Testing gp and spectral coupling

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1 Introduction

When using spectral LAMs, one has to bi-periodize the model fields. The same fields have to be blended with forecast large scale data, usually applied at the lateral boundaries. Both procedures usually use low order schemes that are based on empirical evaluation not on mathematical grounds. Such schemes are widely used because they provide good results. Periodization and blending with low resolution large scale data is the basis of all spectral LAMs.

[Boyd(2005)] proposes to bi-periodize the fields using infinitely differentiable window functions (often refered to as bells) from the wavelet theory. This way, spectral accuracy is preserved. The same functions can be used for blending data on the lateral boundaries and bi-periodization.

The periodization and relaxation using the windowing method [Boyd(2005)] has been implemented in a full three-dimensional spectral semi-implicit semi-Lagrangian limited area model [Termonia et al.(2012)] of the ALADIN System [Termonia et al.(2017)].

One has to distinguish two problems related to LAM lateral coupling. The mathematical formulation of the procedure and the temporal interpolation of the LBC fields.

The periodization and relaxation that uses windowing functions [Boyd(2005)] has the advantage of using physical data for the periodic extension and the excellent spectral convergence. But, one has to avoid overlap between the relaxation and bi-periodization zones in applications that allow long time steps. The observational scores do not show significant differences between using the splines or the windowing function extension zone [Termonia et al.(2012)]. This shows that low order schemes do not ause a systematicerror in he system.

However, as noted in [Termonia et al.(2012)], improvements due to more accurate mathematical formulation of the LBCs can be obscured by errors that originate from the temporal interpolation of the LBC fields. Further tests should be performed using LBC data provided at each time step.

Windowing method [Boyd(2005)] has been applied and tested in a one-dimensional shallow water model, adiabatic model and full NWP model [?]. Scores were neutral with respect to the spline method. But, the forecast was better in a case with strong dynamical forcing at lateral boundaries.

The spline method yields only second order continuity in the model fields across the domain lateral boundaries. The windowing functions yield fields that are infinitely differentiable.

This chapter describes tests performed using ALADIN System [?] with different mathematical formulations of the LBCs in combination with various schemes for temporal interpolation of LBC data.

2 Data and methods

- The mathematical formulations:
    1. Davies relaxation with periodization using splines,
    2. spectral coupling,
    3. use of windowing function for bi-periodization.
- The temporal interpolation schemes used:
    1. linear,
    2. quadratic,
    3. cubic,
    4. coupling of surface pressure tendency.

Ideally, one should run a global model on the same resolution as a LAM in order to have a proper reference high resolution colution to compare to. That global model run should also have output every (LAM) time step to have LBC data available for LAM. Then LAM would be run using the large scale data from every model time step or with a larger interval and interpolated in time. This would allow for avoidance of all interpolation errors. In fact, [?] proposes to run the same model with the same dynamics and physics parametrizations over the global and limited area domains. Such an experiment would be rather expensive in storage. Global models usually have different grids than LAMs (and vertical levels). This means that there is always some spatial interpolation involved, even if both global model and LAM are run at a same resolution. The other problem is that global models do not have to bi-periodize the fields. The numerical procedures in global models and LAMs are slightly different. Therefore the model forecasts can be (and should be only slightly) different.

The coupling files from IFS and ARPEGE global models contain data that are already interpolated on a Lambert conformal grid (and associated spectral coefficients of the fields). The data are already on a limited area domain, but in a lower resolution than the target resolution of a LAM.

First a model run was performed on the coupling files. ALADIN model was run with a same configuration as operational on the domain and resolution of the coupling files, but using the time step that is also used in subsequent high-resolution LAM runs. This should minimize the coupling errors that could arise due to different model formulations between the host and the guest model.

For each configuration that was tested, three model runs were performed:

1. reference run using large scale data without interpolation (available every time step),

2. experiment using hourly large scale data,

3. experiment using three hourly large scale data.

The global model ARPEGE forecasts a small cyclone that moves from west to east over the western Mediterranean. Here we will look at a particular moment after the cyclone enters the operational 8 km resolution domain (HR88). Figures 1 to 6 show an area over the western MEditerranean that is close to the southwest corner of the HR88 domain and over the western edge of HR88 and the coupling domain. Both edges can be seen in the figures as the isobars of the mean sea level pressure "disappear" there. The other laterla boundaries of the domain are far from the edges of the figure. Using coupling data every timestep, the cyclone is detected by every LBC procedure. Actually, one can hardy find any differences, the forecasts look identical (although the numerical values are actually slightly different). The cyclone is deeper in HR88 forecast than in ARPEGE forecast, regardless which coupling procedure was used.

The temporal interpolation does not play a role here (because fresh LBCs are provided every timestep, there is no need for interpolation), but the experiments were run in order to verify that and to provide references for further tests. Although many of the results shown in Figures 1 to 2 seem identical at first glance, there are differences between the experiments that apply different mathematical formulation (Davies, spectral blending, etc).

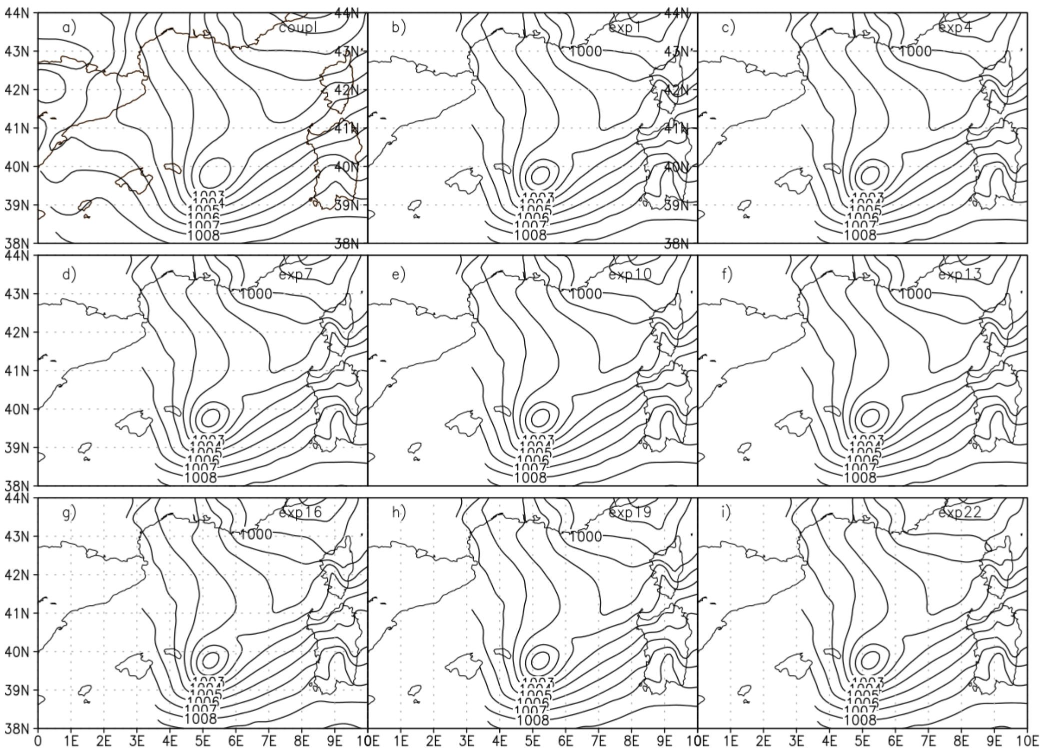

Figure 1: Mean sea level pressure forecasts on the host domain (coupl) and on the guest domain using LBC data from coupl with output every LAM timestep and different mathematical formulations of LBC implementation.

Table 1: Description of the experiments, the experiment numbers, the mathematical formulation and temporal interpolation used, usage of pressure tendency coupling in gridpoint/spectral space and other parameters that are relevant for the experiments.

exp Nos	mathematical formulation	temporal interpolation	coupling $\frac{\partial p_s}{\partial t}$	other features
1, 2, 3	Davies	quadratic	no	
4, 5, 6	Davies	linear	no	
7, 8, 9	Davies	cubic	no	
10,11,12	Davies	linear	yes	
13,14,15	Davies	linear	LALLTC	
16,17,18	Davies	quadratic	yes	RTENC=1
19,20,21	Davies	linear	LALLTC	RTENC=0.95
22,23,24	spectral	linear	no/no	k_1=12, n_1=1, n_2=37
25,26,27	spectral	linear	yes/yes	k_1=12, n_1=1, n_2=37
28,29,30	spectral	linear	no/no	k_1=24, n_1=1, n_2=37
31,32,33	spectral	linear	no/no	k_1=24, n_1=6, n_2=9
37,38,39	Boyd+Davies	linear	no	
40,41,42	Boyd+Davies	quadratic	no	
49,50,51	Boyd+Davies	cubic	no	
52,53,54	Boyd+Davies	linear	yes	
61,62,63	Boyd+spectral	linear	no	k_1=24, n_1=6, n_2=9

These differences are the easiest to spot in the lee of large mountainous islands, such as northeast of Corsica and Sardinia. Spectral coupling indeed interferes with a mountain wave that forms there. Using spectral coupling slightly reduces the gradient in the mean sea level pressure between the upwind and the lee side of the mountain.

Coupling files are operationally available only with three hourly interval. Therefore, an experiment was performed where three hourly coupling files were used from the ALADIN run performed on the coupling domain.

The intense small cyclone almost vanishes from the mean sea level pressure forecast fields, only a through is left. The cyclone is best preserved in an experiment using Davies scheme with cubic temporal interpolation. The experiments using spectral aoupling show traces of the cyclone, but much further eastward than its position in the large scale model forecast.

Coupling of the pressure tendency (exp21) yields a deeper elongated through. However, one may notice that the pressure gradient over the mountains of Corsica also changes depending on the coupling scheme that is used for the model forecast. The pressure gradient is stronger in these experiments (using three hourly data) than in experiments that use fresh LBCs

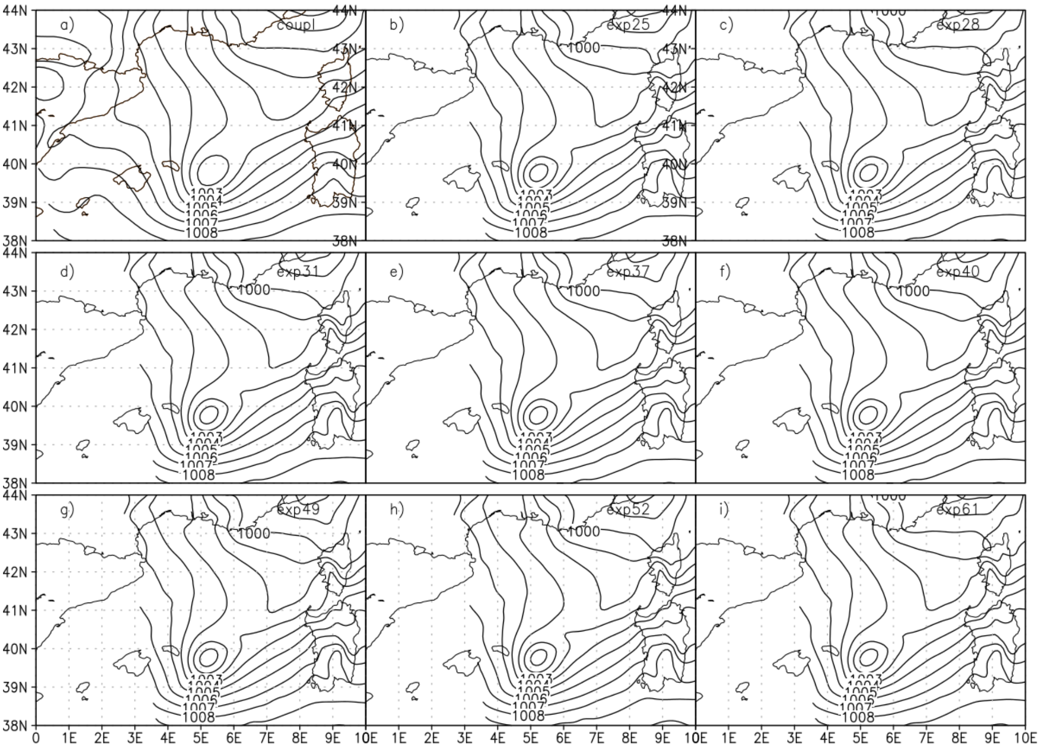

Figure 2: Mean sea level pressure forecasts on the host domain (coupl) and on the guest domain using LBC data from coupl with output every LAM timestep and different mathematical formulations of LBC implementation.

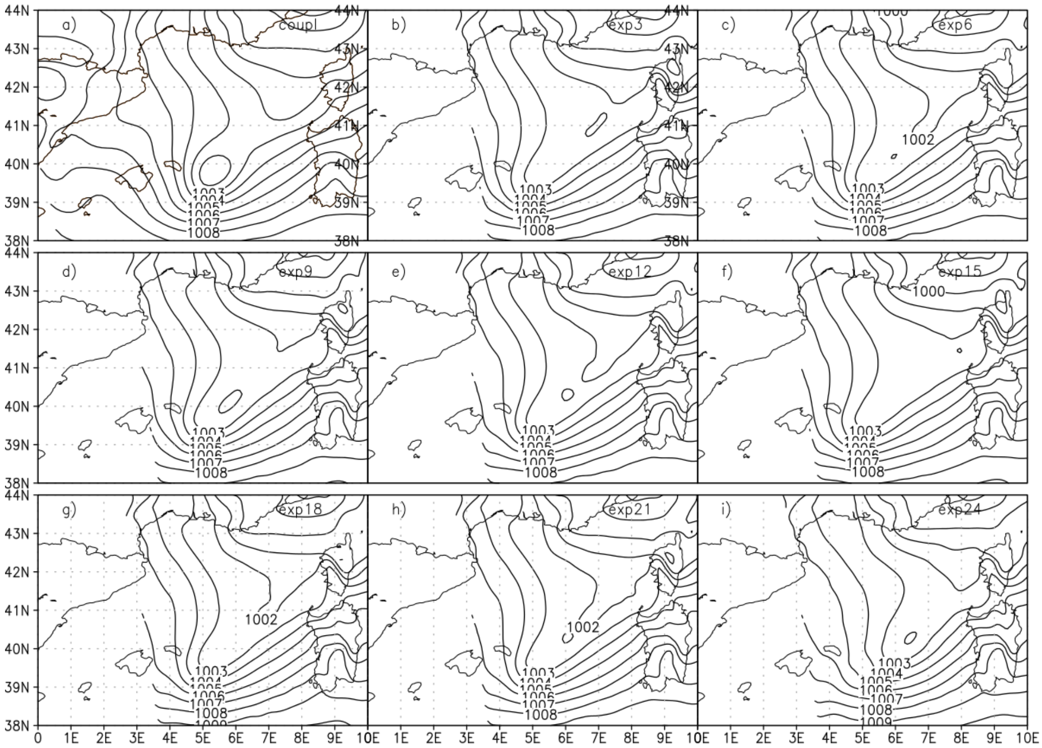

Figure 3: Mean sea level pressure forecasts on the host domain (coupl) and on the guest domain using three hourly LBC data from coupl and different mathematical formulations of LBC implementation and different temporal interpolations.

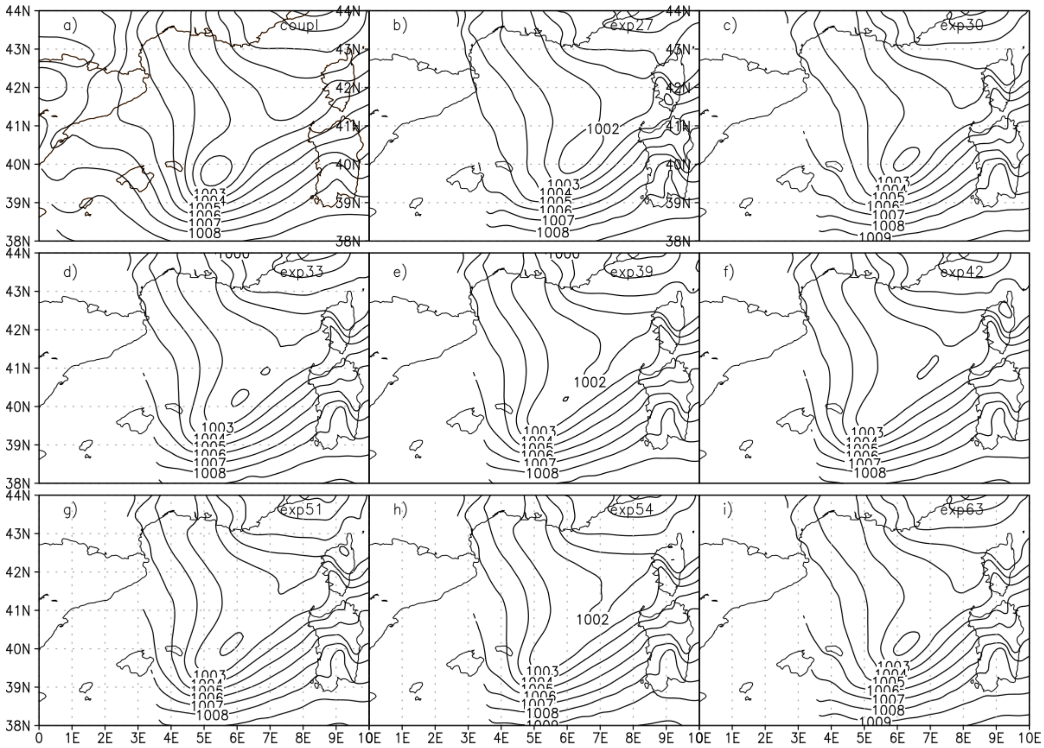

Figure 4: Mean sea level pressure forecasts on the host domain (coupl) and on the guest domain using three hourly LBC data from coupl and different mathematical formulations of LBC implementation and different temporal interpolations.

every timestep. In experimetns that use only gridpoint coupling at lateral boundaries, (and no spectral coupling) there is one closed isobar above north-east Corsica. Experiments with spectral coupling again have lower mean sea level pressure graident over mountains.

Usage of the Boyd scheme (compare exp3 with exp39) yields a deeper through and weaker pressure gradient over Corsica for linear temporal interpolation, but weaker through for quadratic temporal interpolation and very similar results for cubic temporal interpolation. However, using spectral coupling with a Boyd scheme (compare exp33 and exp63) clearly improves the structure of the mean sea level pressure around the storm, although the storm itself is moved eastward with respect to the position of the storm in ARPEGE.

Usage of hourly coupling interval restores the cyclone, but with slightly

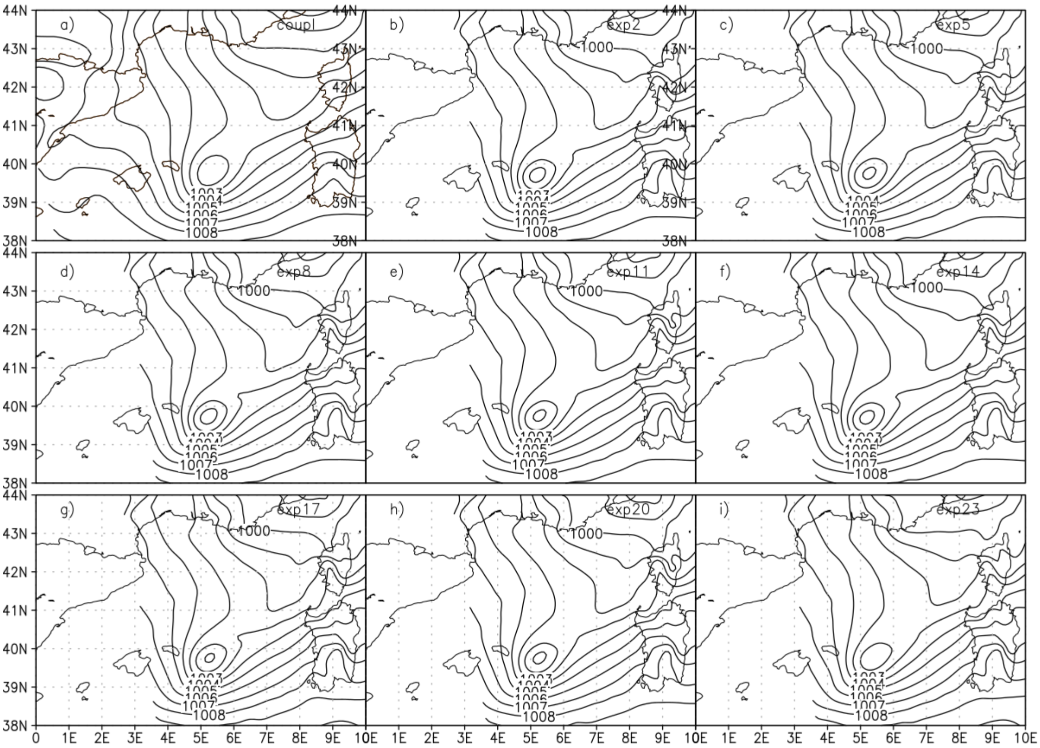

Figure 5: Mean sea level pressure forecasts on the host domain (coupl) and on the guest domain using hourly LBC data from coupl and different mathematical formulations of LBC implementation and different temporal interpolations.

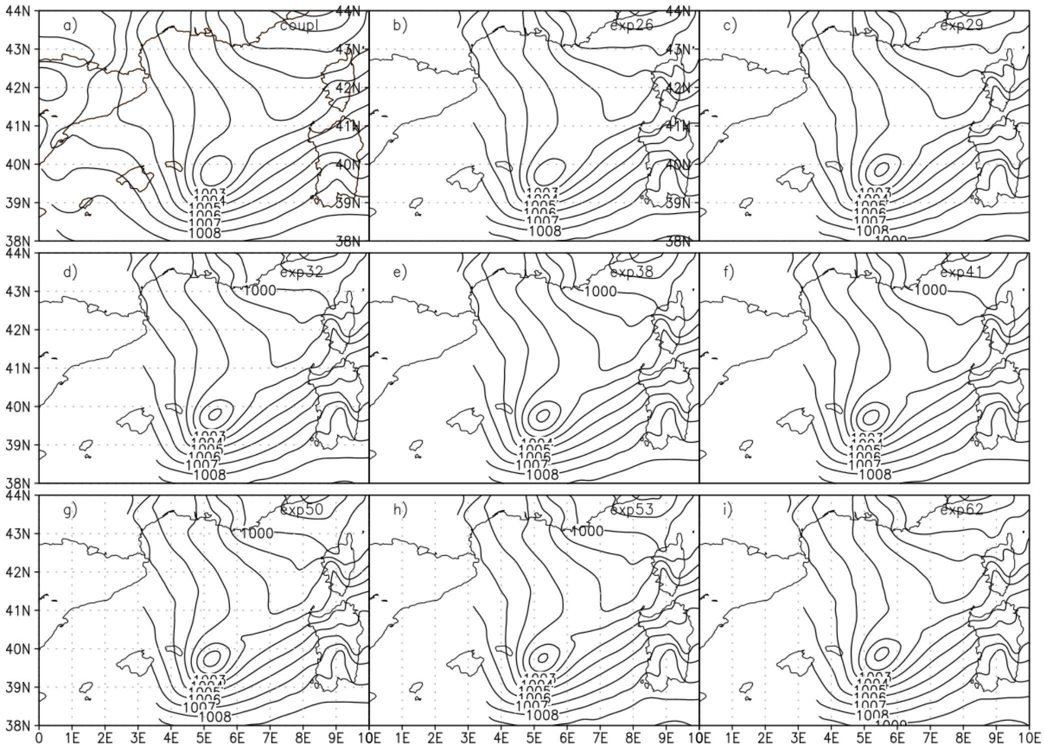

Figure 6: Mean sea level pressure forecasts on the host domain (coupl) and on the guest domain using hourly LBC data from coupl and different mathematical formulations of LBC implementation and different temporal interpolations.

lower intensity. The storm intensity in reduced the most in experiments with spectral coupling used with low value for k_1. Increasing k_1 from 12 to 24 restores the cyclone (compare exp26 to exp29). One should also notice differences in the pressure gradient over mountains of Corsica with several experiments producing a lee wave (exp11 and exp20).

Differences and root mean square errors (RMSE) for experimetns were computed with respect to the corresponding reference. The reference experiments used fresh LBC data provided every model timestep. This way, the errors due to temporal scheme can be revealed.

The evaluation of differences and RMSE evolution during the forecast period for the mean sea level pressure field is plotted in figures 7 to 12. Be aaware that the scales in figures are different for diffferent coupling update intervals (hourly and three hourly) and different groups of experiments.

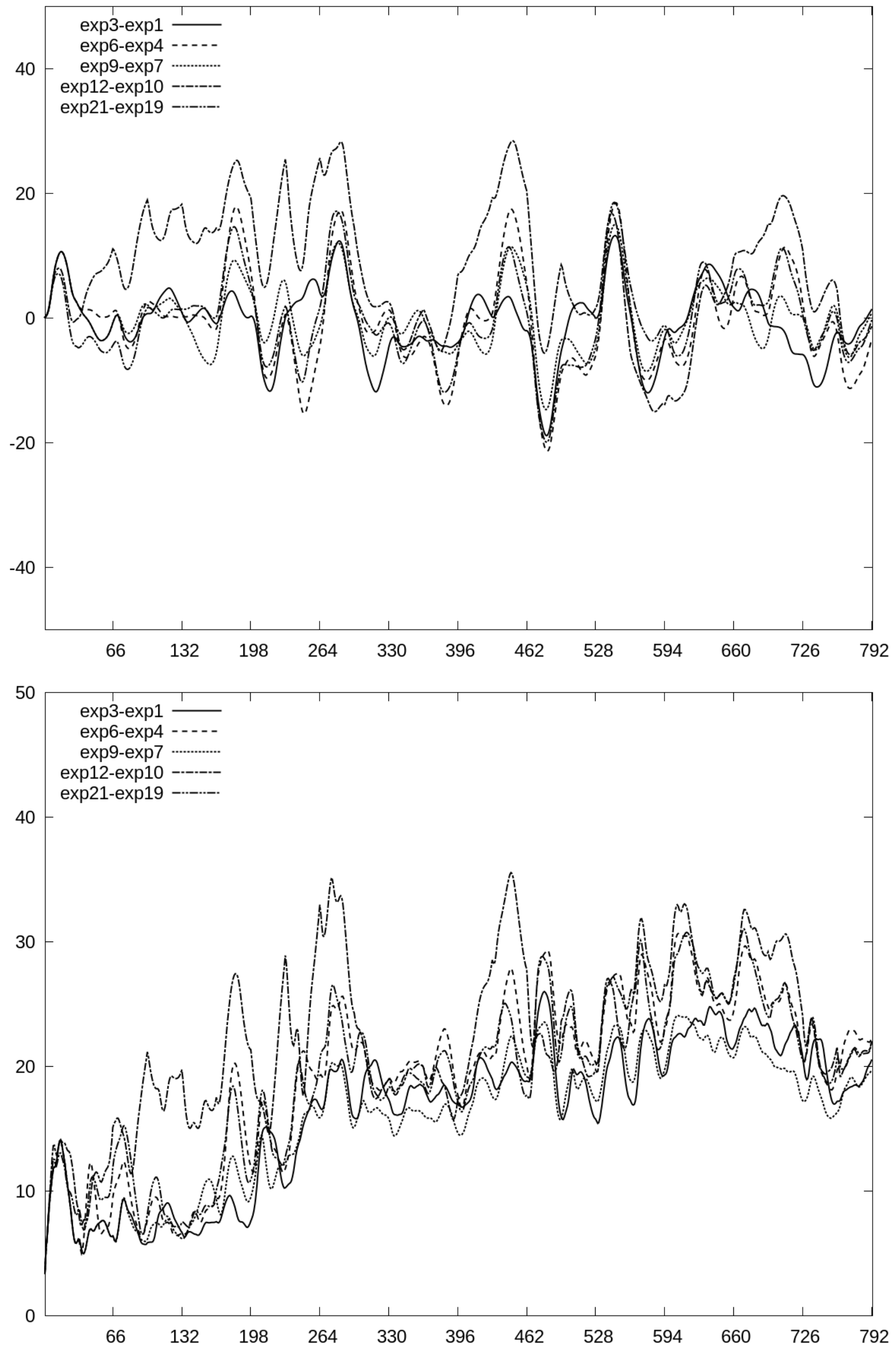

Figure 7: Difference and rmse three hourly LBCs to each timestep LBCs.

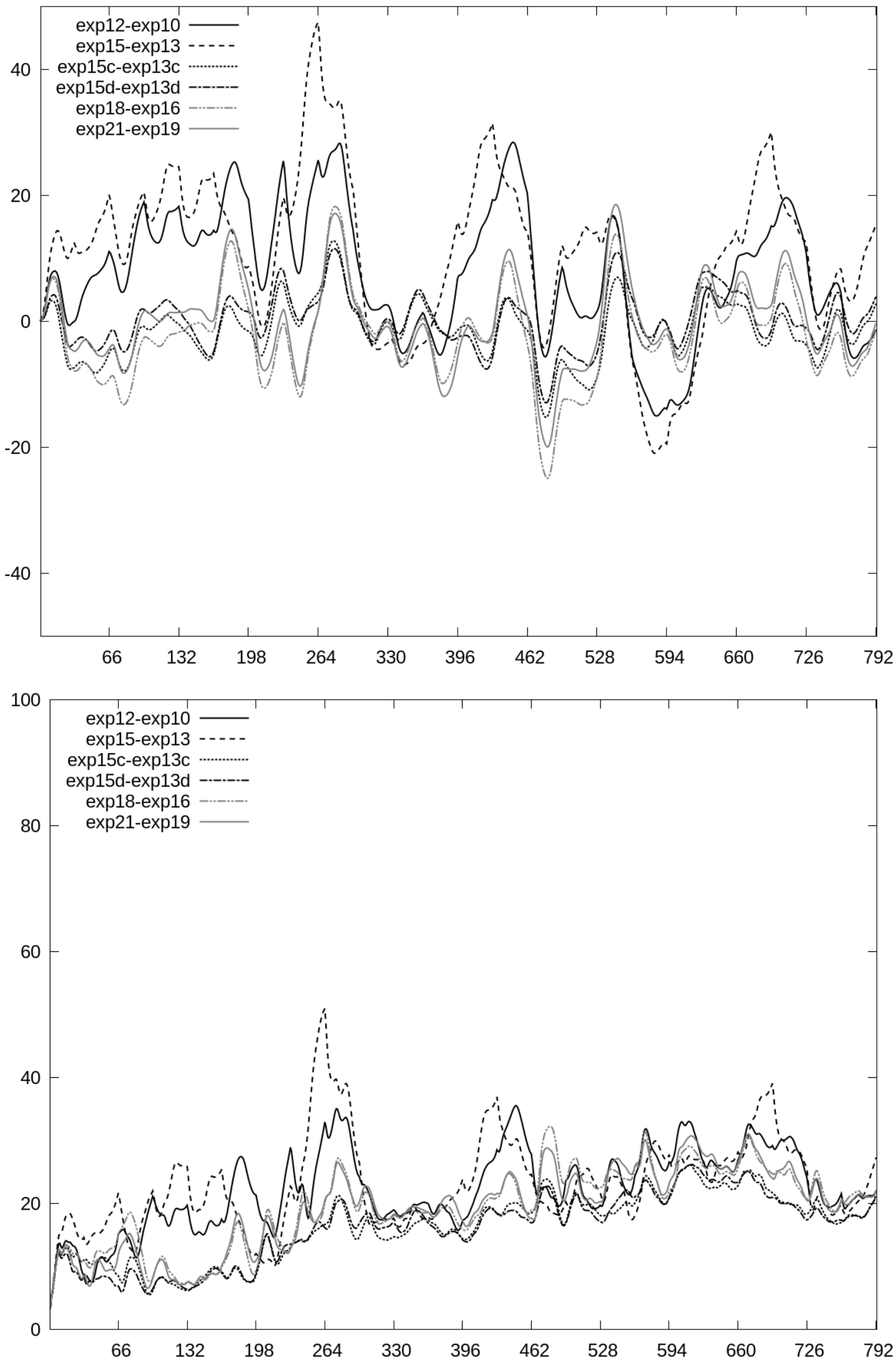

Figure 8: Difference and rmse three hourly LBCs to each timestep LBCs.

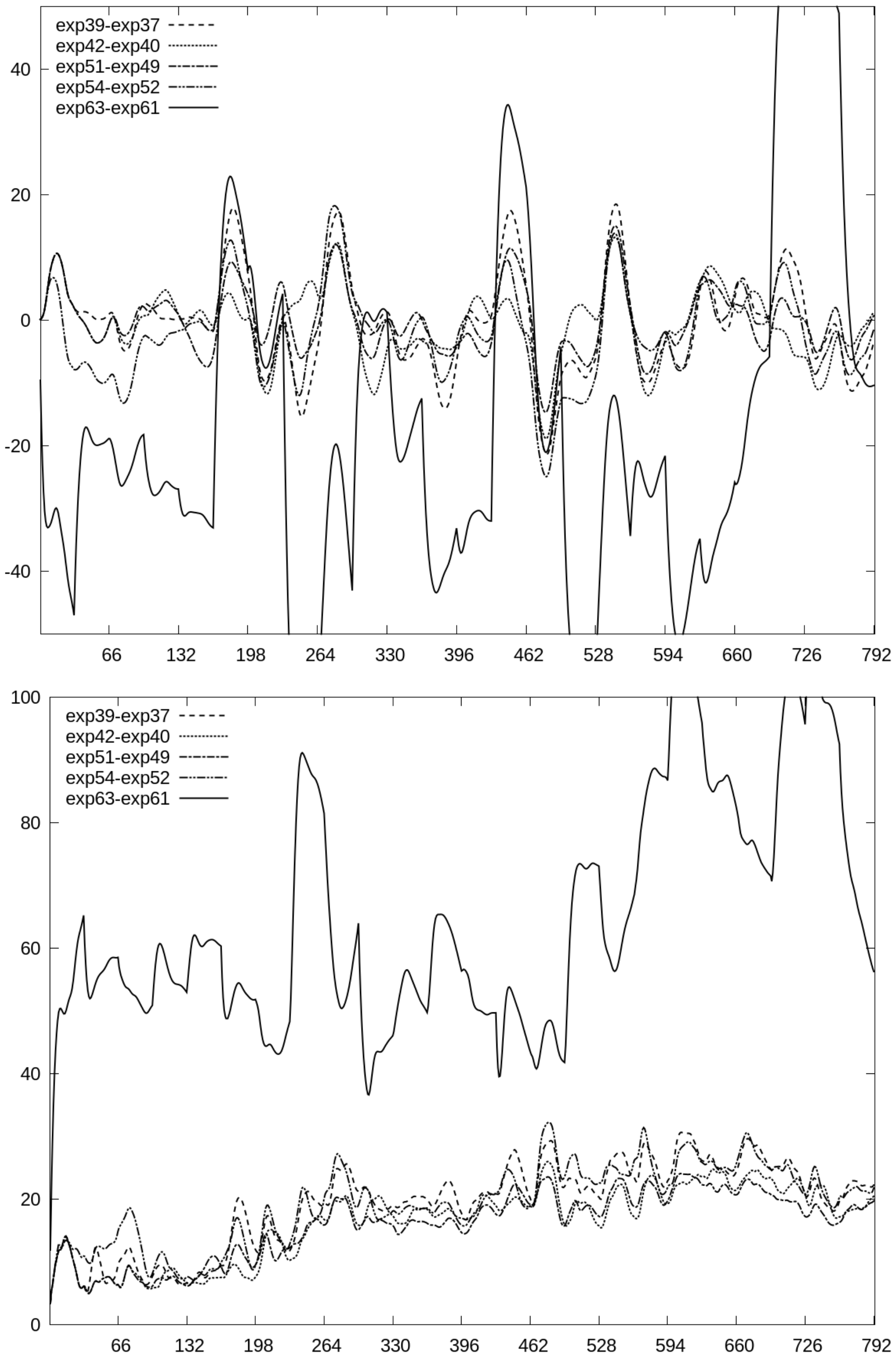

Figure 9: Difference and rmse three hourly LBCs to each timestep LBCs.

Usage of different temporal interpolation schemes with the gridpoint coupling using Davies scheme and three hourly LBC data (Figure 7 and hourly LBC data (Figure 11 does not reveal a clear winner. The RMSE is similar for linear, quadratic and cubic schemes, as well as for one scheme that also employs coupling of the surface pressure tendency.

Introducing coupling of the surface pressure tendency can have detrimental effect to the results. The deterioraton becomes more obvious for shorter coupling update interval. Coupling the pressure tendency can have several variations, but the benefit is not very clear, when compared to experiments without the coupling of the pressure tendency. It does not outperform the experiments using simple temporal interpolation of the p_s field. The errors introduced by wrong choices in coupling the tendency of p_s are more obvious with shorter coupling update interval (see Figures 8 and 12).

Introducing spectral coupling produces the largest differences and errors due to temporal interpolation. Both errors and differences have similar temporal evolution for all spectral coupling experiments regardless of the details of the coupling scheme. The RMSE reduces substantionally only in the experiment where spectral coupling is applied on a reduced number of vertical levels.

2.1 Summary and conclusions

Spectral coupling is most sensitive to the length of the coupling interval and produces large errors even with hourly coupling update interval.

References

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[Degrauwe et al.(2012)] Degrauwe, D., Caluwaerts, S., Voitus, F., Hamdi, R., and Termonia, P.: Application of Boyds Periodization and Relaxation Method in a Spectral Atmospheric Limited Area Model. Part II: Accuracy Analysis and Detailed Study of the Operational Impact. Mon. Wea. Rev., 140, 3149–3162, 2012.

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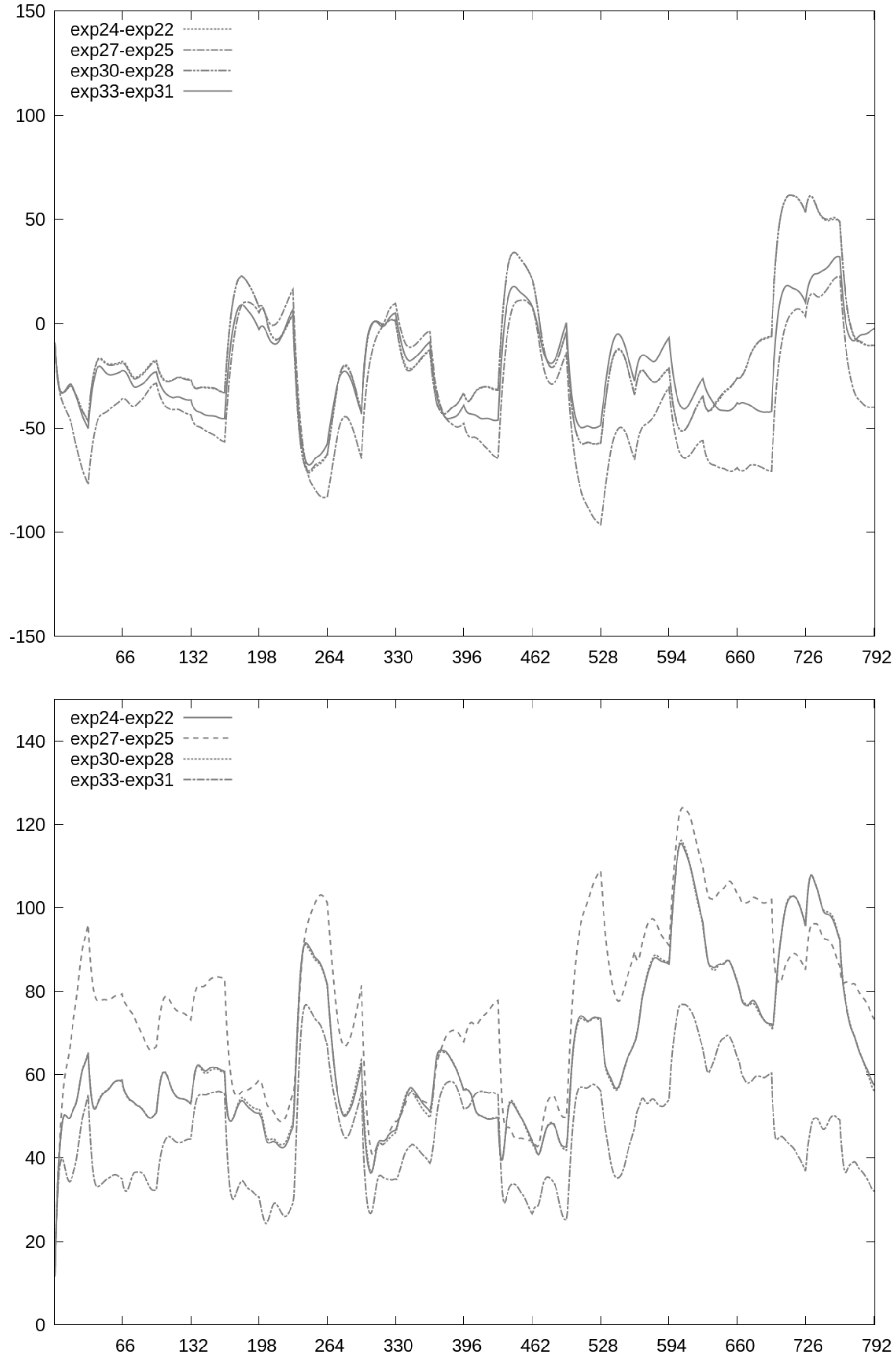

Figure 10: Difference and rmse three hourly LBCs to each timestep LBCs.

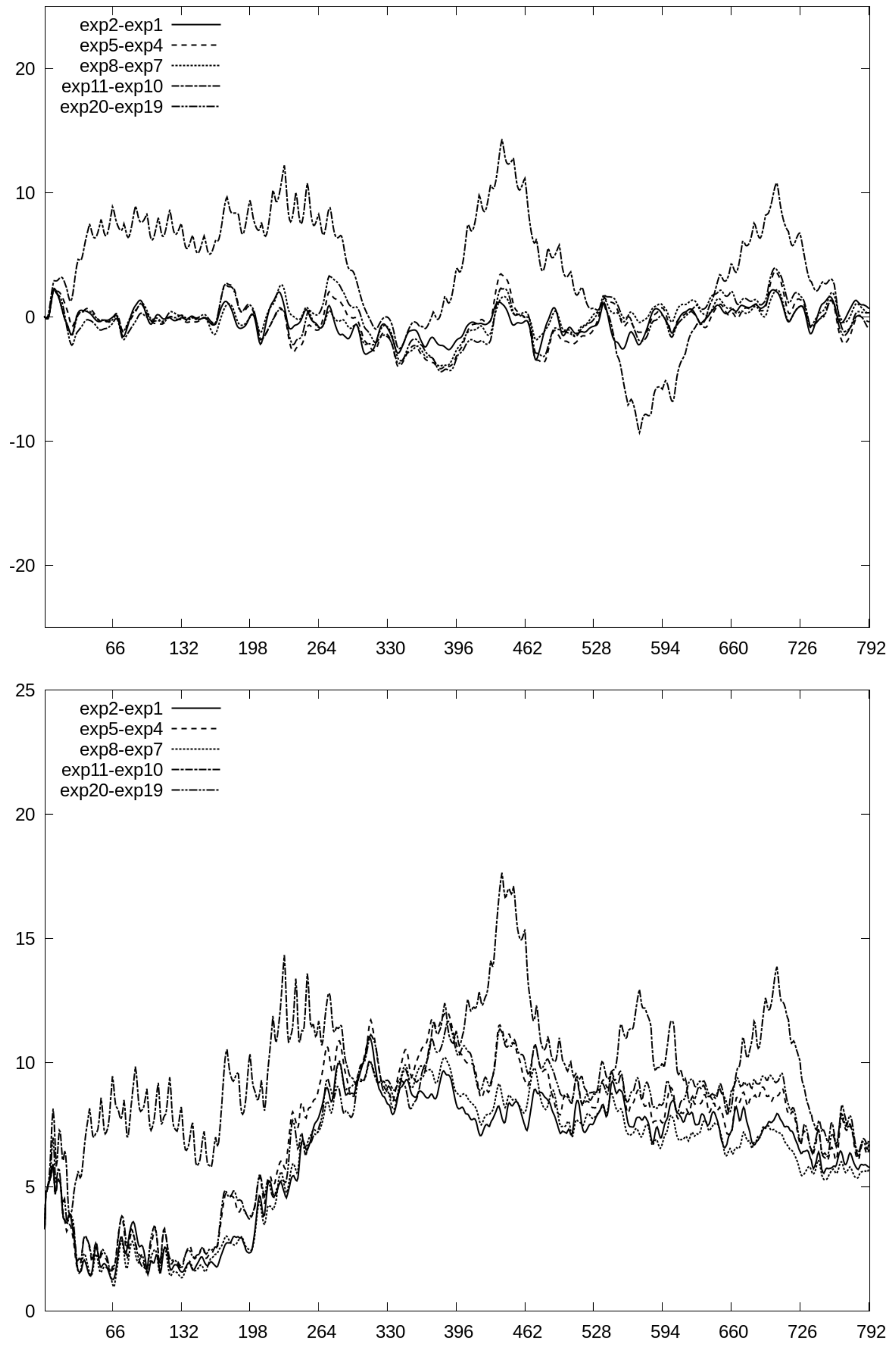

Figure 11: Difference and rmse hourly LBCs to each timestep LBCs.

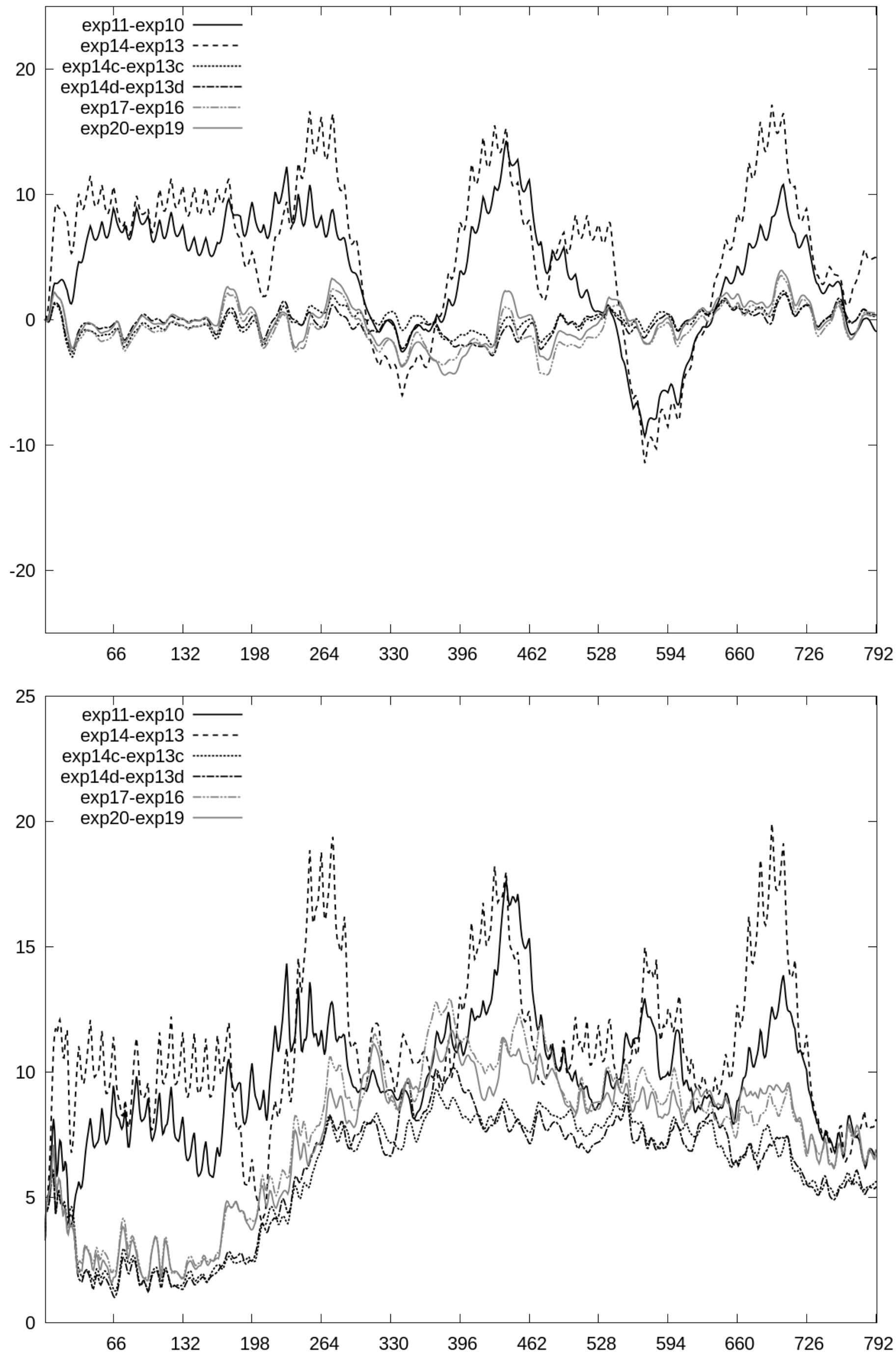

Figure 12: Difference and rmse hourly LBCs to each timestep LBCs.

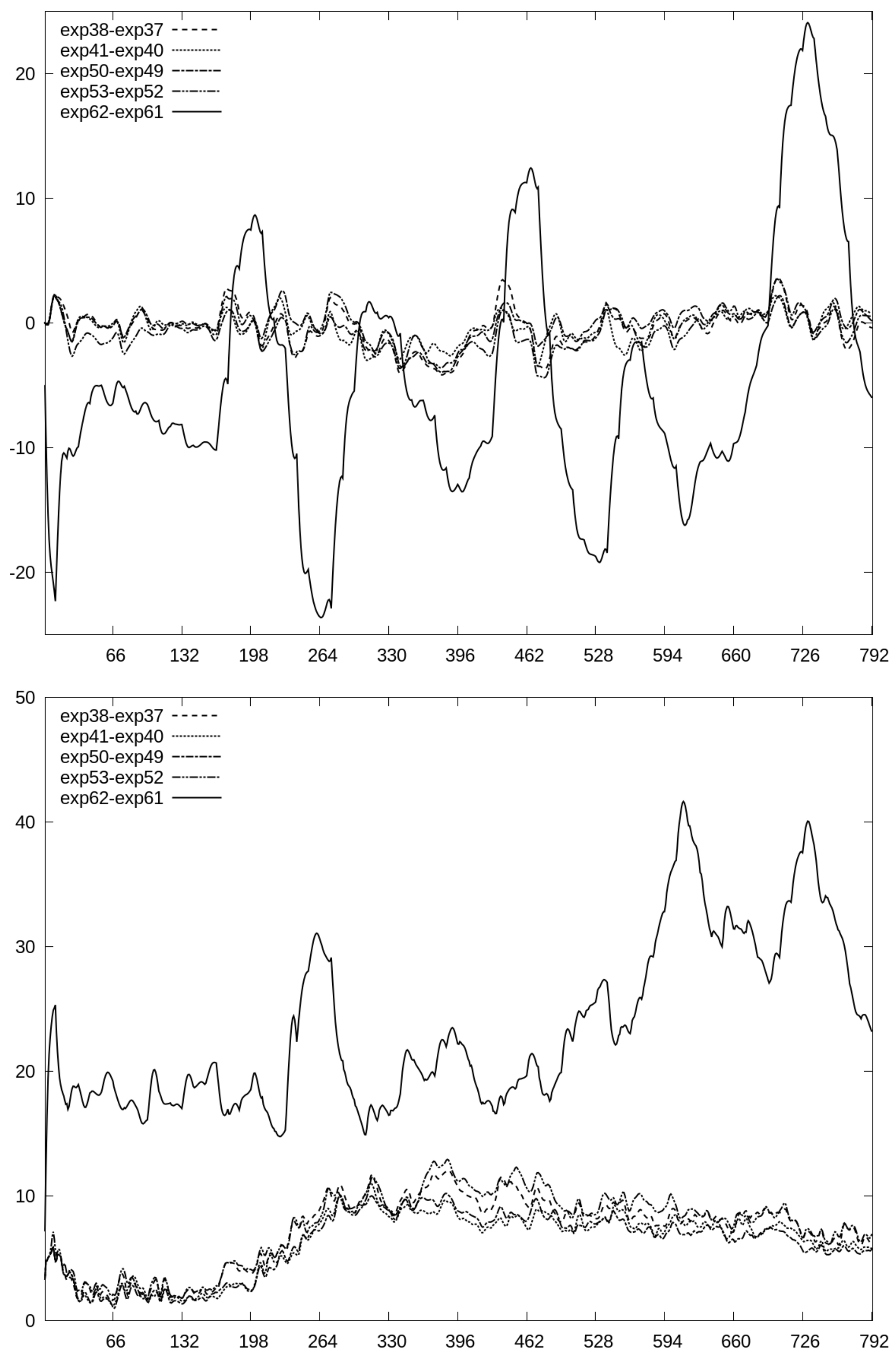

Figure 13: Difference and rmse hourly LBCs to each timestep LBCs.

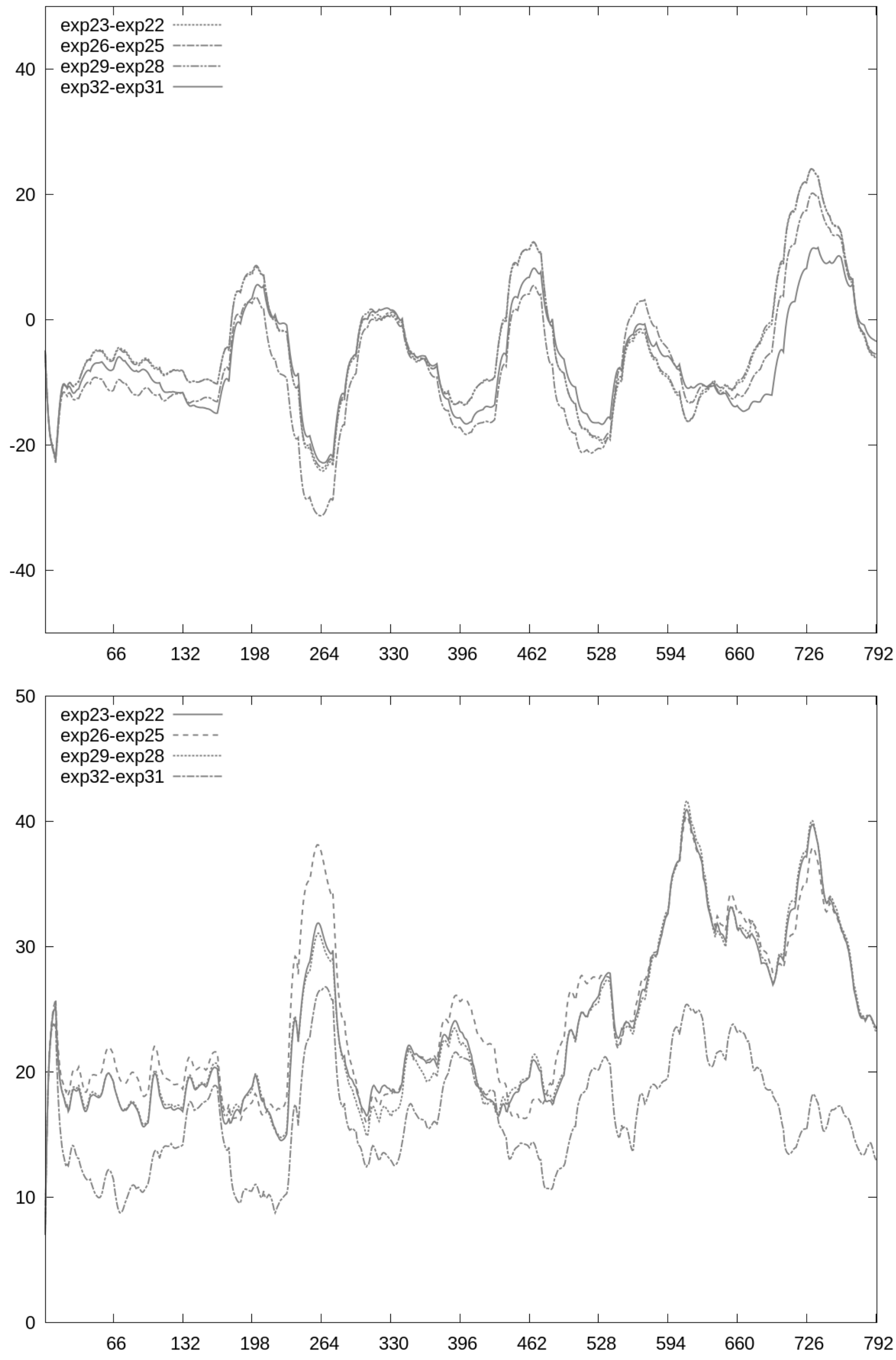

Figure 14: Difference and rmse hourly LBCs to each timestep LBCs.

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