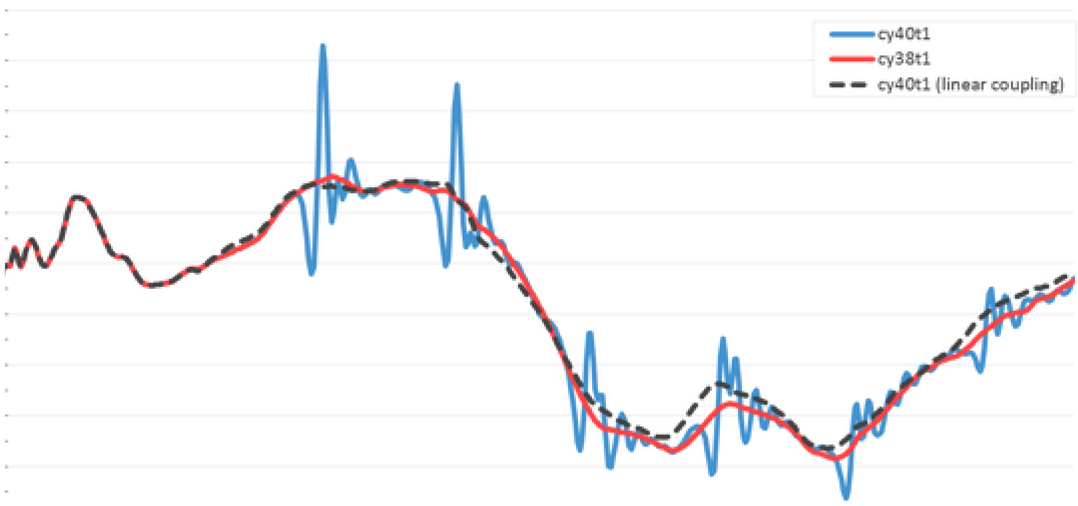
Report on stay at ZAMG

24/10~18/11, 2016, Vienna, Austria

Spectral blending on high resolution issue



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::Acknowledgement

I’m very grateful to Mária Derková for her idea of using incremental digital filter initialization although it unfortunately didn’t solve the issue observed in new ALADIN-LAEF system. Nevertheless, it certainly led us to even deeper investigation of the problem and eventually to surprising finding of a serious bug in the model coupling affecting all prognostic variables in cy40t1 and the cycles above. I’d like to express my gratitude to Jano Mašek as well. He did navigate me to the right direction when hunting for a very unlikely bug.

::Foreword

Following the outcomes from my previous RC LACE stay at ZAMG (M. Belluš, 2016: "*New high resolution ALADIN-LAEF on CY40T1 with ALARO-1 physics*", URL: http://www.rclace.eu/File/Predictability/2016/Report_ZAMG_2016_06_mbell.pdf) it was obvious, that we have a problem somewhere within our new ALADIN-LAEF configuration. Unfortunately, due to given circumstances the several major upgrades of the system were done at the same time (new high resolution domain with 4.8 km horizontal grid and 60 vertical levels; switch from quadratic to linear grid; model version upgrade to cy40t1 with ALARO-1 physics and implementation of new perturbation method BlendVar). In other words, it wasn't quite clear, where the issue could be hidden. Therefore, it remains the goal for this stay.

There were two possible "candidates" responsible for the issue listed in the conclusions of the previous RC LACE report. The first one was the fact, that we have used archived data from 2011 to evaluate the new ALADIN-LAEF system. In order to generate the boundary conditions for our experiments, we had to interpolate the original archived data (containing only 45 vertical levels) into new 60 vertical levels. (That was the logical and necessary approach, because the newer ECMWF EPS data were not stored on the discs.) At that time the most suspicious component was the upper-air spectral blending, in which the signal at the model levels is processed. Hence, we thought that probably some numerical interpolation noise due to the insufficient number of vertical levels on input could have caused the issue. To exclude such a possibility, we performed 2-weeks run on 2016 dataset. This time the LBCs were prepared using the current global ECMWF files containing 91 vertical levels. The results are shown in chapter I.

The second "candidate" was the initialization of the model. It already happened some years ago in project MFSTEP, where due to the big jump between the driving and target model resolutions the initial fields (mostly MSLP) were noisy after the blending procedure. The proposed solution was the model initialization by incremental digital filter (IDFI). The implementation of IDFI in ALADIN-LAEF blending procedure is described and its impact is shown in chapter II.

However, life (not to mention LAEF :) is complicated, so it turned out that none of the above "candidates" were really responsible, nor the actions taken helped to improve significantly the statistical scores of new ALADIN-LAEF. Yet the implementation of IDFI we found important and quite useful for the future. Thankfully, the investigation didn't finish there and the gathered intel led us to the very important finding. We've found and localized the serious bug in cy40t1 (and all the above cycles) within the coupling procedure. This bug in quadratic coupling caused the spurious oscillations of prognostic variables (firstly seen for MSLP) on time-step bases. The oscillations could have been observed also in hourly outputs when looking closely enough. Although, it was quite beyond the scope of this stay to re-run again the EPS experiments, it is very likely that this is the issue we were searching for.

::I. Vertical levels

In principle, there are two ways how to technically prepare boundary conditions from global ECMWF grib files for ALADIN models family. Previously used configuration e901 followed by e927 (which does the conversion from IFS gribs to ALADIN FA-files) unfortunately doesn't support the new reduced octahedral grid used by ECMWF nowadays. The second option is GL tool, but that is also not flawless. Unlike e927, GL is not taking into account target domain orography when interpolating wind field. This leads to visible differences in PBL when compared to the original e927 interpolations. However, for the sake of our evaluation, this was neglected.

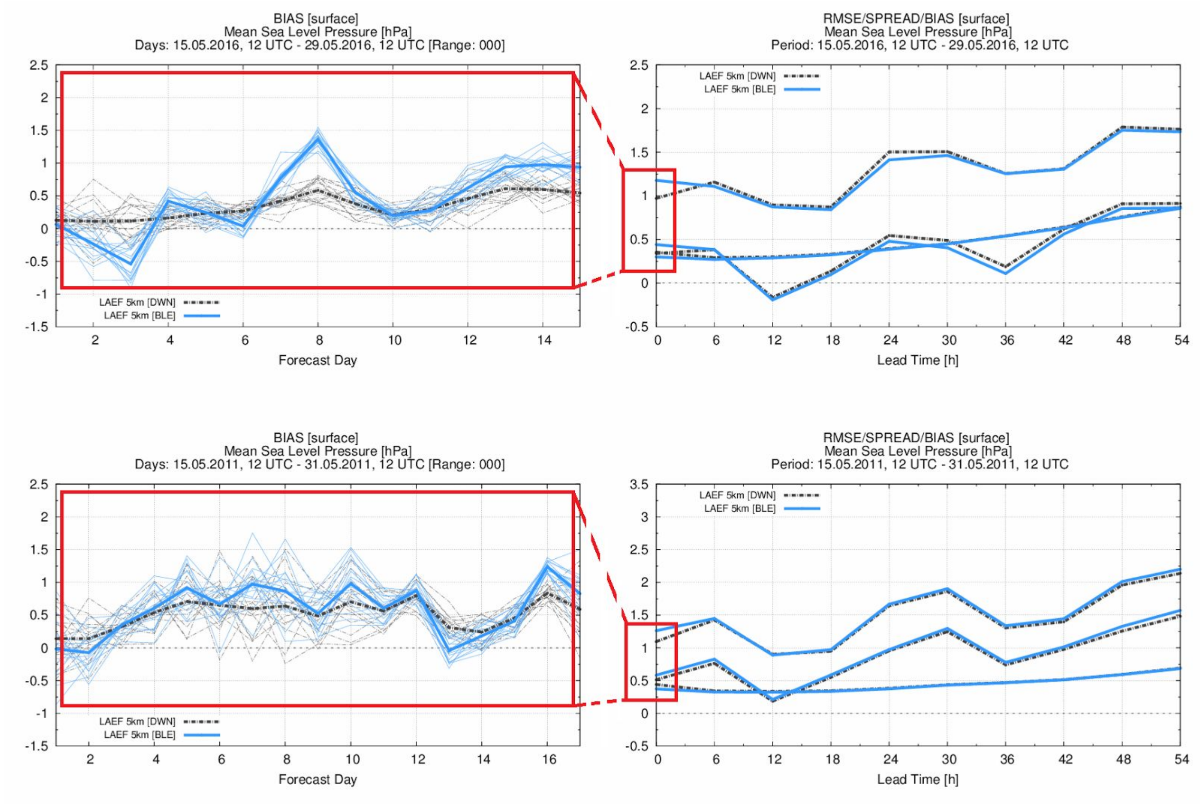

Fig.1: *The comparison of MSLP errors when LBCs were interpolated from 91 vertical levels (case 2016, first row) and from 45 vertical levels (case 2011, second row). There is BIAS for initial time along all the experiment days (left) and RMSE, SPREAD, BIAS for the forecast ranges (right). Blue line represents the blending cycle, while the gray dashed line is just the dynamical adaptation for the reference.*

Two weeks experiment was conducted at ECMWF facility for the period from 15th to 29th May 2016. This time the boundary conditions for ALADIN-LAEF were interpolated from ECMWF files containing 91 vertical levels instead of 45 (new ALADIN-LAEF has 60 vertical levels). However, as one can see in the above pictures, the results were not satisfactory. In principle, the errors are pretty much the same as for 2011 case (see Fig.1).

::II. Incremental digital filter initialization

In order to decrease the initial errors (as seen in chapter I), an &idfi function was implemented inside the blending procedure within the ALADIN-LAEF system. The general idea of incremental digital filter initialization is rather easy. We need to filter out the high frequency noise from the INIT file, while the high resolution information from the guess has to be intact. One assumes that the input short-range model guess is already well balanced and also adapted to the target model orography. Therefore, only the analysis increment is what should be really filtered. Our new analysis "*A*" is obviously a product of guess "*G*" and the increment "*I*", and once we have assumed that the increment can be written as a departure from the analysis, we will get the following equation:

(1) $A = G + (A - G)$ ...where $(A - G) = I$

Now, considering that the guess "*G*" is already balanced, we can write the equation for new filtered analysis:

(2) $A'_{filtered} = G + (A - G)_{filtered}$

(3) $A'_{filtered} = G - G_{filtered} + A_{filtered}$

Furthermore, the difference between G and $G_{filtered}$ is called "BIAS" (LBIAS=.T. in NAMINI namelist) and the product of its result and $A_{filtered}$ is called "INCREMENT" (LINCR=.T. in NAMINI namelist). A standard non-recursive Dolph-Chebyshev digital filter initialization (DFI) within the model configuration e001 is used to create $G_{filtered}$ and $A_{filtered}$. To process the incremental digital filter initialization, two calls of a function &idfi are needed.

```
print "\n[9] IDFI step BIAS (guess - filtered_guess):\n";
$start = time();
&idfi($ald_org, "null", "BIAS", $idfi_bias);
&spent($start);
```

```
print "\n[10] IDFI step INCR (filtered_blend_b +
idfi_bias):\n";
$start = time();
&idfi($blend_b, $idfi_bias, "INCR", $idfi_incr);
&spent($start);
```

The calling sequence of &idfi inside blending procedure in ALADIN-LAEF.

The input for the first step (BIAS) is our short-range guess, i.e. the same guess which has entered the blending procedure. Its filtered state then enters the second step (INCREMENT) together with the output from spectral blending (which plays the role of most recent analysis). In other words, there were added 2 subsequent steps into the ALADIN-LAEF blending procedure (steps 9 and 10).

While running on 288 CPUs at ECMWF cluster, the procedure needs about 5 additional minutes to be finished (for the new ALADIN-LAEF domain at 4.8 km, 60 vertical levels and 16 ensemble members). This is still quite acceptable from the run-time application point of view.

```
[9] IDFI step BIAS (guess - filtered_guess):
 + OK: [ICMSHBL01+0012] input file ready
 + OK: LBCs for constant coupling ready
 + OK: namelist was fully modified
 => BIAS20160515-12 is READY
--->[time spent: 00:02:20]

[10] IDFI step INCR (filtered_blend_b + idfi_bias):
 + OK: [BLB20160515-12] input file ready
 + OK: LBCs for constant coupling ready
 + OK: BIAS20160515-12 ready (ICMSHINCRBIAS)
 + OK: namelist was fully modified
 => INCR20160515-12 is READY
--->[time spent: 00:02:44]
```

The relevant output log from blending procedure with the execution times.

&NAMDFI NEDFI=7, NSTDFI=5, NTPDFI=4, RTDFI=180., TAUS=2400.,	&NAMDFI NEDFI=7, NSTDFI=5, NTPDFI=4, RTDFI=180., TAUS=2400.,

/ &NAMINI LDFI=.T., LBIAS=.T., LINCR=.F., /	/ &NAMINI LDFI=.T., LBIAS=.F., LINCR=.T., /

The appropriate IDFI namelists for BIAS step (left) and INCREMENT step (right).

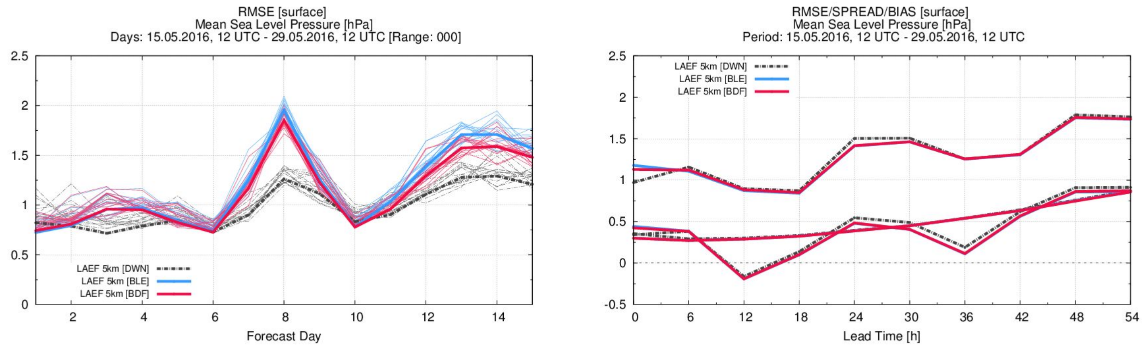

Fig.2: *The evaluation of MSLP errors after the application of IDFI for 15-days verification period. The errors at the initial time for each experiment day (left) and for the forecast ranges (right). Blue line is the original blending, while red line is blending enhanced by IDFI functionality. Gray dashed line is just the dynamical adaptation for the reference.*

It is obvious from the above figure (Fig.2), that some impact of IDFI can be observed only for the very first hours of integration at best where the errors are slightly reduced. Such behaviour was expected. Unfortunately, this hasn't solved our primary issue with the initial errors of the model fields, which are significantly higher. Those findings (in chapter I and II) led us even to the deeper investigation of the problem (proceed to the following chapter).

::III. Quadratic coupling

It was shown, that the initial errors observed in the scores of new ALADIN-LAEF system can not be eliminated neither by coupling with the higher resolution driving model, nor by additional filtration of the initial conditions by IDFI. Furthermore, a similar initial error of MSLP was observed also for Slovak pre-operational suite. What was in common for both the new ALADIN-LAEF system and Slovak pre-operational suite, was the blending procedure and model cycle (cy40t1) with the ALARO-1 physics. In order to better understand this phenomenon, we did several experiments with/without blending, with dynamical adaptation, with different physics packages, etc. Soon we have realized, that there is not only the initial error but also some strange oscillations along the whole integration (see Fig.3).

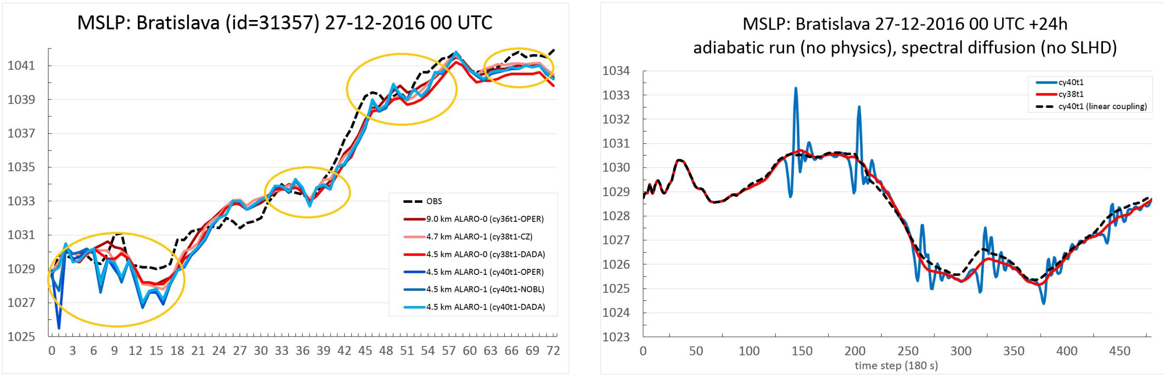

Fig.3: *The oscillations of MSLP for one selected case at Bratislava airport, with the hourly output frequency up to 72 hours (left) and for each time-step (180 s) up to 24 hours (right). The different experiments are shown (explained further in the text).*

In the figure above one case study is shown, but the presence of such problem was almost on daily bases. To cut the long story short, all the experiments on cy40t1 were spoiled by spurious surface pressure oscillations along the whole integration period. Switching off blending as a whole procedure didn't help, nor the change of vertical levels from 63 (ALADIN-SK) to 87 levels (according the CZ setup). The different IDFI settings brought no significant impact on the surface pressure oscillations, so was with the switching between ALARO-1 and ALARO-0 physics. The horizontal resolution did not play any role as well. It looked like a pretty persistent bug! (see the bluish lines in Fig.3, left)

To the contrary, in the reference runs using cy36t1 and cy38t1 there were no such surface pressure oscillations to be seen (the reddish lines in Fig.3, left).

To our big surprise, the oscillations were present even in the run without physics in cy40t1 and with switched off SLHD (i.e. in pure adiabatic run with only the spectral horizontal diffusion). To exclude the possible local installation issue (at SHMU) or compiler problems, we tested cy40t1 at ECMWF facility and also at Meteo-France cluster (thanks to Mariska) with exactly the same results! This was something absolutely unexpected, since export version of cy40t1 has been already used for 2 years.

Now, when problem was clearly localized to cy40t1 and adiabatic runs, we did one hour integration with time-step output frequency to see what really happens there. From the MSLP time evolution for selected geographical point it was clear, that nasty oscillations (~5 hPa) are present in the model on time-step bases (see blue line in

Fig.3, right). Apparently, such behaviour was quite smoothed and masked in hourly outputs. After the deeper analysis of such surprising results (big pressure oscillations repeated every ~3 hours) the coupling came into suspicion. The following picture (Fig.4) shows 2D maps of MSLP differences between the consecutive time-steps.

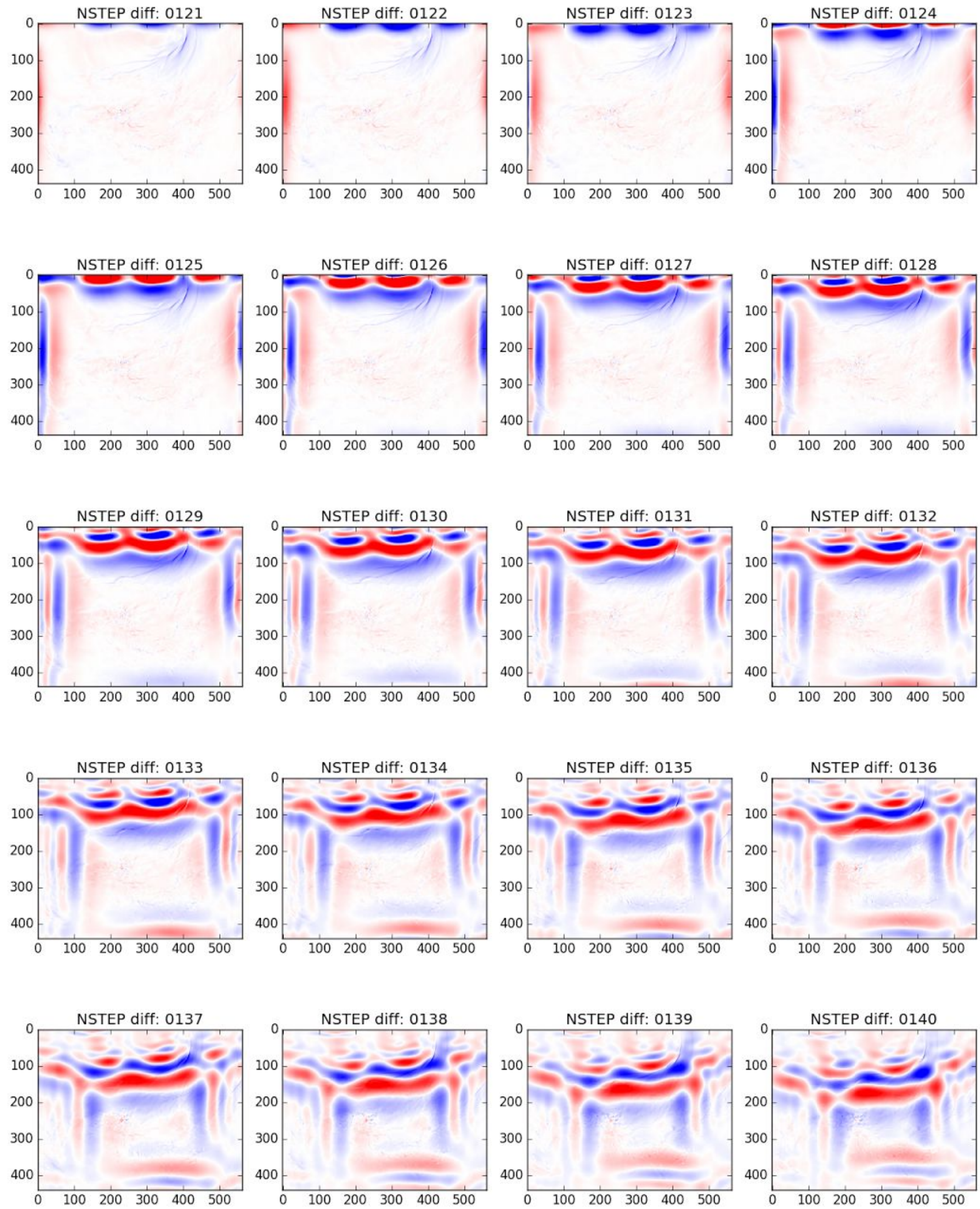

Fig.4: *The MSLP differences between the consecutive time-steps for the adiabatic run on cy40t1 with the operationally used quadratic coupling (20 steps between 6th and 7th integration hour). Images are ordered chronologically from the upper left corner to the bottom right corner.*

Suddenly, everything was clear. As one can see, the artificial signal is advected from the boundaries into the center of computational domain, with the speed roughly equal to ⅔ of the speed of sound! It was obvious, that the coupling procedure must be spoiled. Furthermore, the bug was predicted in the quadratic coupling interpolation because the first several hours of our experiment were “clean” (putting aside the spin-up effect at the very beginning). That is because the linear coupling is always used for the interpolations between the first two files and the oscillations did occur just after, when the quadratic coupling came into play (see blue line in Fig.3, right). A quick proof of such theory was an adiabatic run with turned off quadratic coupling by the namelist parameter (LQCPL=.F.). One can see in Fig.3, right, that the black dashed line is no more oscillating (cy40t1 with the linear coupling for the whole integration) be it slightly different from the cy38t1’s solution (red line). The small difference between black dashed line and red line is due to quadratic coupling used in cy38t1 (quadratic coupling in cy38t1 is obviously OK).

In short time the bug in quadratic coupling procedure in cy40t1 (and all cycles above) was discovered, fixed and reported to ALADIN community by Jozef Vivoda. The bug was related the the buffers rotation. When the condition (4) was fulfilled, the wrong coupling file has been used for the interpolations resulting in a spurious high frequency signal spreading from the coupling zone very quickly inside the center of the domain (as it was shown in Fig.4).

(4) $NSTEP = TEFRCL / TSTEP - 1$

This happened repeatedly every *NSTEP* according (4), i.e. always 1 integration step prior the coupling file validity. Depending on given synoptic situation, such discrepancy could have been bigger or smaller, but still present.

::Conclusions

An extensive investigation of the ALADIN-LAEF issue led us to the important discovery of strange bug in the quadratic coupling procedure in cy40t1 and the cycles above. This is indeed beneficial for the whole ALADIN community, but we believe that it explains also our unsatisfactory results with the new ALADIN-LAEF system. Thanks to the nature of given bug, the most spoiled model state was unfortunately pushed to the blending cycle as the first guess. Moreover, such high-frequency noise could not have been filtered out by blending. However, it was already beyond the scope of this stay to re-run EPS experiments, hence the bug-fixed code needs to be tested in ALADIN-LAEF configuration to prove such conclusion.