Working Area Dynamics & Coupling

Progress Report

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Period:	01/2014-08/2014
Date:	10/09/2014

Progress summary

In 2014, work has been continuing on the main topics in the Area of Dynamics&Coupling, as the implementation of finite elements in the vertical discretisation of NH model. We expect to continue the work on other topics at the end of this year (physical tendency of vertical velocity in NH). We have started several new topics as the application of ENO technique in the SL interpolations and tuning of SLHD for high resolution runs of model ALARO. We feel as a success that our young colleagues started to work with us on dynamics and we hope to continue in this appreciated trend in the future.

Concerning our already established collaboration with HIRLAM group of dynamics, we have had a calm period in 2014, but we expect to meet our colleagues from HIRLAM in Valencia during the dynamics working days in October 2014.

Two stays have been realized during the first half of 2014, Jozef Vivoda (Sk) and Alexandra Craciun (Ro) have been working with us at CHMI in Prague, and we expect to host David Lancz (Hu) at the end of 2014 again in Prague.

Scientific and technical main activities and achievements, major events

Let us mention the biggest achievements in the planned topics and illustrate them by several figures.

Task 1. VFE NH

Subject: 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: JV – 2.5 months (1 month of local work, 1.5 months - LACE stay at CHMI, Prague), PS – 2.5 months (local work); total 5 months

Estimated efforts: JV – 3.5 months (2 month of local work, 1.5 months - LACE stay at CHMI, Prague), PS – 3.5 months (local work), total 7 months

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

Documentation: report from stay, draft of paper for further publication

Status: As the most important task for the year 2014 it was identified the need to explain in details why the currently implemented version of VFE in NH model (cy40t1) works and what are its benefits. For this reason we have concentrated ourselves on the theoretical explanations and studies of the current method choices. We describe in short the conclusions achieved.

The eigenvalues of discrete vertical Laplacian term have been studied. In order to ensure stability for centred implicit time scheme, these eigenvalues have to be real and negative. Two different expressions of vertical Laplacian term were taken into account, one with first derivative operator applied twice and second with two applications of the first derivative operator and one application of the second derivative operator. On the simplest possible vertical discretisation of the domain being derived from five regular eta levels it was concluded that only with the second form of vertical Laplacian definition and with imposed

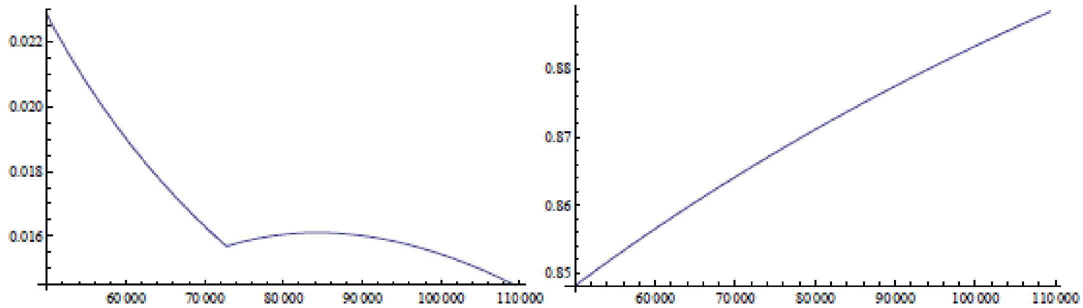

Figure 1: The spectral radius of the matrix for discretized vertical operator C1 as a function of surface pressure for two different FE discretisations of the vertical integral. Left: Stiff matrix calculated from the top, right: stiff matrix calculated from the bottom; both with first derivative set to 0 on the top and bottom boundary.

bottom boundary conditions on the used vertical operators one can reach real and negative eigenvalues of the whole Laplacian. Furthermore, it was shown that eta levels must be regularly placed (not used in real applications) or their placement has to be denser towards the bottom of the vertical domain. The crucial boundary condition imposed on operators used in the vertical Laplacian definition was identified in the bottom level of first derivative operator (zero value is implicitly imposed through the input spline bases definition).

Properties of vertical integral operator have been studied as well with respect to the fulfilment of the so called C1 constraint. It was shown that if the stiff matrix for the vertical integral operator is calculated directly from top to the η level (instead of being calculated from bottom to the η level and subtracted from the whole integral from bottom to the top) then the spectral radius of C1 operator may be significantly reduced; see Fig.1. The first derivative is imposed to be 0 on top and bottom of the domain through the spline bases functions definition and the value of the integral on the top is prescribed again to be 0 (the value of integral being 0 on the bottom for the definition of integral from the bottom). The modified discretisation of vertical integral operator was implemented into the code of the model.

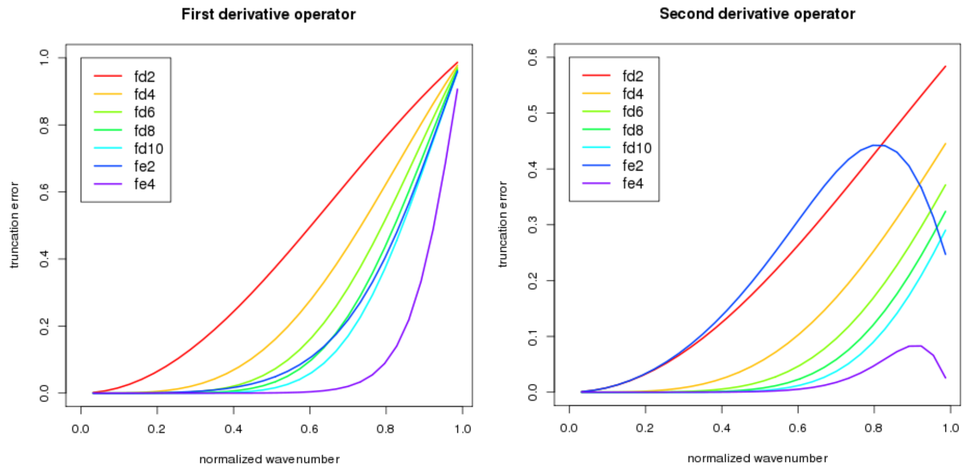

Figure 2: The absolute value of the truncation error of first and second differential forms determined by approximation of given functions by Taylor series expansion in terms of Fourier components for different finite difference (fd) and finite element (fe) discretisations with uniform resolution (after Staniforth and Wood); in the legend the number indicates the order of scheme used.

The accuracy of all vertical operators has been studied carefully. It was shown by approximation of given splines by Taylor series expansion in terms of Fourier components (by Staniforth and Wood) that the truncation error of the FE first derivative and integral operators of order 4 (cubic splines) is 8 (this phenomenon being called *superconvergence*)

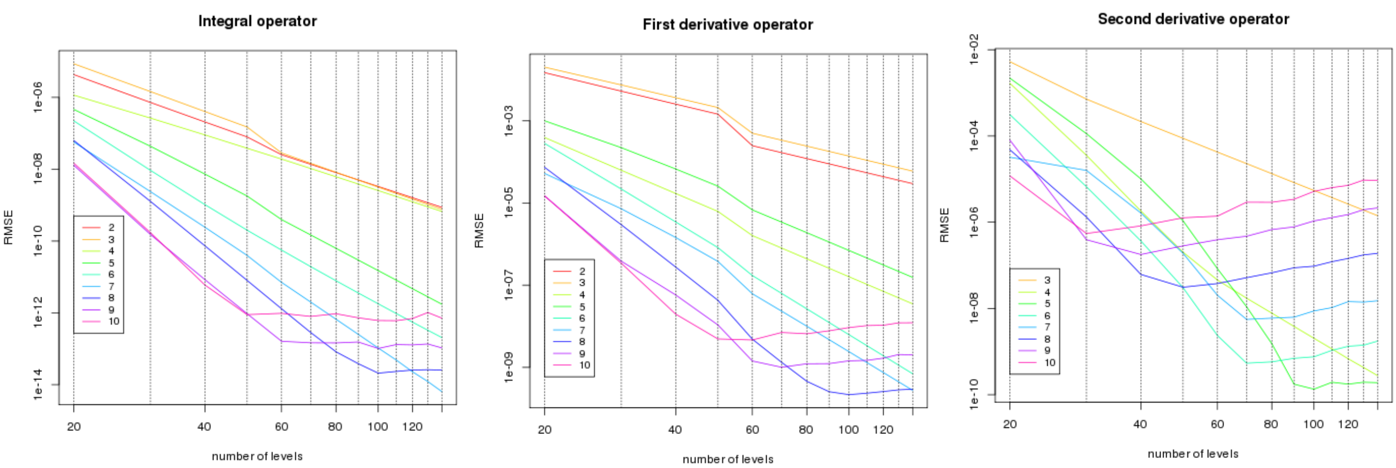

Figure 3: Root mean square error for the whole domain for vertical operators, the colour scale gives the order of splines used for FE discretisation.

for uniformly placed η levels with ignored top and bottom boundary effects. We showed that the truncation error of the second derivative operator calculated under the same conditions for the same η levels placement is only 6. Truncation errors for several discretisation method and derivative operators may be seen on Fig.2. Moreover, we have shown that this results are in good agreement with the real accuracy of vertical operators being applied on smooth function $sin(6\pi\eta)$ with uniformly placed η levels and ignored top and bottom boundary effects. We have to admit that the vertical derivative operator which transforms a function defined on half levels to a function being defined on full levels which is used for vertical velocity *w* has truncation error only 4, since there is no superconvergence effect.

The code has been again cleaned and a new key LVFE_FIX_ORDER has been introduced. For this key being set to "TRUE" knots are calculated for any vertical operator independently with regards to the boundary conditions imposed on it. For LVFE_FIX_ORDER=FALSE, the knots are calculated first and the order is determined from the number of internal knots (the mandatory option for invertible operators defined for integral and derivation according to the proposition of Alvaro Subias).

Since an arbitrary choice of the order of splines used for FE discretisation has been enabled recently, we have investigated RMSE of distinct vertical operators applied on a smooth function depending on the order and number of vertical levels. We may observe strong "saturation" for higher orders and vertical resolutions, see Fig.3. We see the explanation in rounding error cumulation for needed high number of operations.

We expect to use these results and conclusions in the prepared publication. There are still remaining tasks planned for the near future which are described in details in the work plan for 2015.

Task 2. Physics-dynamics interface

Subject: 2.1 Feasibility study to add the physical tendency of vertical velocity to the adequate prognostic (NH) variable

Description and objectives: For parameterization schemes used in HPE systems, the horizontal momentum 'feels' the sub-grid effects of mountain drag, turbulence and convection. The impact of these processes on the vertical momentum in the case of NH dynamics has to be reconsidered.

Executed efforts: none

Estimated efforts: 1 month (LACE supported stay at CHMI, Prague), 0.5 month of local work (CHMI)

Contributors: David Lancz (Hu), Petra Smolíková (Cz)

Documentation: none

Status: planned for October-November 2014

Subject: 2.2 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 was 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 accuracy uniformly. Aim of the work was to implement ENO interpolation technique in ALADIN and evaluate its performance/cost.

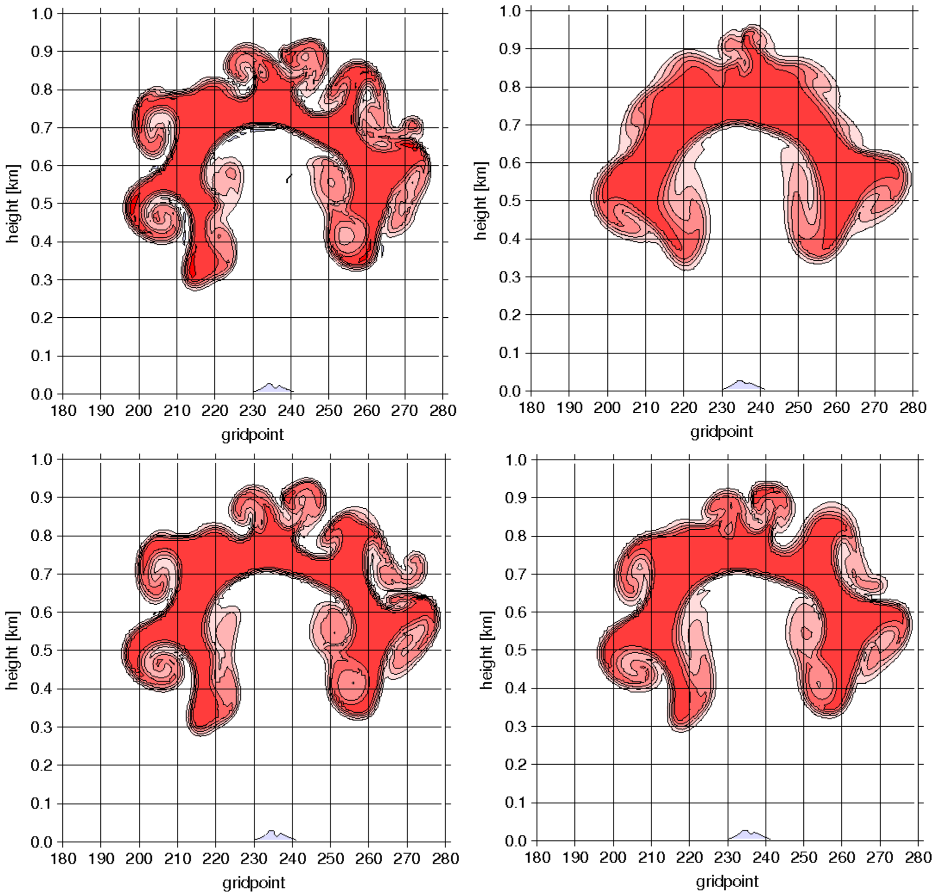

Figure 4: Sharp warm bubble (+0.5K) in the field of constant potential temperature (300K) advected with the speed of 2m/s. Upper left: quadratic Lagrange interpolator, upper right: quadratic interpolator with ENO, lower left: cubic Lagrange interpolator, lower right: quadratic interpolator with WENO.

Executed efforts, contributors: Alexandra Craciun (Ro) – 1 month, research stay at CHMI, Prague; Ján Mašek (Cz) – 0.5 month (local work)

Documentation: progress report, published on the RC LACE web sites

Status: An extension of the SL stencil to 6-point one was found to be technically very demanding. On the other hand it was found that the same ideas may be tested for quadratic interpolators on the existing 4-point stencil in the full model or in its 2D vertical plane simplification. Hence it was decided to start with the task to implement different proposed interpolators in their quadratic version in the full model and compare them in classical Robert experiment of an advected or non-advected cold and warm bubble.

It can be concluded from the tests made that the second order ENO interpolation produces a very smooth solution which may not be used in practice. On the other hand, it was shown that the weighted variant, the WENO scheme, could lead to better results. Another advantage of this scheme would be the higher accuracy. See Figure 4 for an illustration.

Another tested method was the application of the mixture of accurate enough cubic Lagrange interpolator in smooth parts of solution and non-overshooting linear operator in the vicinity of discontinuities. The idea is similar as the one used for SLHD, but the advected field itself is considered instead of the deformation field as the indicator of weights for the two interpolators combination as it is done in SLHD.

Comparative tests of proposed and currently used interpolators have been made in a toy system – 1D linear advection scheme. See Fig.5 for an illustration.

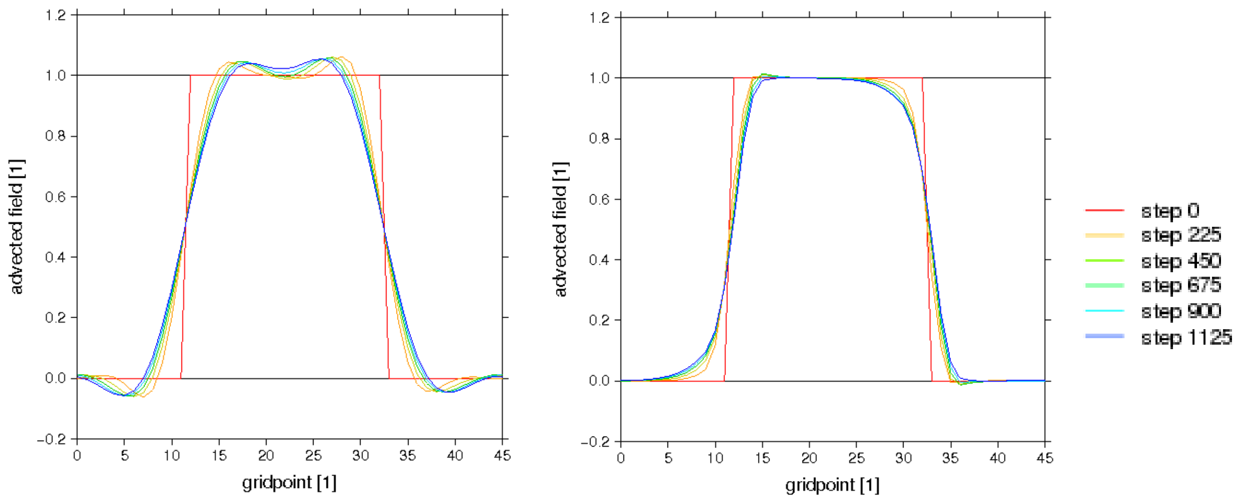

Figure 5: Linear advection of a rectangular pulse in periodic domain. Left: cubic Lagrange interpolator, right: cubic Lagrange interpolator with ENO technique.

Even if cubic Lagrange interpolator with ENO stencil was not yet implemented in full model, results obtained with 1D linear advection equation demonstrate its clear superiority over other tested approaches. See Figure 5 for an illustration. One can thus hope that it will provide an improvement in the resistibility against deformations caused by quasi-monotonic treatment or constant background advection. Taking this into account we consider this technique promising and worth to be tested in 2D or 3D experiments despite of being technically and computationally demanding. This work is left for future research.

Subject: 2.3 Design of the ideal share between the horizontal turbulence and numerical 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 is a flexible tool to represent the numerical diffusion in the model. On the other side there is the horizontal extension of the scheme for vertical diffusion called TOUCANS as a tool for the horizontal turbulence control. 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.

Executed efforts: 2 months of local work

Contributors: Petra Smolíková (Cz)

Documentation: none

Status: During realization of the Grey zone experiment in the cascade of horizontal resolutions from 16km to 1km (Radmila Brožková) problematic behaviour of the model ALARO has been observed for higher horizontal resolutions in the higher vertical levels. This

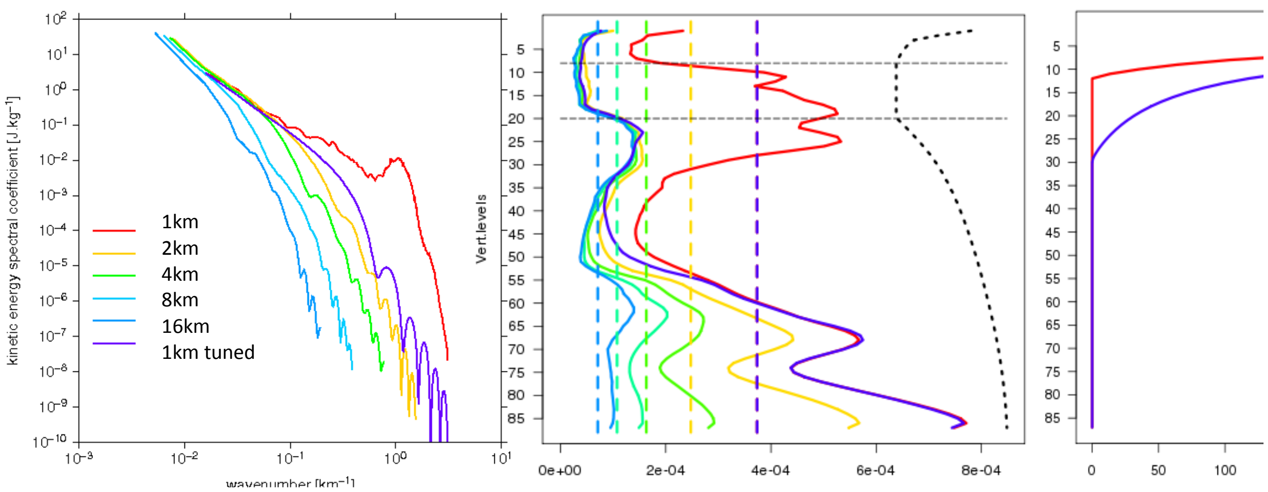

Figure 6: Left: the spectrum of kinetic energy for the Grey zone experiment in the cascade of horizontal resolutions; middle: the 75th percentile of the field of deformation calculated as an average over the whole horizontal domain (the color scale as on the left picture; black dashed line shows the vertical profile of temperature in the standard atmosphere calculated from the SI background values and given vertical levels); right: vertical profile of the reduced spectral diffusion coefficient (red – original tuning; blue – new tuning).

behaviour demonstrates itself in the spectrum of kinetic energy as an energy increase for higher wavenumbers (see Fig. 6). As a result several fields are numerically deformed as high level cloudiness (see Fig. 7) or cumulated precipitation. Since in the model ALADIN/ALARO/

AROME there is a powerful tool for the elimination of numerical noise called SLHD (semi-Lagrangian horizontal diffusion scheme) with a big number of tuning parameters, it was decided to tune SLHD for the given experiment. SLHD has three main components; gridpoint part, supporting spectral diffusion and reduced spectral diffusion with damping enhanced with the height. For the given experiment we got satisfactory results with changed vertical profile of the reduced spectral diffusion coefficient (SLEVDH = 0.4, RRDXTAU = 31.; original values being SLEVDH = 0.1, RRDXTAU = 123.).

The vertical profile of the field of deformation has been studied then and it was found that for the given case there is an enormous increase in this field in the tropopause and close under it. The new tuning of SLHD helps to reduce this increase by starting the reduced spectral diffusion under the tropopause. See Fig. 6(middle) for the illustration of the problem.

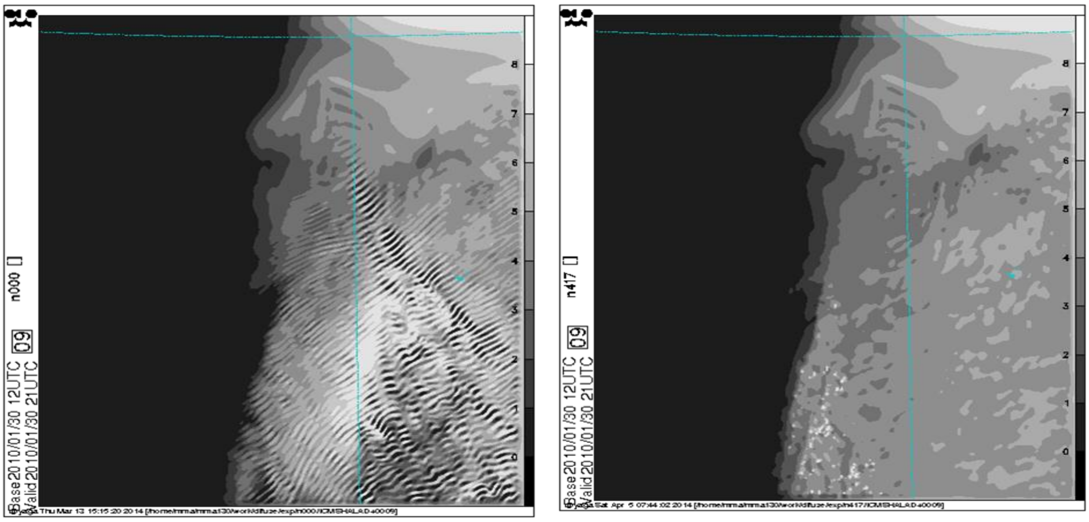

Figure 7: The high cloudiness field for the original SLHD setting (left) and the new setting (right).

Since SLHD is a tool with autotuning developed for changing horizontal resolution, further investigation is needed to keep this feature working even in very high resolutions. We find this topic as urgent and expect intense work being done in 2015 on it.

Task 3. 1D2D turbulence scheme for ALARO

Subject: 3.1 Scientific validation of 1D2D turbulence

Description and objectives: Scientifically correct behaviour of the whole 1D2D system is a necessary condition needed to be satisfied to be able to fulfil further tasks. It follows that the compliance of the whole 1D2D turbulence scheme behaviour with the laws for transport of energy from bigger to smaller scales has to be carefully examined. Energy spectrum study is foreseen as an instrument for such validation. Preparation of a testing environment is considered as a part of the issue.

Executed efforts: none

Contributors: Ján Mašek (Cz)

Documentation: none

Status: POSTPONED TO 2015
The work has not been started yet for the reason of tasks in 2D turbulence not being finished yet and due to no availability of the dedicated workforce.

Subject: 3.2 Tests in <1 km resolutions

Description and objectives: As soon as the previous task is successfully finished, academic tests with the full model may be targeted to further study scheme behaviour and its interconnection with other model parts. Very fine horizontal resolutions (subkilometric) are needed for such tests.

Executed efforts: none

Contributors: Ján Mašek (Cz)

Documentation: none

Status: POSTPONED TO 2015
The work has not been started yet for the reason of tasks in 2D turbulence not being finished yet and due to no availability of the dedicated workforce.

Task 4. LBC coupling strategy

Subject: Rapid changes in surface pressure field

Description and objectives: Interpolation in time applied on LBC data of the large scale model to get the data on lateral boundaries for each timestep of a LAM distorts the model fields and can lead to LAM forecast failures in case of fast propagating storms. The analysis of the MCUF (Monitoring the Coupling-Update Frequency) field from ARPEGE coupling files for the common LACE coupling domain may help to monitor the occurrence of such storms to draw conclusions on coupling zone positioning etc. Distinct warning index could be designed to capture high precipitation events again with consequences on LACE domain boundaries. It is a continuation of work from 2012.

Executed efforts: MT - 2 months (local work)

Estimated efforts: 2 months (local work, DHMZ - Zagreb)

Contributors: Martina Tudor (Cr)

Documentation: none

Status: No new development in 2014, no workforce available.

Documents and publications

Two reports have been published on te RC LACE web page:

1) Alexandra Craciun, Report from the stay at CHMI, June 2014: Application of ENO technique to semi-Lagrangian interpolations

2) Jozef Vivoda, Report from the stay at CHMI, July 2014: Consideration about vertical Laplacian operator being discretized using VFE.

Activities of management, coordination and communication

Activities in the first half of the year 2014:

1) Joint 24st ALADIN Workshop and & HIRLAM All Staff Meeting 2014, 7-11 April 2014, Romania (participation of Petra Smolíková – presentation "LACE – dynamics and coupling")

2) Third RC LACE management group meeting in Balatonfeldvar, Hungary (participation of Petra Smolíková)

We expect the following events for the second half of 2014:

3) 36th EWGLAM & 21th SRNWP joint meetings, 29 September - 2 October 2014, Offenbach, Germany (participation of Petra Smolíková – presentation „Latest developments in the LACE dynamics")

4) EMS & ECAC 2014: 6-10 October 2014, Prague, Czech Republic (participation of Petra Smolíková – presentation „Finite elements used in the vertical discretization of the fully compressible forecast model ALADIN-NH")

5) ALADIN/HIRLAM joint dynamics working days in Valencia, Spain, October 2014 (participation of Jozef Vivoda).

LACE supported stays – 4 person/months in 2014

There have been two stays realized during the first half of 2014:

1) Alexandra Craciun (NMA, Romania) - 1 month in Prague (CHMI), May-June 2013

2) Jozef Vivoda (SHMI, Slovakia) – 1.5 months in Prague (CHMI), May-July 2014

We expect to have another stay at the end of 2014:

3) David Lancz (OMSZ, Hungary) – 1 months in Prague (CHMI), October-November 2014.

Summary of resources/means

The total effort invested into the area of Dynamics&Coupling in frame of LACE in 2014 is estimated to be 12 person/months. Major part of it was already executed up to September 2014, 2.5 person/months was already executed as scientific stays and one research stay (1 person/month) is planned to be realised during autumn 2014.

Unfortunately, we have not been able to invest as much as it was planned for 2014. Reasons for that remain similar as in the past - several people workforces being dedicated to more urgent topics in the area of Physics and the work on coupling being stacked by the maternity leave of the dedicated colleague.

Task	Subject		Resources			Stays	
			Planned	Executed	Expected in 2014	Executed	Expected in 2014
VFE NH	1.1	Design of VFE in NH model	6	5	7	1.5	1.5
Phys-dyn interface	2.1	Physical tendency of w	1.5	0	1.5	0	1
	2.2	Application of ENO technique in SL interpolations	1.5	1.5	1.5	1	1
	2.3	Ideal share between horizontal turbulence and numerical diffusion	2.5	2	2	0	0

1D2D turbulence	3.1	Scientifique validation	1	0	0	0	0
	3.2	Testing	0.5	0	0	0	0
Coupling strategy	4.1	Rapid changes in surface pressure field	2	0	0	0	0
Total manpower			**15**	**8.5**	**12**	**2.5**	**3.5**

Problems and opportunities

In the past, we were inviting people from LACE countries to join our common endeavour in the field of model dynamical core. In last two years we have had an opportunity to host several young colleagues from Hungary, Romania and Spain (HIRLAM) in Prague and to work with them on topics in dynamics. We believe that we may establish a long living cooperation based on this new and appreciated trend. We believe that we will be able to start close joint work with people working in the area of physics to provide a reasonable 1D2D turbulence scheme. We should evaluate the abilities of the existing model versions in high resolutions and define the most pressing problems after it.