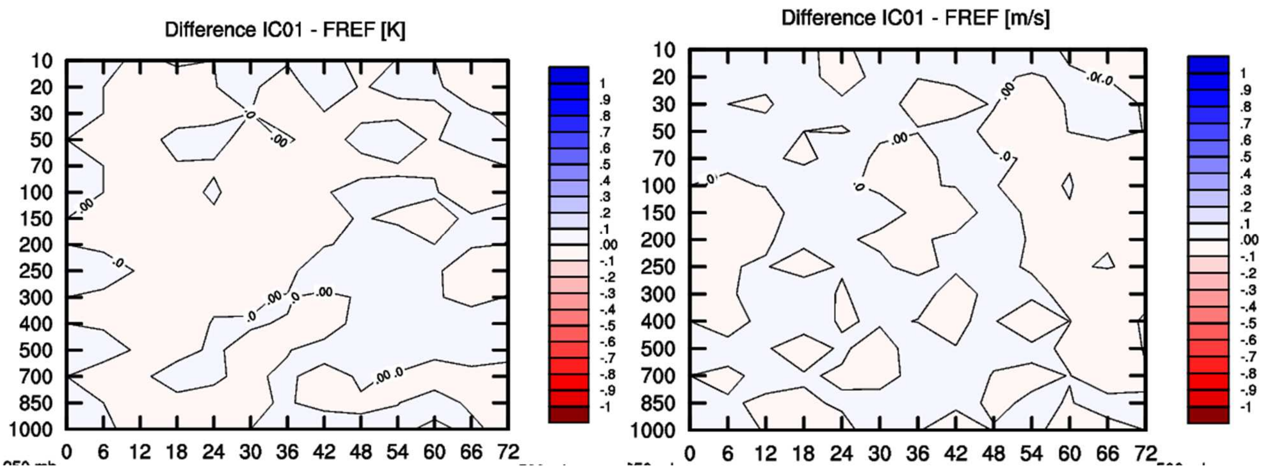


Figure 6: Temporal evolution of difference in RMSE between hollow (ICPLSIZE=1) and the reference forecast for air temperature (left) and wind speed (right) at different pressure levels (vertical axis).

In addition to mean value of accuracy metrics, we "visually" checked 4 parameters (temperature, wind components and precipitation) at three levels (S087, S060 and S040). Two examples are shown in Fig. 7. Some differences occur mainly within the front zones that are near centers of lows (e.g. in central Italy and at the North Sea), however they are local in space and thus do not affect the overall accuracy of the forecast measured by the verification scores.

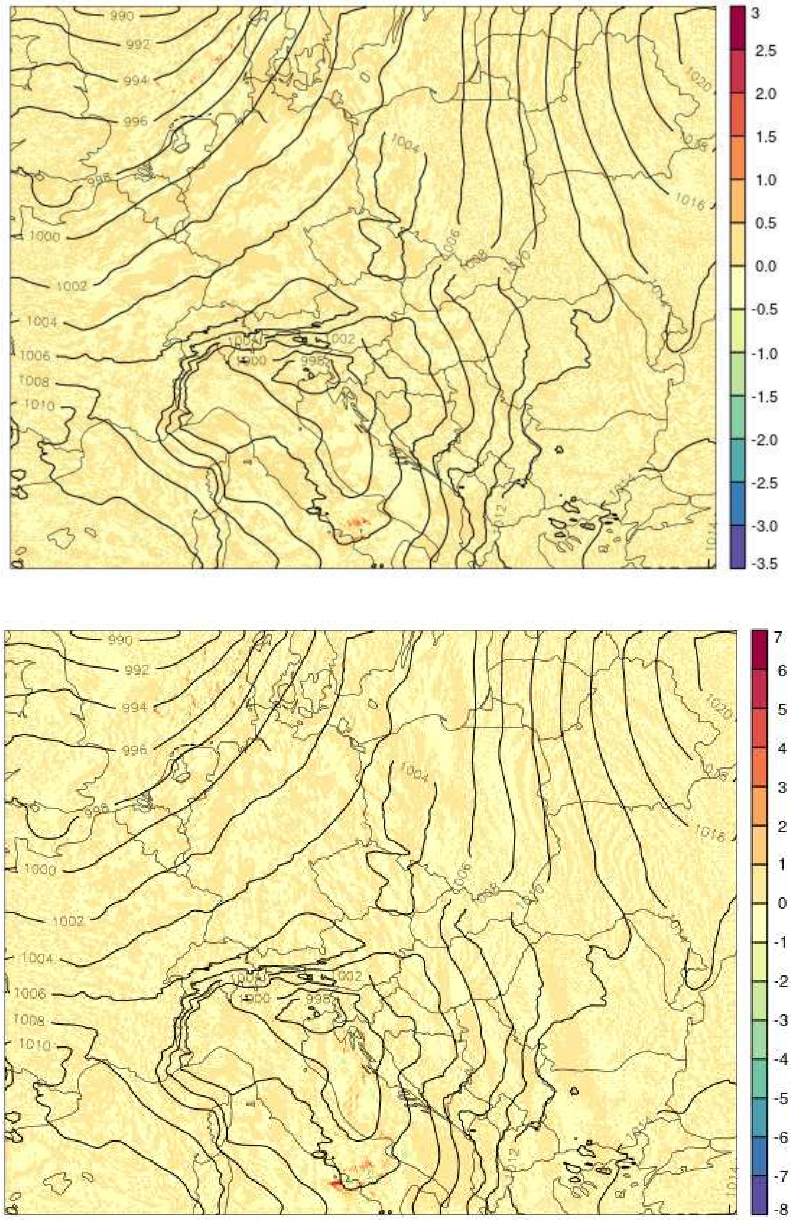


Figure 7: Difference of a) air temperature b) meridional wind component between hollow forecast and the reference. The isolines show MSLP (hPa).

4. Core coupling

In case of core coupling, we work on LBC files in the spectral representation. As most of information from the host model is included within smaller wavenumbers, one can remove small-scale features by cutting off the meridional and zonal maximum wavenumber (NSMAX and NMSMAX). As elliptic truncation is applied in the model, the parameters refer to the semi-major (NMSMAX) and semi-minor axis (NSMAX) of the ellipse. The goal of the experiment is to check, how much the truncation may be increased so that it will not worse forecast verification metrics.

Initially, as in the case of hollow coupling, we prevent surface fields of the LBC files from modification. We tested the cubic truncation, i.e. the biggest integer k which matches the relationship k ≤(N −1)/4, where N is a grid size of a domain in one direction: zonal (NDLON) or meridional (NDGL). In our case, k=269 and 215. The reference LBC files are based on quadratic truncation. Although verification results didn't get significantly worse, we noticed some strange noise at the near-surface levels of LBC files occurring in the vicinity of mountain ranges and water bodies (rivers, lakes and reservoirs, see Fig. 8). The deviation near water bodies diminishes rapidly at higher levels, while in case of mountains it disappears only for the highest levels. Some other strange noise occurs also in historical files within the extension zone. This leads us to the conclusion that orography has to be truncated in the same way as upper fields. In order to implement it, the process of geometry transformations of the LBC files needs to be modified (the *lancelot* script). The transformation has to be done in two steps since different climfiles need to be used. At first, we transform only the domain, with resolution as it is in the host model (8 km). As the size of the domain of the original LBC files[1] is 384x360 grid units and the quadratic grid is used, the maximum wavenumbers are NSMAX=127 and NMSMAX=119. The truncation is done by moving to a cubic grid (with NSMAX=89 and NMSMAX=95). In the next step, the configuration e927 is applied again to resolve meteorological fields at final resolution by means of interpolation. In this way, LBC files were produced.

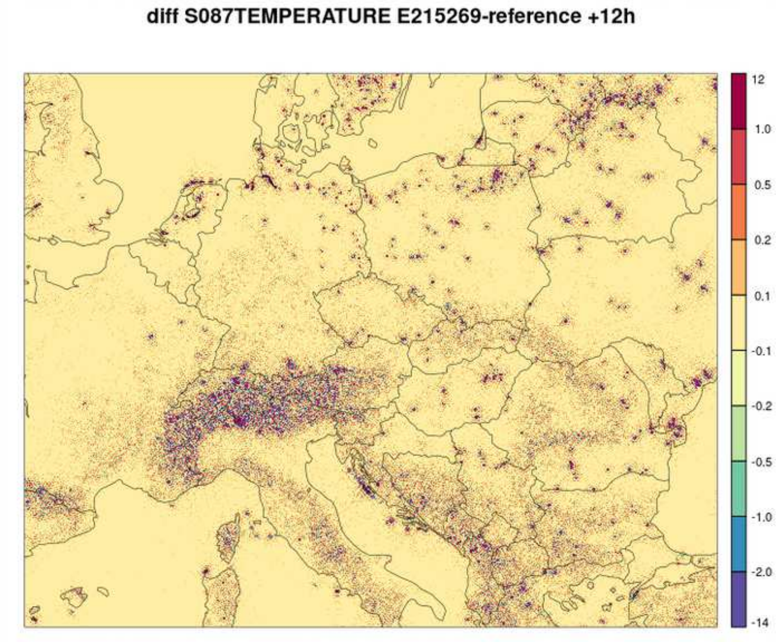


Figure 8: Local-scale deviations of air temperature at the lowest model level between the cored and the reference LBCs.

We can see that in case of air temperature (Fig. 9a), deviations relate to mountains and highlands. Big differences that used to occur near water bodies are gone. On higher levels, deviations tend to have lesser spatial extent. The magnitude of the deviations is generally acceptable

[1] e.g. LBC files fetched from MF server

(hardly exceeding +-1). In case of wind speed (Fig. 9b), deviations relate to orography. Some noise may be attributed to the different scale thresholds (it is about crossing zero).

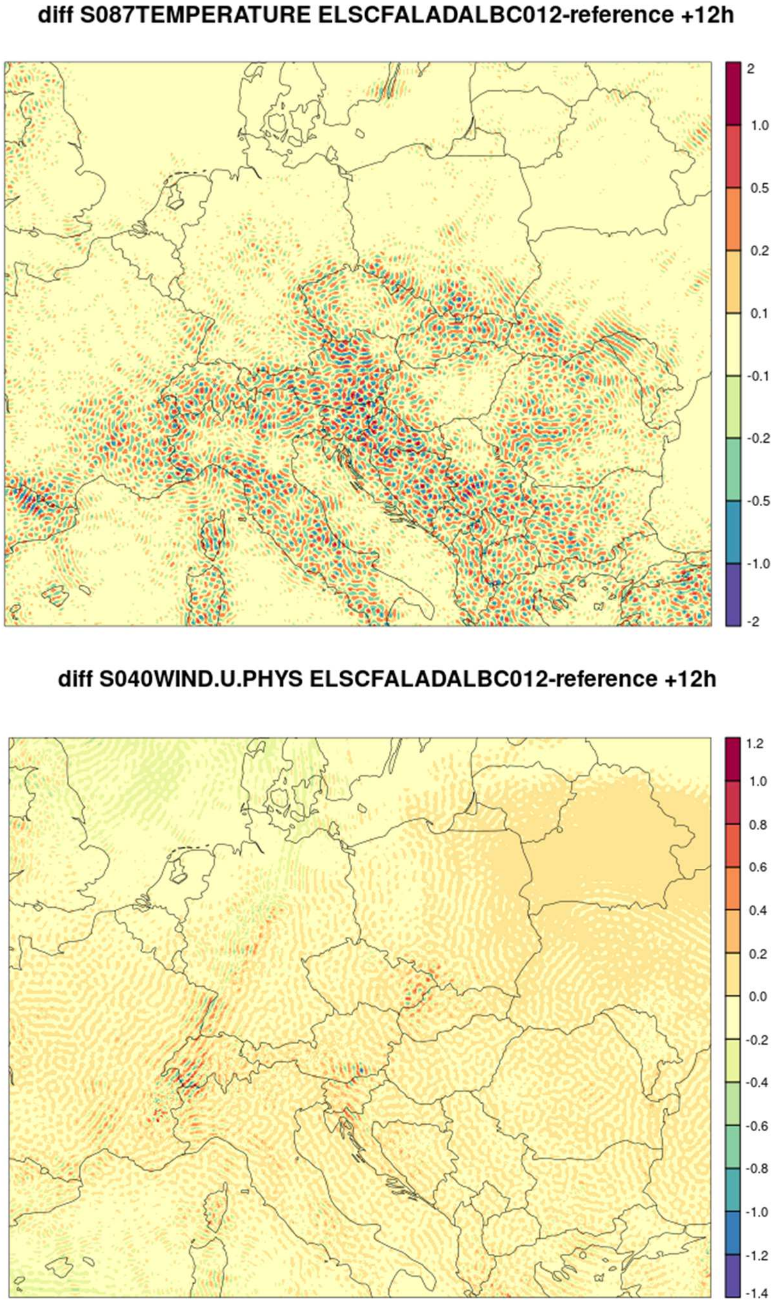


Figure 9: Difference of a) air temperature and b) zonal component of wind between modified LBC files (cored ellipse) and the reference.

Moving to forecast verification, we can see on Fig. 10 and Fig. 11 that the cored forecast has generally similar accuracy to the reference one. Some systematic bias is distinct only in case of geopotential and wind speed, however its magnitude is small. What is probably more concerning is the fact that geopotential bias is the most distinct at higher levels of the atmosphere as we see in the Fig. 12. The bias is mostly positive and reaches up to 10 m^2/s^2, which is around 1 m of geopotential height.

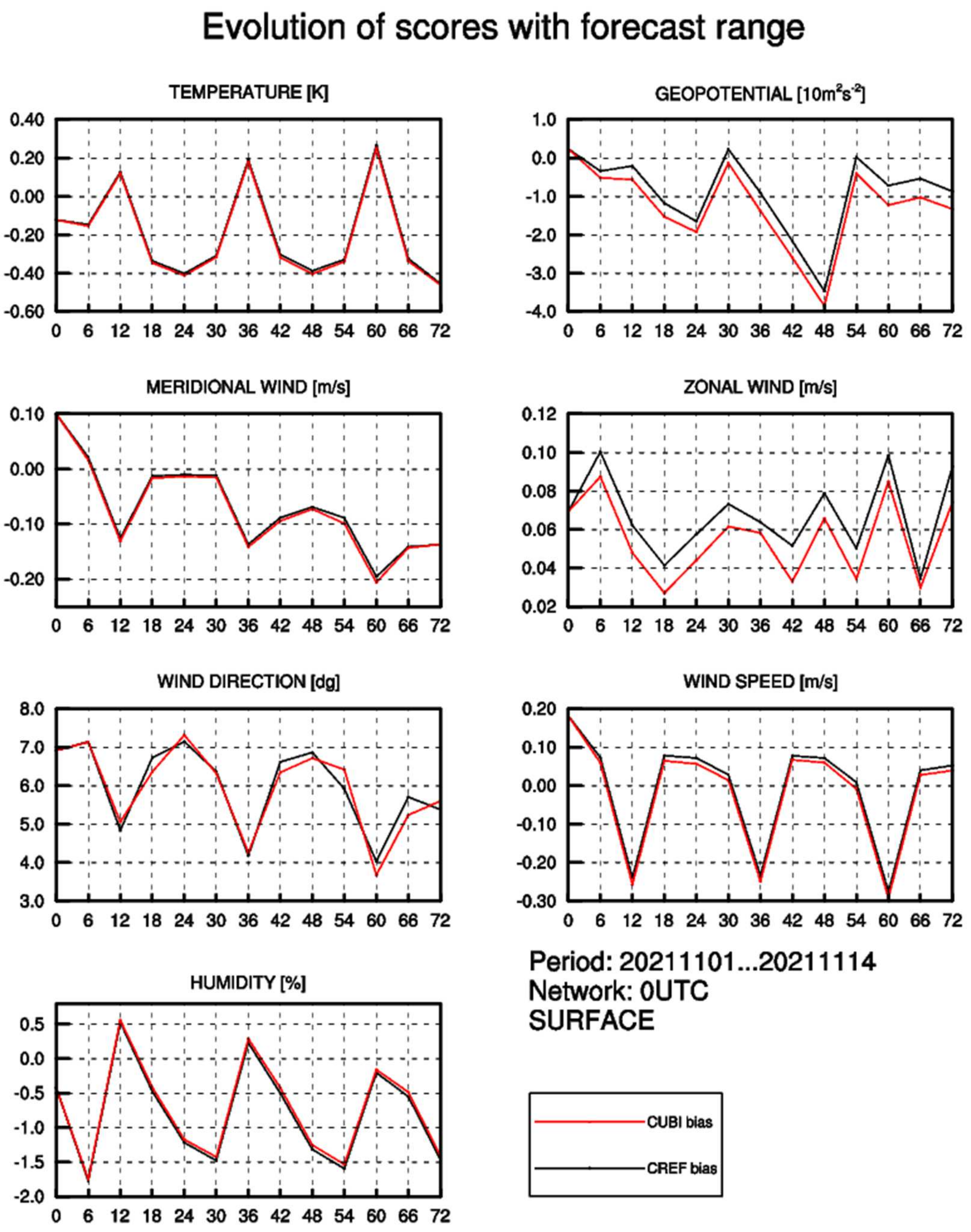


Figure 10: RMSE of cored forecast (CUBI) and the reference forecast (CREF) for selected meteorological fields.

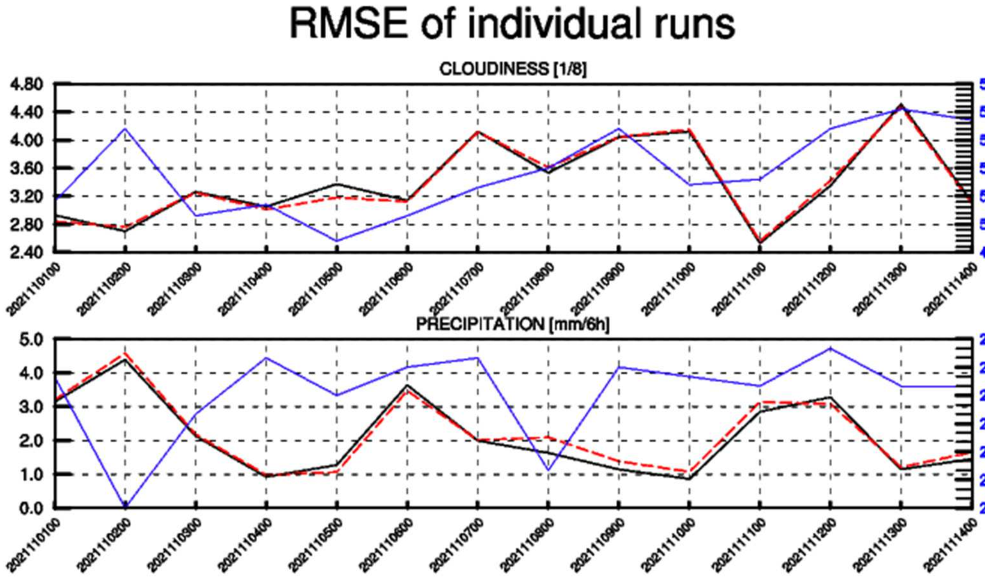


Figure 11: RMSE of the reference forecast (black) and a forecast produced from cored LBC files (red) for 72h leadtime.

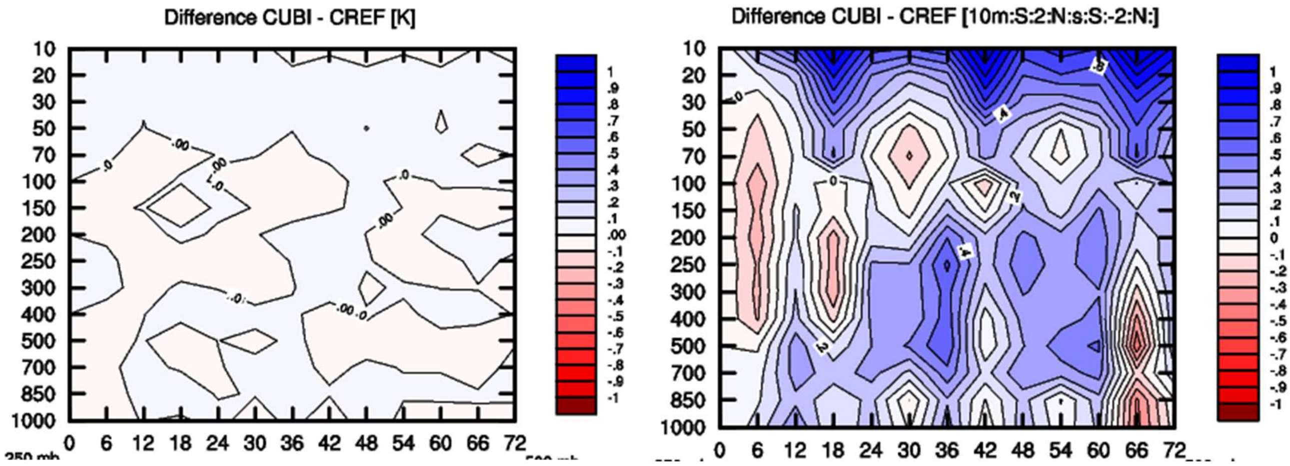
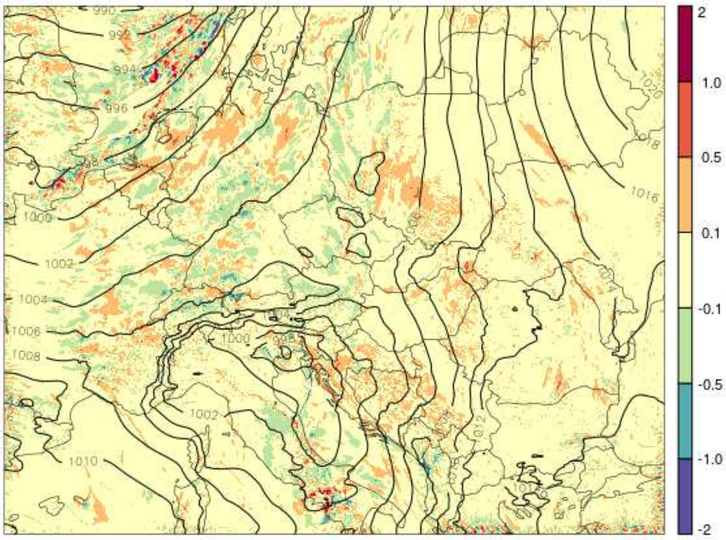


Figure 12: Temporal evolution of difference of RMSE between the cored and the reference forecast for air temperature (left) and geopotential (right) at different pressure levels (vertical axis).

The produced forecasts were also checked “manually” in order to spot some potential outstanding values occurring on small area and therefore not influencing the average domain statistics (Fig. 13). We can see that main differences occur in front zones in western Europe. As in case of hollow coupling, they are related to front zones near low-pressure areas. Temperature deviations mostly stay within +-1 degree. In case of wind speed, there are a few spots with greater deviations (from –8 to +6 at the 87th level and from –16 to 6 at 40th level) which again appears near lows’ center. The deviations don’t influence the verification scores, which are averaged over the whole domain.



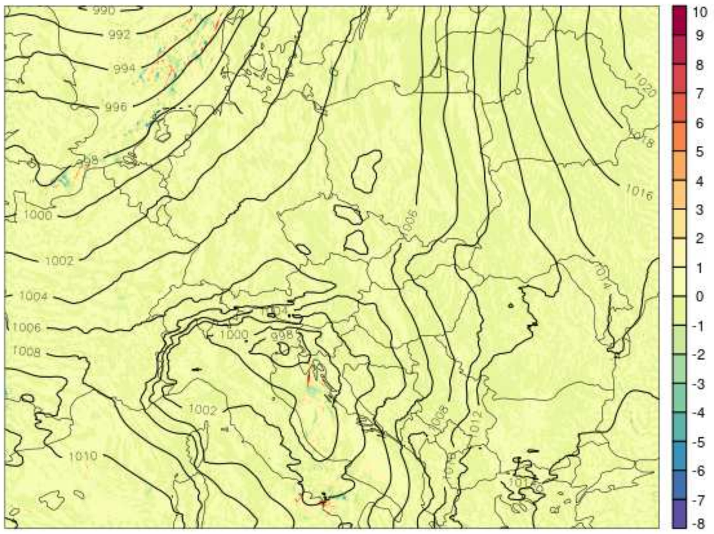


Figure 13: RMSE of difference of a) air temperature and b) zonal component of wind between the cored forecast and the reference one.

5. Calculation of the size compression

We calculated an expected file size compression in case of both modes of coupling. In Table 1 there are general formulas, while particular numbers are in Table 2. The calculations are done for one horizontal array, usually one vertical level of an upper air field or a surface field. We can compare the value [3] with the value [2] to see that the reduction in a hollowed file is up to 60%. This would be satisfying, but one has to notice that it is calculated with a reference to a grid-point LBC file in final resolution. If we take into consideration the spectral representation in the reference file [1], the reduction was even smaller, with only 59% of value [3] in hollowed file.

*Table 1: The size of a spectral and grid-point array in different LBC files. Denotations: N_a – NMSMAX, N_b - NSMAX, a – NDLON, b – NDGL, z=NDLON-NDLUX+2*NBZONL+2 (45 in our case).*

	Reference file	Hollowed file	Cored file
spectral array	$\pi N_a N_b = \pi \frac{ab}{9}$	-	$\pi N_a N_b = \pi \frac{ab}{16}$
grid-point array	ab	$z(a+b-z)$	ab

Table 2: The size of a spectral and grid-point array in different LBC files given as the number of reals saved.

	Reference file	Hollowed file	Cored file
a	384	1080	384
b	360	864	360
spectral array	48 254 [1]	-	27 143 [4]
grid-point array	138 240 [2]	85 455 [3]	138 240 [2]
reduction		62% [3:2]	56% [4:1]

As for core coupling, we expected compression to be proportional to the ratio of truncation order between LBCs with a quadratic and cubic grid, i.e. 9/16= 56%. In practice, for the whole LBC file, it turned out to be only 70% since there are 35 surface fields remaining in grid-point representation.

All calculations are without compression which may play an essential role in the final size of the represented field. One has to point out here, that for hollow coupling, the hollowed LBC files have to be prepared on the final domain and in the final resolution and then hollowed. It means that it is work which would have to be done at Météo France before file transfer and for each specific domain separately. After the transfer of the LBC files, the hollow would be filled, and the file would serve for coupling process. It means that the file preparation would be a demanding process which may be paid only by substantial gain in the LBC file size compression.

6. Summary

Frame approach occurred to be not capable to sufficiently reduce the size of LBC files to compensate the demanding process of the LBC files preparation and to speed up the operational process of producing forecasts. However, the core coupling turned out to have the potential to do so for LBC files in spectral representation, which is currently the basic one for transferring LBCs. Notice that the compression has to be made already at Météo-France.

No progress on this subject would have been made, had it not been for my supervisor Petra Smolíková, whom I would like to thank for great support and guidance.