Working Area Dynamics & Coupling

Work Plan Proposal

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1 Introduction and background

In 2023 we do not propose new topics compared to 2022 since there are still workforce vacancies in already planned ones. Moreover, we decided to close topics which were pending for several years and no workforce was dedicated on them. In case there is an available workforce, they may be easily included in the plan again in next years.

This plan is reflected in the ACCORD Work Plan for 2023 in Work Packages DY1 - Improvement of SISL spectral dynamical core (H and NH), PH1 – Turbulence and shallow convection and PH8 – On the interface of Physics with Dynamics (and time stepping). We plan to participate in the ACCORD common efforts towards the just started project DEODE.

2 Goals

Our main goals in the area of Dynamics&Coupling emerging from the common efforts toward the LAM component of the Earth Digital Twin should aim on the near future used horizontal resolutions of several hundred meters. With these hyper-resolutions the question of compatible vertical discretization arises. Moreover, the need of adequately accurate and sufficiently stable integration schemes adapted to high orographic slopes reappears. With increasing horizontal resolutions comes together the increasing size of the application domains which may constitute a substantial technical and scientific problem. The question of scalability on the new HPC architectures and of the physiographic data preparation for such demanding problems reemerges. Within RC LACE, we try to address some of these problems and to contribute to their solution.

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 NH system formulated as a departure from HPE system with VFE will be studied and the code will be modified to allow usage of both these options together.

Proposed contributors: Petra Smolíková (Cz)

Estimated efforts: 2 PM of local work

Planned deliverables: report, code changes

Subject: 1.2 Modularization of vertical discretization

The topic was CLOSED.

We face the unavailability of needed workforce and the probability of being able to solve this topic decreased to zero. We may come back to the idea later in case there is an available workforce.

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.

Further, the necessity of including the 3D processes like horizontal wind shear and advection to improve the representation of turbulence kinetic energy (TKE) and of turbulence total energy (TTE) in runs with kilometric horizontal resolution was recognised. In the frame of this

topic the implementation of horizontal features of the turbulence scheme TOUCANS was started. In the proposed solution horizontal shear effects were parametrized using three different approaches and were included in the prognostic equations for TKE and TTE. The work will continue.

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

Estimated efforts: 1 PM – research stay at CHMI, Prague, 2 PM of local work

Planned deliverables: problem analysis, code modifications; 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

The topic was CLOSED.

We face the unavailability of needed workforce and the probability of being able to solve this topic decreased to zero. We may come back to the idea later in case there is an available workforce.

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.

During autumn 2022 the "on demand" PC scheme was implemented where a decision on the time scheme used in the given time step is done at its beginning depending on the stability characteristics calculated in all grid points. The stability criterion is based on the time derivative of the vertical divergence nonlinear residual. If its value exceeds a given threshold in a given number of grid points, the PC with NESC predictor is applied, cheaper SI with SETTLS treatment of nonlinear terms is used otherwise. It was shown that stable "scenarios" exist for considered test cases enabling savings in the CPU time needed.

We will continue the study with longer test period to see whether the stability of the scheme and the number of time steps where necessarily the PC scheme is used is really flow dependent (or meteorological situation dependent) or it is more or less constant for a given domain, time step and dynamics setting used. In the latter case the stability would be more triggered by orography and other parameters chosen for the given domain and experimental setup.

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

Estimated efforts: 1 PM – research stay at CHMI, Prague, 2 PM of local work

Planned deliverables: report, code changes

Subject: 3.4 Terms redistribution through new vertical velocity variables

The topic is CLOSED.

The idea for this topic came from Fabrice Voitus from Météo France. Fabrice has implemented the new vertical motion variables as an alternative to the implementation done under RC LACE and made it compatible with VFE. This led to the modifications in the

VFE design. We do not consider as useful to farther develop two alternatives for this topic and do not plan to continue the work on it.

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 new dynamical adaptation application will be set up in Croatia after the finished migration to the new HPC facility. Higher horizontal and vertical resolutions and fully compressible dynamics will be part of the new setting. The work does not have a high priority and was postponed to the next years.

Estimated efforts: none

Subject: 4.2 Upper boundary condition

The topic was CLOSED.

We face the unavailability of needed workforce and the probability of being able to solve this topic decreased to zero. We may come back to the idea later in case there is an available workforce.

Subject: 4.3 Experiments in very high resolution

Description and objectives: Concerning the participation of RC LACE members in the project DEODE our focus must be in hyper-resolution applications. Hence, we prepare a LAM test case with the horizontal resolution under 1km over relatively large domain (covering Central

Europe) expected to be run first as the dynamical adaptation from the leading global model. Connected problems start with the preparation of reasonably fine surface parameters and usage of recent developments in the dynamical model part to allow stable integration with reasonable time steps. Many technical and scientific challenges will be addressed including scalability issues. First, we would like to technically prepare the test, assess the model behavior and document the problems encountered. Several domains will be prepared for several test cases.

Proposed contributors: Petra Smolíková (Cz), Ján Mašek (Cz), Christoph Wittmann (Au)

Estimated efforts: 5 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: Continuous process toward more and more CPU demanding model applications lead to the efforts to decrease number representation precision from so called “double” to “single” precision everywhere where the accuracy of calculations is not in danger. These goals were assessed at ECMWF and Météo France and a substantial part of model codes was adapted to them. 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 plan to carefully test all code branches of the dynamical core commonly used in our applications to identify potential risks of this approach. Then the physical parametrizations of the ALARO package will undergo the same procedure. The envisaged code changes are rather technical including replacement of hard coded thresholds with intrinsic precision functions, avoiding divisions by floating point numbers that may become zero etc.

Since the dynamical kernel is being shared with global models of ECMWF and Météo France and single precision runs of EPS are foreseen in these institutions, a progress was being made there. It was indicated that double precision is needed in several parts of the code as for example in VFE. Hence, to progress in this topic we may propose some tests to assess the performance of SP and DP runs.

Proposed contributors: Oldřich Španiel (Sk)

Estimated efforts: 1 PM of local work

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

Subject: 5.2 The FFTW algorithm

Description and objectives: It was reported by Météo France, that the usage of the Fastest Fourier Transform in the West algorithm may bring substantial CPU savings depending on the platform used (up to 5%). We will test the possibility to run this algorithm in the export code cycle CY46t1 and assess its performance compared to the standard FFT algorithm.

Proposed contributors: Petra Smolíková (Cz)

Estimated efforts: 1 PM of local work

Planned deliverables: 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 to suppress nonhydrostatism close to the model top where the vertical resolution is too coarse to properly sample NH processes.

Work outline: Instead of one parameter ε, a set of control parameters 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

some of control parameters slightly bigger then 1 used only in the linear model part, or with some of the control parameters smaller than 1 used similarly in both, the linear and the full model parts. This surprising conclusion was confirmed in the 3D systematic study. Like this it was possible to run SI SETTLS time scheme in cases when the NH integration is unstable. It was shown that results have satisfying accuracy.

We will test the existing implementation in high resolution experiments, partially fulfilling the goals of the DEODE project. Further, we will assess the stability properties of the proposed scheme in the presence of constant slope orography via classical SHB stability analysis.

We will phase the existing implementation in the next cycle CY49t1.

We will finish the preparation of a paper for Monthly Weather Review.

We will assess the behavior of the scheme in relation to steep slopes present in the domain.

Proposed contributors: Petra Smolíková (Cz), Nika Kastelec (Sl)

Estimated efforts: 1 PM – research stay at CHMI (Nika), 5 PM of local work

Planned deliverables: code changes, report

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 (Cr), Ana Sljivic (Cr)

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: It was shown that framed LBC files with the values in the central zone being reconstructed using an inverse distance-weighted 2D interpolation from the central zone edges may serve well as the coupling files and the resulting forecast quality is not degraded. Nevertheless, in case the final resolution LBC files are prepared and framed the size of one grid-point field may not be reduced enough in comparison to commonly used spectral representation of the coarse resolution field. The only way out would be to frame the coarse resolution LBC files and make the interpolation to higher resolution and central zone values reconstruction afterwards. This approach was tested in 2022. The savings in the file size were found substantial.

Proposed contributors: none, since Gabriel Stachura moved to surface aspects of physics

Estimated efforts: none

Subject: 7.3 The impact of higher truncation in LBC files

The topic is CLOSED.

Subject: 7.4 Preparation of new LBC files from IFS

Description and objectives: Preparation of new LBCs in higher horizontal and vertical resolution from the IFS files is planned for all partners using the lateral data from ECMWF forecasts. A decision on the common setting for RC LACE partners is needed based on a parallel study for several proposed settings.

Proposed contributors: Ana Sljivic (Cr), Martina Tudor (Cr), Christoph Wittmann (Au)

Estimated efforts: 3 PM of local work

Planned deliverables: report on tested options; decision on the LBC files setting satisfying the needs of all RC LACE partners

3 Summary of resources

The total effort invested into the area of Dynamics&Coupling in the frame of RC LACE during 2023 is expected in the amount of 26 person/months, 3 person/months from that supported by LACE budget directly. The planned efforts are kept roughly on the level of the previous year, but the plan is made more realistic by removing multiyearly pending topics and focusing on the topics which are ongoing.

Task		Subject	Resources	
			Total	Stays
1. Vertical discretization	1.1	Design of VFE in NH model	2	-
	1.2	Modularization of vertical discretization	0	-
2. Horizontal diffusion	2.1	Tuning and redesign of the horizontal diffusion depending on the scale	3	1
3. Time scheme	3.1	Generalization of the semi-implicit reference state	0	-
	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	0	-

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	0	-
	4.3	Experiments in very high resolution	5	-
5. Optimization of the model code	5.1	Single precision	1	-
	5.2	The FFTW algorithm	1	-
6. Basic equations	6.1	Reformulation of the NH system as a departure from HPE	6	1
7. Coupling strategy	7.1	The impact of higher coupling frequency	2	-
	7.2	Frame approach in the LBC files	0	-
	7.3	The impact of higher truncation in LBC files	0	-
	7.4	Preparation of new LBC files from IFS	3	-
Total manpower			**26**	**3**

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 – Nika Kastelac (Sl), 1 PM in Prague

5 Meetings and events

1) Very High Resolution Modelling Workshop, Norrkoping, Sweden, 14-16 February 2023, attended by 4 RC LACE colleagues, presentation of AL "Dynamical setting in very high resolutions"
2) 40th LSC Meeting, March 2023
3) 3rd ACCORD All Staff Workshop 2023, March 2023
4) 3D Turbulence Working Week, 3-5 July 2023, Toulouse, France, attended by several RC LACE colleagues
5) 41th LSC Meeting, September 2023
6) 44th EWGLAM and 29th SRNWP joined meetings, September 2023

6 Risks and constrains

All the RC LACE endeavour is connected to the available workforce. The fulfilment of this plan is endangered in case there is none. We suffer from the drain of experts (Jozef Vivoda) to the project DestinE. On the other hand, we plan to contribute to the LAM part of the project and thus have to aim our efforts to related topics.