Working Area Dynamics & Coupling

Work Plan Proposal

Prepared by:	Area Leader Petra Smolíková
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1 Introduction and background

In 2021 we do not propose new topics compared to 2020 since there are workforce vacancies in already planned ones. This plan is reflected in the ALADIN/HIRLAM Work Plan for 2021 in Work Packages DY1 - Improvement of SISL spectral dynamical core (H and NH) and HR1 - (Sub)-km modelling.

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 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.

Task 1. Vertical discretization

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 compatibility of the newly proposed vertical velocity variable with VFE will be studied and code will be modified to allow the usage of both.

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

Estimated efforts: 2 PM of local work

Planned deliverables: report, code changes

Subject: 1.2 Modularization of vertical discretization

Description and objectives: The influence of a vertical discretization on stability and accuracy of the model integration is still not well understood. This task incorporates two parts, one technical – to modularize the vertical discretization from other parts of the dynamics; and second scientific, to understand better the influence of vertical levels definition on the behaviour of the model. It is a known fact that SL interpolations are less accurate when applied in terrain following vertical coordinates then in smooth pressure levels (Park et al., 2019). The usage of hybrid levels up to the stratosphere is a common practice in our community. However, it can be a source of noise in the upper model levels. This undesirable phenomenon can be simply pacified by using pressure levels already from the middle troposphere and higher. Such a choice could have a positive influence on the quality of the upper level turbulence (CAT) prediction and it could possibly avoid the generation of vertical chimneys in the vertical velocity field observed often over an orography. This could have as well a positive impact on precipitation field which may become smoother. Hence, we propose to investigate the influence of "hybridism" on the quality of the model prediction and to try to find an optimal choice for vertical coordinate setting.

[S.-H. Park, J. B. Klemp, and J.-H. Kim, *Hybrid mass coordinate in WRF-ARW and its impact on upper-level turbulence forecasting*, MWR, in press, 2019]

Proposed contributors: **NONE**

Estimated efforts: 2 PM of local work

Planned deliverables: code changes

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. The work started in the last year with the sensitivity study in the cascade of resolutions (4km, 2km, 1km). Moreover, the domain covering roughly the same territory with the horizontal resolution of 500m was prepared to complement the existing experimental environment. The original method was designed to determine the resolved TKE. We continue in the work.

Proposed contributors: Mario Hrastinski (Cr), Petra Smolíková (Cz)

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

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

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: **NONE**

Estimated efforts: 2 PM of local work

Planned deliverables: code modifications, report

Subject: 3.2 The trajectory search in the SL advection scheme

The topic is CLOSED.

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.

The work started in 2017 with stability analysis of a set of schemes for 1d advection being second order in time accurate and using available information from three consecutive time steps and location of departure and arrival points. A time scheme which combines two methods SETTLS and NESC was proposed with theoretically beneficial properties (stability and accuracy). This combined scheme was implemented in the code of ALADIN-NH. Based on a measure of stability it may be followed by one or several corrector steps. The proposed combined scheme was tested in real simulations for several stability indicators. On top of that we would like to prepare an analysis of the iterative time scheme properties (convergence, stability) to be published in a peer review paper. Such publication is missing since the PC scheme was implemented to the ALADIN dynamics code.

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

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

Planned deliverables: report, code changes

Subject: 3.4 Terms redistribution through new vertical velocity variables

Description and objectives: Motivated by the work of Fabrice Voitus being presented at the ALADIN Workshop in Toulouse in April 2018 we started this new subject. The aim is to reformulate the nonhydrostatic nonlinear model to obtain simple bottom boundary condition which is easily fulfilled. This aim may be reached only for restricted choices done in the dynamics of the ALADIN system. In particular, only the case when vertical velocity variable is used in the nonlinear nonhydrostatic model in the two-time level SI SL scheme. The bottom boundary condition was proven to be very important for the stability and accuracy of the whole discretization of the system of prognostic equations. Several new formulations of vertical velocity were already proposed in 2018 and implemented in the model code. Parallelly, new vertical motion variable was implemented in Toulouse by F.Voitus. Its usage with VFE discretization will be studied and code will be modified.

Proposed contributors: Jozef Vivoda (Sk)

Estimated efforts: 2 PM of local work

Planned deliverables: code changes, report, paper

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

Subject: 4.1 Tuning of dynamical adaptation of the wind field at different resolutions

Description and objectives: The quality of the wind field forecast may be improved in case of strong wind and rugged terrain through a dynamical adaptation to high resolution topography by running short range forecast of the ALADIN system in higher than standard operational resolution. Wind field from the dynamical adaptation may be used as well to evaluate local wind climatology. This strategy was applied in Croatian domain to better capture the local wind “bura” being developed due to large gradients of pressure over the coastal mountains having large spatial variability and local terrain dependence. The influence of nonhydrostatic dynamics setting in several high resolution experiments (500m, 250m) will be studied.

The work is connected to physics, since the influence of parameters of the turbulence scheme is being questioned as well.

The topic is PENDING.

Proposed contributors: NONE

Estimated efforts: none

Planned deliverables: none

Subject: 4.2 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: **NONE**

Estimated efforts: 2 PM of local work

Planned deliverables: not defined yet

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

Subject: 4.3 Experiments in very high resolution

Description and objectives: As reported by Fabrice Voitus (Météo France) the numerical stability of the ALADIN nonhydrostatic dynamical core is endangered as soon as the horizontal resolution of 350m is approached above steep orography. To be able to test this statement and to analyse the model dynamical core behaviour we have to start experiments

in the very high resolution. For these goals the climate files must be prepared from a fine database.

Proposed contributors: Petra Smolíková (CHMI)

Estimated efforts: 2 PM of local work

Planned deliverables: experiments results, report

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. First tests with adiabatic hydrostatic LAM were started in 2018, followed by tests of NH adiabatic model version. A redesign of semi-Lagrangian interpolation weights was proposed based on these tests. The work will continue.

Proposed contributors: Jozef Vivoda (Sk), Oldřich Španiel (Sk)

Estimated efforts: 1 PM of local work

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

Task 6. Basic equations

Subject: 6.1 Reformulation of the NH system as a departure from HPE

Description and objectives: Currently hydrostatic (HY) and fully compressible nonhydrostatic (NH) system of equations and its numerical integration form two dynamical cores which are separated in a substantial part of the model code. Recently Voitus showed that unification in the spectral Helmholtz equation solver is possible through elimination of all variables except

horizontal divergence in both these worlds. The aim of the topic is to reformulate the compressible nonhydrostatic system of equations as a departure from the hydrostatic system which may be controlled through a new parameter ε (ε = 1 NH core, ε = 0 HY core). Then all computations of the dynamical core can be treated in a unified code. Moreover, this parameter ε can be vertically dependent. It would allow us to suppress nonhydrostatism close to the model top where the vertical resolution is too coarse to properly sample NH processes.

The set of control parameters derived from ε mastering separately the nonhydrostatic terms was introduced in the EE system, in the continuous and discretized context. The stability analysis was prepared. Simplified experiments were run in the 2D vertical slice model. The conclusion made is that the best stabilization effect is reached with ε slightly bigger then 1 used only in the linear model part. This surprising conclusion must be confirmed in the 3D systematic study. The question we would like to answer is the following:

Is it possible to run SI SETTLS time scheme with control parameter ε ≠ 1 in cases when the NH integration is unstable with satisfying accuracy of results?

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

Estimated efforts: 2 PM – research stay at CHMI (J.Vivoda), 2 PM of local work

Planned deliverables: code changes, report, eventually paper in a peer-reviewed journal

Task 7. Coupling strategy

Subject: 7.1 The impact of higher coupling frequency

Description and objectives: The impact of higher coupling frequency was already investigated in the past and revealed an interesting option which may help to capture meteorological features which would be omitted with lower coupling frequency. Moreover, the LBC files started to be operationally available for the LACE domain in 1h frequency recently. We would like to assess the impact of the increased frequency of coupling on real cases in the context of our current operational resolutions. The operational usage of 1h coupling frequency is limited by the available transfer speed of LBC files to the partner countries.

Proposed contributors: Mario Hrastinski, Iva Dominovic (DHMZ)

Estimated efforts: 2 PM of local work

Planned deliverables: report

Subject: 7.2 Frame approach in the LBC files

Description and objectives: 1 hour coupling frequency is believed to be an interesting option, but the current LBC files prepared from ARPEGE for the LACE domain are "huge" while our HPCs are "fast". It follows that we are not able to get the LBC files quickly enough to use them operationally in high frequency (1h). We might think about frames implementation in FA format and about connected problems (LBC transformed to grid point space, the central part removed and just the frame distributed, central values smoothly completed, the whole field biperiodized and transformed to the spectral space). Such procedure must keep the values in the coupling zone reasonably precise. We would like to start to design such frames and to test them. These activities must be strongly coordinated with our partners, mainly Météo-France, as the producer of LBC files.

Work outline: The work will consist of the following parts:

- to design and prepare framed LBC files (GP) using external tools + e927
- to design and prepare spectral fields calculated from these framed LBC files in several steps: to consider the way how the internal part is filled to get reasonable spectral fields; to consider the size of the frame etc.; to compare spectral fields in the original LBCs and the ones reconstructed from the framed LBCs in the area of interest (the coupling zone); to compare model results using original LBCs and framed LBCs; to get an estimate of the achievable reduction of the LBCs size (the size of a spectral field is smaller than the size of a GP field, hence to decrease the overall file size we need a framed GP field with the size reasonably smaller than the size of a spectral field).

We omit at this stage all considerations concerning the framed LBC file format, packing etc.

Proposed contributors: Polish team - Bogdan Bochenek, Piotr Sekuła, Gabriel Stachura

Estimated efforts: 0.5 PM of local work, 0.5 PM – a research stay in Prague in case of a favourable epidemiologic situation, local work otherwise

Planned deliverables: report

Subject: 7.3 The impact of higher truncation in LBC files

Description and objectives: Another way how to decrease the size of LBC files while hoping in keeping the quality of the final forecast is to increase truncation of spectral fields in LBC files (quadratic, cubic etc.). This will be tested.

Proposed contributors: Polish team - Bogdan Bochenek, Piotr Sekuła, Gabriel Stachura

Estimated efforts: 1 PM of local work

Planned deliverables: report

3 Summary of resources

The total effort invested into the area of Dynamics&Coupling in the frame of RC LACE during 2021 is expected in the amount of 24 person/months, 4.5 person/months from that supported by LACE budget directly. The planned efforts are kept on the level of the previous year.

Task		Subject	Resources	
			Total	Stays
1. Vertical discretization	1.1	Design of VFE in NH model	2	-
	1.2	Modularization of vertical discretization	2	-
2. Horizontal diffusion	2.1	Tuning and redesign of the horizontal diffusion depending on the scale	2	1
3. Time scheme	3.1	Generalization of the semi-implicit reference state	2	-
	3.2	The trajectory search in the SL advection scheme	0	-
	3.3	Dynamic definition of the iterative time schemes	3	1
	3.4	Terms redistribution through new vertical velocity variables	2	-
4. Evaluation of the dynamical core in very high resolutions	4.1	Tuning of dynamical adaptation of the wind field at different resolutions	0	-
	4.2	Upper boundary condition	2	-
	4.3	Experiments in very high resolution	2	-
5. Optimization of the model code	5.1	Single precision	1	-

6. Basic equations	6.1	Reformulation of the NH system as a departure from HPE	2	2
7. Coupling strategy	7.1	The impact of higher coupling frequency	2	-
	7.2	Frame approach in the LBC files	1	0.5
	7.3	The impact of higher truncation in LBC files	1	-
Total manpower			**24**	**4.5**

4 LACE supported stays

1) Tuning and redesign of the horizontal diffusion depending on the scale – Mario Hrastinski (Cr), 1 PM in Prague
2) Dynamic definition of the iterative time schemes - Alexandra Craciun (Ro), 1 PM in Prague
3) Reformulation of the NH system as a departure from HPE - Jozef Vivoda (Sk), 2 PM in Prague
4) Frame approach in the LBC files – a colleague from Poland, 0.5 PM in Prague

5 Meetings and events

1) 36th LSC Meeting, virtual, March 2021
2) **Machine learning for numerical weather predictions and climate services,** ECMWF, virtual, the afternoons of 14-16 April 2021
3) 1st **ACCORD All Staff Workshop** 2021, virtual, 12-16 April 2021
4) 37th LSC Meeting, September 2021
5) 43nd **EWGLAM** and 28th **SRNWP** joined meetings, October 2021

6 Risks and constrains

All RC LACE endeavour is connected to available workforce. The fulfilment of this plan is endangered in case there is none.