Working Area Dynamics & Coupling

Progress Report

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Progress summary

This report summarizes the work done in the Area of Dynamics and Coupling of RC LACE during the whole year 2016. The first part covering the work being done from January 2016 till September 2016 is only summarized and may be found in more details in the previous report from September 2016 on RC LACE web pages.

Scientific and technical main activities and achievements, major events

Let us mention the biggest achievements in the tasks planned for the year 2016.

Task 1. VFE NH

Subject: 1.1 Design of vertical finite elements scheme for NH version of the model

Description and objectives: The main objective of this task is to have a stable and robust vertical finite elements (VFE) discretization to be used in high resolution real simulations with orography with the expected benefit being the enhanced accuracy for the same vertical resolution when comparing with vertical finite differences (VFD) method. We want to stick as much as possible to the existing choices in the design of dynamical kernel (SI time scheme, mass based vertical coordinate) and to stay close to the design of VFE in hydrostatic model version (according to Untch and Hortal).

Executed efforts: 2x1 month research stay of Jozef Vivoda at CHMI, Prague; 2x2 weeks of research stays of our HIRLAM colleagues (Juan Simarro, Álvaro Subías) at CHMI, Prague, 3 months of local work (Jozef Vivoda, Petra Smolíková)

Status: The following steps towards efficient Finite Element Scheme in the vertical discretization of ALADIN NH version have been achieved:

1) **Phasing of development** into export version 40t1_bf5.

2) **Clean merge with the new switches from** Álvaro Subías: LVFE_DDI and LVFE_GSN for the definition of vertical operators based on projection from FD to the spline space and satisfying the (C1) constraint; these operators could bring back the possibility to eliminate all the prognostic variables but one in the Helmholtz equation and solve the inversion problem without iteration. This is work in progress.

3) **Testing the vertical operators which satisfy the (C1) constraint** in the standard 2D vertical plane tests: potential flow, flow over Agnesi shaped mountain and Straka test. This work depends on the progress made in the implementation of vertical operators satisfying the (C1) constraint by Álvaro Subías from AEMET. The current

implementation suffers from several problems resulting in noisy solutions of standard 2D vertical plane tests. Since Álvaro Subías has left the area of dynamics at the end of 2016 it is questionable who might finish the work.

4) **Work on article to be posted to MWR**: Juan Simarro was working on the text improvement and we discussed the way of testing the new scheme and the whole content. This is work in progress.

5) **Fixing the definition of vertical integral operators** to satisfy natural conditions for constant function integration.

6) **Revised definition of knots and explicit values of hybrid vertical coordinate η on model half and full levels using minimization of a given cost function**: The position of knots is based on the position of maxima of splines used for the definition of basis under the key LVFE_MAXIMAS=.T., or on a Greville abscissa under the key LVFE_MAXIMAS=.F. The result of the new procedure is that B-spline basis of order C-1 has maxima of splines on the full model levels, while the B-spline basis of order C has the maxima of splines on the model half levels, where C is the namelist parameter NVFE_ORDER representing the order of B-splines. The minimization uses the standard MINPACK routine LMDIM1.

7) **The clean implementation of the key LVFE_APPROX** for the non-oscillatory approximation of functions based on Schoenberg VDA algorithm which provides more stable and less noisy solution then previously implemented interpolating polynomial while keeping still high order of accuracy.

8) **Revised definition of m*, A and B** used for model levels definition which satisfies three important relations, see report of Jozef Vivoda. The new definition enables the whole vertical discretization to profit from properties which may lead to better accuracy and less noise production.

9) **Revised formulation of pressure gradient term** in horizontal and vertical momentum equation in a way that the real pressure depth is treated consistently.

10) **Design of an interface routine** for the integration and derivation (VERDISINT) with the aim to choose only parameters of the desired operation when applying vertical operators and to keep details of the operator´s definition as the internal procedure to the interface routine: The application of vertical derivative and integral operators should become easy and without long decision trees inside. This is work in progress.

11) With the use of revised definition of knots and model half and full levels, the choice of invertible operators with fixed sequence of knots has been designed under the key LVFE_FIX_ORDER=.F. which enables **the usage of staggering of *gw* in the FE scheme**,

similarly as it is done for FD. The modification appears under the switch LVFE_GW_HALF. Unfortunately, a noise appears in the solution of standard 2D vertical plane tests when this modification is switched on. The problem needs further investigation.

The topic is still ONGOING.

Task 2. SL scheme

Subject: 2.1 Application of ENO techniques to semi-Lagrangian interpolations

Description and objectives: High order semi-Lagrangian interpolations, in 1D typically represented by cubic Lagrange polynomial on 4-point stencil, are not monotonic and produce spurious overshoots in the vicinity of discontinuities or sharp gradients. Their quasi monotonic version exists, but simple cut off procedure reduces accuracy dramatically. However, if interpolation stencil is extended to 6-points, 3rd order ENO (Essentially Non-Oscillatory) interpolation could be applied. It is able to reduce spurious oscillations/overshoots while keeping high order of accuracy uniformly. Aim of the work is to implement ENO interpolation technique in ALADIN and evaluate its performance/cost. A first study of the problem has been already done in 1D – linear advection toy model, and for quadratic interpolators in 2D vertical plane model. Quadratic interpolators have been found too smoothing, but 1D experiments show promising results for cubic interpolators, or WENO technique in which interpolators are combined depending on the advected field. We continue in the already started work.

Executed efforts: 1 month stay at CHMI, Prague (Alexandra Craciun), 1 month of local work (Alexandra Craciun, Petra Smolíková)

Status: The cubic ENO technique has been implemented in 2015 to the code of ALADIN and shortly tested. As the next step we decided to implement a variation of this method called WENO (Weighted Essentially Non-Oscillatory) scheme where instead of choosing the "smoothest" stencil possible, the weighted sum of values interpolated on several stencils is used with weights based again on smoothness evaluation. Moreover, the weights can be chosen in such a way that in smooth regions it approaches certain optimal weights to achieve a higher order of accuracy (5^{th} in our case), while in regions near discontinuities the stencils which contain discontinuities are assigned a nearly zero weight. ENO schemes are not cost effective on vector supercomputers because the stencil-choosing step involves heavy usage of logical statements, which perform poorly on such machines.

On the other hand, WENO scheme completely removes the logical statements that appear in the ENO stencil choosing step. As the result, WENO scheme appear to be much faster than ENO scheme on vector machines. This year we implemented the third order WENO interpolation technique through several alternative definitions of the smoothness parameter found in literature. The implementation of the method was based on the previous work. We compared the WENO scheme with the classical cubic Lagrange interpolation and cubic ENO scheme in several 2D vertical plane tests based on warm bubble in the field of homogenous potential temperature.

Unlike in 1D case, remaining under/overshooting is present in the 2D bubble test results for all proposed definitions of the WENO scheme, even if having various intensity. We may say that interpolations are subject of a tradeoff between accuracy and noise production near discontinuities. More smoothing schemes give less over/undershoots while more accurate results suffer from noise created near sharp gradients or discontinuities in the interpolated field. The results show that the WENO scheme, for all definitions of smoothness indicators and other parameters tested, produces smoother solution than cubic Lagrange interpolator while under/overshooting is not completely eliminated. It seems to us that slight improvement in the production of over/undershoots observed for the best behaving choice of the smoothing parameters does not compensate the increase in the computational cost of the new WENO scheme compared to the classical cubic Lagrange solution.

The topic is FINISHED.

Subject: 2.2 COMAD weights for SL interpolations

Description and objectives: The COMAD weights have been designed at ECMWF (Sylvie Malardel). The linear and cubic semi-Lagrangian weights are modified to take into account the deformation of air parcels along each direction, with deformation factor defined with the respect to the local velocity in the given direction and the time step used. The proposed modification had a positive impact on the objective scores of the IFS runs and on the AROME 1.3km runs. We would like to know if we may get some benefit from this modification for the local model ALARO.

Contributors: Petra Smolíková (Cz)

Executed efforts: 1 month of local work

Documentation: **report published on the RC LACE web pages**

Status: The COMAD weights modification has been implemented in the cycle CY41 which is not available to the most of the services of RC LACE for available computer resources reasons. To test the modification we have back phased this code to the cycle CY38t1 for which there is the ALARO-1 physics package with bug fixes for radiation and turbulence scheme available. This code has become a branch in the CVS versioning system of CHMI. As the testing case the meteorological situation described in the paper [1] of Sylvie Malardel was used with slightly different domain over the Alpine region, with 1.25km horizontal resolution and 87 vertical levels of the Czech operational application. First, we tried to get the grid-point storms which were created with AROME 1.3km version and Météo France operational setting. It has turned out that this is not possible if ALARO physics is applied, neither with deep convection parametrization being a part of the 3MT package, nor with the so called STRAPRO parameterization restricted to stratiform precipitation and avoiding any deep convection parameterization.

It shows that even if such grid-point storms may originate in dynamics, the interaction between dynamics and physics (divergence/convergence etc.) is crucial for their further evolution. With ALARO physics, even if some grid points with stronger convection have appeared in the beginning of integration, they were not persisting for more than two hours. The usage of COMAD was not important for their appearance and disparition. Moreover, similar role may be played by SLHD (semi-Lagrangian horizontal diffusion) which works against sharp gradients in the interpolated fields depending on the flow deformation and hence it has local character as well. We believe that COMAD weights in SL advection are not needed when ALARO physics is used.

The topic is FINISHED.

[1] *Malardel S., Ricard D. 2015: An alternative cell-averaged departure point reconstruction for pointwise semi-Lagrangian transport schemes, Q. J. R. Meteorol. Soc. 141, 2114-2126.*

Task 3. Horizontal diffusion

Subject: 3.1 Tuning and redesign of the horizontal diffusion depending on the scale

Description and objectives: A numerical diffusion has a significant role among the other mixing parameterizations since it must be present from planetary to viscous scales, mimicking the continuation of the energy cascade at the end of model spectrum and simulating residual processes which are not well captured by other parameterizations, as well as acting to filter-out unwanted discretization noise. The SLHD (semi-Lagrangian horizontal diffusion) is a flexible tool to represent the numerical diffusion in the model which was proven to be well working throughout a wide range of resolutions. Nevertheless, this tool has an enormous number of tunable parameters and includes not only flow dependent grid-point diffusion, but a supporting spectral diffusion as well. The behavior of the whole scheme in high resolutions appears to be not understood well. The topic covers the proposal of an experimental setup enabling to test schemes in multiscale environment, developing tools to diagnose energy and entropy in the model system and SLHD tuning to get a consistent and scale invariant parameterization of mixing processes. For the start of the work, the diffusion coefficient used in SLHD and being a monotonic function of the total flow deformation along the terrain-following vertical levels will be redesigned.

Executed efforts: none

Status: The topic is POSTPONED to 2017 for non-availability of the dedicated workforces.

Task 4. Evaluation of the model dynamical core in very high resolutions

Subject: 4.1 Clear comparison of SETTLS and ICI time schemes

Description and objectives: On workshops, during meetings with our colleagues from ALADIN, HIRLAM and ECMWF, in email exchanges, we are facing complaints on the speed, affordable timestep, computational time requirements and stability properties of the centred iterative time schemes (called PC scheme) developed under the RC LACE auspices. In 2011, a study of Filip Váňa has shown problems which may be faced when using alternative non-iterative 2-time-level scheme called SETTLS. From our case studies we believe that iterative schemes offer better stability properties than SETTLS without danger of creating spurious oscillations. We would like to compare time schemes available in the code of ALADIN/ALARO/AROME model and show benefits and drawbacks of them in a clear and convincing way.

Contributors: Petra Smolíková (Cz), Jozef Vivoda (Sk)

Executed efforts: 1 month of local work

Documentation: none

Status : It was reported that LPC_FULL scheme with reiteration of SL trajectories produce noisy solution. We have confirmed these results. We tried to understand this fenomenon. As we increase the model horizontal resolution, the local divergence can increase significantly and the Lipschwitz criteria may be broken locally. Then the trajectory search may become divergent. Then the increase in the number of iterations in the process to search for a SL trajectory may lead to even less accurate solutions. Similar problems have been identified at ECMWF in IFS and fixed by local change of the computation of the half level wind. These considerations should be confirmed in more detailed study. We propose to follow up with the new topics **3.2 The trajectory search in the SL advection scheme** and **3.3 Dynamical definition of the iterative time schemes** in the next year.

Moreover, we discovered that default values for the LPC key are not correctly set for GFL fields being subject of the advection. For all advected GFL fields X one has to set YX_NL%LPC=.T. and YX_NL%LPT=.T. when using LPC_FULL scheme. In forthcoming cycles we will iniciate the correction of default values for « new » GFL fields in physics (ALARO) to avoid usage of wrong value if not fixed in the namelist. For « old » GFL fields the correct value is already set.

The topic is ONGOING.

Subject: 4.2 Upper boundary conditions

Description and objectives: Mariano Hortal (HIRLAM, Spain) has introduced upper boundary nesting based on Davies relaxation similar as it is used on lateral boundaries. He has shown that this relaxation helps to get rid of upper level explosions observed in real cases for SETTLS time scheme. We would like to understand better the behaviour on the upper boundary and its interaction with PC time scheme used in most operational applications.

Contributors: Petra Smolíková (Cz)

Executed efforts: 1 month

Documentation: **report published on the RC LACE web pages** [Petra Smolíková, Namelist dynamic parameters for high resolution experiments, 2015].

Status : Regarding computational price paid, the SETTLS scheme is the most cheap one and it is extensively used in operational installations of ALADIN/AROME/ALARO model among various services for horizontal resolutions above 3km. For higher resolutions, this simple and cheap solution may become unstable as referred to in many studies. It was shown by Mariano Hortal that in some cases this instability originates in the reflection from the upper boundary. There was a proposal to apply the Davies relaxation on the upper boundary similarly as it is applied in the LAM model on the lateral boundaries via coupling. Hence the upper boundary levels are relaxed to LBC files being results of a run of a global model, ARPEGE in our case. The idea of upper boundary relaxation has been implemented by Mariano Hortal on the base of cycle cy38t1.

We have slightly modified this implementation with the aim to introduce a new namelist parameter NBZONZ being the width (or better "the height" in this case) of the relaxation zone in the vertical. The upper boundary relaxation is switched on by the key LUNBC=T. The relaxation coefficients have not yet been adjusted to the non-uniform spacing of the vertical levels and are calculated as for the regular spacing. Nevertheless, we have modified the relaxation coefficients and the sensitivity to this tuning was very weak.

Then we have been testing the SETTLS time scheme with distinct choices of NBZONZ parameter in a real case study of an orographic wave over the western Czech boundary from 27 January 2008, 00UTC. We integrated for 24 hours with the horizontal resolution of 1.25km, 87 vertical levels of a Czech operational application and a timestep of 20s. Despite the fact that for the case of the orographic wave the most unstable parts are in the higher atmosphere, to eliminate them we would have to use too big NBZONZ. It means to apply the relaxation on too wide part of the atmosphere. Moreover, for the prolonged timestep of 50s, the relaxation on the upper boundary is not able to stabilize the scheme at all.

Nevertheless, on the kinetic energy spectra we may see that in upper levels (20th vertical level) there is a peak in all the experiments using the SETTLS scheme regardless of the upper boundary relaxation used, while results of the experiment with iterative time scheme (and SLHD applied) coincide with the results from the global model ARPEGE used as lateral boundary conditions. In central vertical levels (50th vertical level), all experiments coincide with LBC results, and near the ground (80th vertical level), all experiments coincide but differ from LBC results.

As a consequence, it seems that SETTLS scheme is not able to produce stable results for higher horizontal (and consequently vertical) resolutions even with the upper boundary relaxation applied and it is necessary in some cases to apply iterative time schemes (so called PC scheme). See the report for further details.

The topic is ONGOING in modified version.

Documents and publications

Six reports describing the results achieved are published on the RC LACE web pages:

1) Jozef Vivoda, Vertical finite element discretization in NH kernel of model system AAA, 2016
2) Juan Simarro, 2016
3) Álvaro Subías, Testing B-splines as a tool to solve constraints in ALADIN-NH, 2016
4) Alexandra Craciun, Application of ENO technique to semi-Lagrangian interpolations, 2016
5) Petra Smolíková, Testing COMAD correction of interpolation weights used in SL advection scheme with ALARO physics in high resolution experiments, 2016
6) Petra Smolíková, Namelist dynamic parameters for high resolution experiments, 2015

Activities of management, coordination and communication

1) **Joint 26th ALADIN Workshop & HIRLAM All Staff Meeting 2016**, 4-8 April, Lisbon, Portugal – presentation of Petra Smolíková “Dynamics in LACE”
2) **Dynamics Working Days**, 13-24 June 2016, Prague, Czech Republic, with four participants from CHMI (Petra Smolíková), SHMI (Jozef Vivoda) and AEMET (Juan Simarro, Alvaro Subias).
3) **38th EWGLAM – 23rd SRNWP EUMETNET Meetings** in Rome, Italy, 3 – 6 October 2016 -– presentation of Petra Smolíková “Dynamics in LACE”
4) **Dynamic Day**, 25 November 2016, Toulouse, France - participation of Petra Smolíková and Jozef Vivoda

LACE supported stays in 2016

1) Alexandra Craciun, NMA, Romania - 1 month in Prague (CHMI), 9 May – 3 June 2016
2) Jozef Vivoda, SHMU, Slovakia - 1 month in Prague (CHMI), 30 May – 29 June 2016
3) Álvaro Subías, AEMET, Spain – 2 weeks stay in Prague (CHMI), 13-24 June 2016
4) Juan Simarro, AEMET, Spain – 2 weeks stay in Prague (CHMI), 13-24 June 2016
5) Jozef Vivoda, SHMU, Slovakia - 1 month in Prague (CHMI), 06 November – 03 December 2016

Summary of resources/means for the whole year 2016

The total effort invested into the area of Dynamics&Coupling in frame of LACE in 2016 is 12 person/months, 4 person/months from that as scientific stays. This amount almost fulfils the plan for 2016. One scientific stay was postponed to the next year. Several topics have been finished and we expect to start new topics in the next year or years.

Task	Subject		Resources		
			Planned	Executed	Stays (Planned/ Executed)
1. VFE NH	1.1	Design of VFE in NH model	6	7	2/3
2. SL scheme	2.1	Application of ENO technique in SL interpolations	2	2	1/1
	2.2	COMAD weights for SL interpolations	1	1	0/0
3. Horizontal diffusion	3.1	Tuning and redesign of the horizontal diffusion depending on the scale	2	0	1/0
4. Evaluation of the dynamical core in very high resolutions	4.1	Clear comparison of SETTLS and ICI time schemes	2	1	0/0
	4.2	Upper boundary conditions	1	1	0/0
Total manpower			**14**	**12**	**4/4**

Problems and opportunities

There exists a fruitful cooperation between the Dynamics group in RC LACE and in HIRLAM. It would be nice to have new power on the side of RC LACE to be able to progress in work on ongoing or new topics.