Working Area Dynamics & Coupling

Work Plan

Prepared by:	Area Leader Petra Smolíková
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1 Introduction and background

This material is being prepared for LACE Steering Committee which is invited to give opinion on the activities and resources planned here.

This year the planning for the Area of Dynamics&Coupling was more difficult and the resulting plan is less reliable than in previous years. The reason is that several topics have been closed in the last years ("Application of ENO technique to semi-Lagrangian interpolations", "The physical tendency for vertical velocity in NH") and we plan to start new work. It follows that there is no dedicated workforce for several new topics while some of them could be solved in the cooperation with the HIRLAM consortium which may make the planning even more cumbersome.

2 Goals

Our main goals in the area of Dynamics&Coupling remain the same as in the last years and are connected to the future increase in the horizontal and vertical resolutions of model ALADIN/ALARO/AROME applications. We have to face connected problems which may in the future include revisiting of the basic choices made during the model design in the past, as for example chosen time and space discretizations. However, in the frame of RC LACE we concentrate ourselves more on the improvements in the existing non-hydrostatic kernel and its existing discretization then on more scientifically oriented problems of the design of a scalable solution for compressible flows being subject of the research in the partner countries (grid-point Helmholtz solver, grid-point representation of model variables etc.) and being scheduled as more long term aimed as a solution for the next decade.

We have been working already for many years on the implementation of finite element method in the vertical discretization of ALADIN NH (Task 1) targeting at the increase in accuracy in higher resolutions. There are signals from Météo France that with the increase in horizontal resolution the used time scheme (semi-implicit with linear part being solved implicitly and non-linear part being solved through iterated centred implicit method, linearization being done according to a simple horizontally homogeneous basic state constant in time) may not guarantee physically correct and numerically stable solution converging to the right solution when the time step is being decreased. We need to know more about the envisaged problems and start to anticipate solutions (Task 3). Another part which has to be reconsidered is the horizontal diffusion being solved through a combination of spectral diffusion and SLHD scheme. The current solution has an enormous number of tuneable parameters. We feel as an urgent need to prepare a methodology how to tune these parameters for different resolutions (Task 2). Further we propose to reconsider the optimised usage of supercomputer resources for time and spatial scales of our model applications in Task 5. There are as well less urgent topics which may be solved in case there is an available workforce (Task 4).

We do not have any plans in coupling for the next year.

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 remains the same for years - 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 difference (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).

The phasing of the existing modification of the VFE scheme is planned for the first part of 2017 to be prepared for the cycle 44T1, followed by thorough testing in 2D vertical plane and in real simulations. We still have to finish the paper for MWR and keep the code consistent with the work done by our HIRLAM colleagues. We expect to master the work done by our colleague Álvaro Subías (AEMET) who left the dynamics area in the end of 2016. Some optimization work is anticipated as well concerning the memory used, vectorization and the amount of tuneable or optional parameters of the designed scheme.

Proposed contributors: Jozef Vivoda (Sk), Petra Smolíková (Cz)

Estimated efforts: 1 months – research stay at CHMI, Prague; 5 months of local work

Planned deliverables: code for phasing, results of tests, a paper prepared for publication in MWR

Task 2. Horizontal diffusion

Subject: 2.1 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 tuneable parameters and includes not only flow dependent grid-point diffusion, but a supporting spectral diffusion as well. The behaviour 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.

Proposed contributors: Viktória Homonnai (Hu), Petra Smolíková (Cz)

Estimated efforts: 1 month – research stay at CHMI, Prague; 2 months of local work

Planned deliverables: problem analysis, eventually redesign of SLHD; report

The following topics are newly defined and the first task has to be to study the extent and character of the envisaged problems. The thorough diagnosis has to be followed by the redesign of proposed methods to cure the detected problems. The state-of-the-art and current status of research in our partner institutions has to be taken into account. For two subjects, some appropriate candidates should be found and dedicated to them.

Task 3. Time scheme

Subject: 3.1 Generalization of the semi-implicit reference state to include vertical profile of background variables and horizontal features as orography

Description and objectives: One of the possible ways to attack this subject is a direct inclusion of the tangent-linear approximated model in the semi-implicit time scheme. The stabilising effect of such method was identified at ECMWF for the hydrostatic IFS by Filip Váňa, and the potential of the new design of SI scheme has been exploited in low spatial resolution (corresponding to usual values in global applications). The most interesting point is the incorporation of orography and real vertical profiles into the linear model, while in the existing reference state for linearization no orography and only constant vertical profiles are present. The consequence of this new design of SI scheme would be no need of the spectral space representation of model variables and of transformations between spectral and grid-point spaces once the horizontal derivatives are calculated in a local way (for example through finite differences). The crucial point is here the iterative method used to solve the Helmholtz problem and its convergence behaviour in higher spatial resolutions (with steeper slopes).

There are other less ambitious ways how the vertical profile of the reference state could be incorporated in the semi-implicit scheme which may be also investigated.

The aim of this topic would be to extent the hydrostatic tangent-linear model to its non-hydrostatic version for 2D vertical plane model based on the code existing in Météo France, and to try to answer the open questions concerning higher spatial resolutions and designed method properties in idealized 2D vertical plane tests.

Proposed contributors: **NOT KNOWN**

Estimated efforts: 2 months of local work

Planned deliverables: code modifications, report

Subject: 3.2 The trajectory search in the SL advection scheme

Description and objectives: 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 phenomenon. 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.

Proposed contributors: Alexandra Craciun (Ro), Petra Smolíková (Cz)

Estimated efforts: 1 month – research stay at CHMI, Prague; 3 months of local work

Planned deliverables: report, code changes if needed

Subject: 3.3 Dynamic definition of the iterative time schemes

Description and objectives: Tests in higher horizontal resolutions then those used currently in operational applications (being close or less than 1km) reveal that in most of the cases the SETTLS time scheme is enough to deliver stable solution while there appear some cases when at least one iteration of the iterative centred implicit scheme is needed. When going to higher resolutions it may happen that even one iteration is not enough as reported by Karim Yessad. The idea of this topic is to determine a condition which will evaluate the stability of the integration and in case there is an indication of poor stability the iteration will be started. Ones such condition defined, the time scheme would become more efficient and the computer time will be invested only when needed. Iterative time stepping procedure could be used as well regularly every Nth time step (N>1) to better balance the cost/stability properties of the whole scheme. Implementation of such choice would require careful allocation of corresponding buffers and thorough handling of the data flow between consequent time steps treated in a different way.

Proposed contributors: Jozef Vivoda (Sk), Petra Smolíková (Cz)

Estimated efforts: 1 month – research stay at CHMI, Prague; 1 month of local work

Planned deliverables: some statistics (spectral norms, …) to access the condition for dynamic calculation of iterations needed, report, code changes

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

Subject: 4.1 Upper boundary condition

Description and objectives: There are some indications that upper boundary may cause a problem in higher resolutions. There could be a big jump in vertical levels needed which may destabilize the whole model as it was observed for finite elements used in the vertical discretization of ALADIN-NH.

In general, on the top boundary there is no material surface contrary to the bottom boundary and vertically unbounded atmosphere may be undesirable in some applications. In practice, velocity normal to the upper boundary is set to zero causing wave reflection similar to lateral boundaries. Free-slip conditions are used for other variables. This means that the vertical derivatives of these variables are equal to zero and there is no mass and heat transfer across the boundary. Radiation boundary condition can be imposed by diagnostic relationship between pressure and vertical velocity at the top (Klemp, Durran 1983; Bougeault 1983). However, it is formulated in terms of vertical wavenumbers and frequencies and is difficult to be implemented. To overcome this problem an explicit absorbing layer is applied for example in SLHD (semi-Lagrangian horizontal diffusion) where spectral diffusion works only when approaching to the top, and an implicit absorbing layer is applied through the coarsening of the vertical resolution when approaching to the top. It should be investigated if there are some new or enhanced problems at the model top in horizontally or vertically higher resolutions and solutions could be proposed if needed.

Proposed contributors: **NOT KNOWN**

Estimated efforts: 2 months of local work

Planned deliverables: not defined yet

This topic has quite low priority, being solved in case there is an interested candidate.

Task 5. Optimization of the model code to better balance computer resources/results achieved

Subject: 5.1 Single precision

Description and objectives: We propose to investigate the impact of limiting the precision of real-number variables used in the model code to only 32 bits (single precision) in most of the calculations instead of commonly used 64 bits (double precision). The results from annual integration of IFS and from medium range ensemble forecasts indicate no noticeable reduction in accuracy and an average gain in computational efficiency by approximatively 40%. We would like to carefully check the limited area model dedicated part of the code to obtain similar results in CPU reduction while keeping reasonable accuracy level. The envisaged code changes would be rather technical including replacement of hard coded thresholds with intrinsic precision functions, avoiding divisions by floating point numbers that may become zero etc.

Proposed contributors: Jozef Vivoda, Oldřich Španiel

Estimated efforts: 2 months of local work

Planned deliverables: code changes, accuracy/efficiency statistics, report

3 Summary of resources

The total effort invested into the area of Dynamics&Coupling in frame of LACE during 2017 is expected in the amount of 21 person/months, 4 person/months from that supported by LACE budget directly. The expected resources are slightly exceeding those invested in the area in previous years. The absolutely necessary condition for fulfilment of our plans is a dedication of the available workforce for the planned topics.

Task		Subject	Resources	
			Total	Stays
1. VFE NH	1.1	Design of VFE in NH model	6	1
2. Horizontal diffusion	2.1	Ideal share between horizontal turbulence and numerical diffusion	3	1
3. Time scheme	3.1	Generalization of the semi-implicit reference state	2	0
	3.2	The trajectory search in the SL advection scheme	4	1

	3.3	Dynamic definition of the iterative time schemes	2	1
4. Evaluation of the dynamical core in very high resolutions	4.1	Upper boundary condition	2	0
5. Optimization of the model code to better balance computer resources/results achieved	5.1	Single precision	2	0
Total manpower			**21**	**4**

4 LACE supported stays

1) VFE – Jozef Vivoda (Sk), 1 month in Prague
2) Ideal share between horizontal turbulence and numerical diffusion
   – Viktória Homonnai (Hu), 1 month in Prague
3) The trajectory search in the SL advection scheme
   – Alexandra Craciun (Ro), 1 month in Prague
4) Dynamic definition of the iterative time scheme
   – Jozef Vivoda (Sk), 1 month in Prague

5 Meetings and events

1) 27th ALADIN Workshop & HIRLAM ASM 2017 - participation of Petra Smolíková
2) EWGLAM & SRNWP joint meetings - participation of Petra Smolíková

6 Risks and constrains

We start new topics where even the problem formulation and extent of work needed may not be exactly known. Moreover, solutions are not known either and problems should be studied extensively to be able to propose some. Hence the predictability of our capacity to finish such topics is low and uncertainty in delivered solutions is high. Anyway, to be able to proceed in problems formulation, investigation and solution, we need to dedicate appropriate workforce to these topics.