Working Area Dynamics & Coupling

Work Plan Proposal

Prepared by:	Area Leader Petra Smolíková
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1 Introduction and background

For 2024 we proposed a restructuralization of several tasks and more detailed structure of the subjects being proposed to be solved. We got closer to the structure of the ACCORD Work Plan for 2024. The workforce was estimated per task. This year we skip the topics which were previously closed, and thus the numbering of opened topics may jump up several numbers. We keep the structure proposed for the last year.

This plan is reflected in the ACCORD Work Plan for 2026 in Work Packages DY1 - Improvement of SISL spectral dynamical core (H and NH), HR – Sub-km modelling, PH1 – Turbulence and shallow convection and PH8 – On the interface of Physics with Dynamics (and time stepping). RC LACE members participate as well in the second phase of the project DE_330, WP10.3.

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 and of produced data which may constitute a substantial technical and scientific problem. Within RC LACE, we try to address some of these problems and to contribute to their solution. Our plan is also to provide concise technical and scientific documentation that accurately describes the recently developed features of the ACCORD system's dynamical core.

Task 1. Vertical discretization

Subject: 1.3 Ways how to decrease the first model layer height

Description and objectives: A necessary condition for the possibility to increase the density of model layers close to the surface is a lower placement of the first model layer. This placement has consequences in the turbulence scheme and must be done properly. The work has already started and was registered in the RC LACE Area of Physics.

Subject: 1.4 Study the effects of increased vertical resolution

Description and objectives: When going to very high (hectometric) horizontal resolutions we face the necessity to increase the vertical resolution to avoid a situation when the horizontal resolution would beat the vertical one and the model grid box will transform from a horizontal slice to a narrow vertical column. We will investigate how to benefit from this necessary change.

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

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

Planned deliverables: report, code changes

Task 2. Horizontal diffusion

Subject: 2.2 Evaluation of resolved and total TKE in the cascade of resolutions

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. Traditionally, the vertical part is treated in a parametrization scheme, while the horizontal part is being calculated by model dynamics. We expect that when going to higher horizontal resolutions the resolved part will increase and the sub-grid part decrease. This behaviour must be controlled, and the separated parts evaluated to ensure the correct behaviour of the whole process in all scales. An original method to determine the resolved TKE was already designed. The work will continue.

Subject: 2.3 Scale adaptation of horizontal and vertical turbulence

Description and objectives: After assessing the resolved and total TKE in all scales, adaptations of the horizontal turbulence (SLHD, spectral) and vertical turbulence (TOUCANS) must be proposed to ensure the correct behaviour of the whole diffusion process.

Subject: 2.4 Horizontal features of the turbulence scheme TOUCANS

Description and objectives: 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 recognized. The implementation of horizontal features into the turbulence scheme TOUCANS was

already 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: 2 PM of local work

Planned deliverables: problem analysis, code modifications; report

Task 3. Time scheme

Subject: 3.3 Dynamic definition of the iterative time schemes

Description and objectives: Iterative centred implicit schemes are able to ensure stability of the model integration in most of the cases. Each iteration indeed represents a significant increase in the CPU time needed. The numerical stability of the time scheme is influenced either by the chosen parameters of the domain (horizontal and vertical resolution, slopes present in the domain, time step) which are constant during the whole integration, or by the parameters of the meteorological situation which may vary during the integration. The idea is thus that maybe the number of iterations needed for a stable integration in a given time step could be adjusted according to “a stability criterion”. Such method could bring even more benefit in high resolution experiments which are more demanding in terms of the computer resources 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.

Recently, Fabrice Voitus (MF) has developed an ICI scheme modification that allows to change several reference state values in time during integration, among those parameters SITR, SITRA, SIPR. These parameters may be now evaluated at the beginning of the time step according to the value of temperature and surface pressure attained in the whole domain and represented by the spectral norms of model variables. Thus, the non-linear residual may be decreased and better numerical stability of the ICI scheme reached. The evaluation of

temperature and surface pressure and the following calculation of the Helmholtz matrix in each time step asks for some computational expenses. The exact computational time needed for these operations must be evaluated and an optimal procedure has to be designed in which the reference state values are evaluated as often as needed for a reasonable computational cost.

Subject: 3.5 Orographic terms in the linear part of the ICI time scheme

Description and objectives: Steep slopes of orography seem to play crucial role in the stability of the ICI time scheme with constant coefficients which is used in ALADIN/AROME/ALARO models. Linear model in the current approach does not include orographic terms at all. Following proposal of Fabrice Voitus and Jozef Vivoda, a new vertical Laplacian operator was proposed containing linearized second order terms associated with the horizontal gradient of orography. This method will be further developed, tested and evaluated.

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

Estimated efforts: 1 PM – research stay at CHMI, Prague, 3 PM of local work

Planned deliverables: report, code changes

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

Concerning the participation of several RC LACE members in the project DE_330 our focus must be in high-resolution applications. We aim for the horizontal resolution under 1km run as the dynamical adaptation from the leading global model, or LAM with lower horizontal resolution. 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. Several problems were identified as playing crucial role for the success of such high-resolution forecasts. We identified the following topics as being the most important ones and we will focus on them.

Subject: 4.4 Exploring capability of existing dynamics choices in VHR experiments

Description and objectives: The setting of dynamical parameters, truncation of spectral fields etc. may help to run successfully in VHR. Choices already prepared in the model code must be explored and tested.

Subject: 4.5 Testing recently developed approaches in model dynamics

Description and objectives: The new vertical motion variable w5 was formulated and implemented by Fabrice Voitus. The "on demand" time scheme and the blended NH/HY dynamics were formulated and implemented in the frame of RC LACE. Could some of these techniques increase the numerical stability achieved in VHR experiments? On top of that, the scientific and technical (code describing) documentation describing these new features is needed and will be prepared.

Subject: 4.6 Horizontal diffusion setting in VHR experiments

Description and objectives: It was shown that the adaptivity of the spectral diffusion to the change in the horizontal resolution is not sufficient. A stronger spectral diffusion has to be applied at least on motion variables to get rid of the small-scale noise produced by the model. Tuning of SLHD is foreseen as well in VHR experiments.

Subject: 4.8 Model initialization for VHR experiments

Description and objectives: The balance in the initial fields is crucial for the stable integration of the model. Available processes as DFI may be involved. On top of that, based on ideas developed in Subject 6.1 the non-hydrostatic dynamics is being introduced as an increment of the hydrostatic one based on some control parameters. Hence, if these control parameters will evolve in time during the integration, the non-hydrostatic dynamics will be introduced smoothly, keeping the current atmosphere always in a balanced state without sudden jumps in the prognostic fields. This approach will be implemented, tested and evaluated.

Proposed contributors: André Simon (Sk), Petra Smolíková (Cz), other colleagues in DE_330

Estimated efforts: 6 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.

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%). The performance of the transformation method is platform dependent. It follows that it is recommended to test FTTW for each forecast operations separately, on the targeted computer system. It was done already at Hungary and Czech Republic with not very satisfactory results. Some code enhancement might help with the performance on the targeted platforms and this will be investigated.

Proposed contributors: Petra Smolíková (Cz), Oldřich Španiel (Sk)

Estimated efforts: 2 PM of local work

Planned deliverables: 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, Fabrice 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 several control parameters (all = 1 NH core, all = 0 HY core). Then all computations of the dynamical core can be treated in a unified code. Moreover, the non-hydrostatic dynamics may be introduced smoothly during the integration with in time changing control parameters when started from hydrostatically balanced initial state.

Work outline: The non-hydrostatic dynamics was formulated as a departure to the HPE system. A paper describing the method was published. The method was implemented based on CY46T1 and recently phased to become a part of cycle CY49T1. We will test the existing implementation in high resolution experiments, partially fulfilling the goals of the DE_330 project.

Subject: 6.2 Options for calculation of the X-term in vertical divergence variable

Description and objectives: The model variable for vertical motion in the linear part of the ICI time scheme may have several variants in the dynamical core of the ACCORD system. It was shown that the time scheme's numerical stability depends on its choice and that the most stable option is with modified vertical divergence including the so-called X-term depending on the model orography. On the other hand, in the non-linear part of the ICI time scheme, vertical velocity is used instead in all cases. It follows that a direct and reversed conversion between the two model variables must be applied in each time step. The X-term needed for this conversion may be either calculated from other variables or saved. In the latter case, it is necessary to treat X as a separate model variable which is being transformed between grid-point space and spectral space. Such transformation of an additional model variable is expensive but may have an important impact on the whole integration results. We implemented a logical key allowing to skip these transformations. This approach resulted in the CPU time savings. The code must be phased to CY50 and CY49T2_deode.

Subject: 6.3 Sweep interpolations in the SL advection scheme

Description and objectives: The interpolation process is the most computationally expensive step of the semi-Lagrangian (SL) approach for solving advection. It significantly impacts the accuracy of the solution and, besides spectral transformation, it can be the most computationally expensive part of model integration. Sweep interpolation was first proposed in [1] and further developed in [2]. It was subsequently implemented in the IFS global forecasting system by Filip Váňa (ECMWF). Theory and experience suggest that this new method could offer a faster yet precise alternative to the classical cubic Lagrange interpolation currently used in the ACCORD system. We intend to implement sweep interpolation in the LAM version of the ACCORD system, and then perform extensive testing

to demonstrate its advantages for LAM applications.

[1] Mortezazadeh, M. and Wang, L., 2017, *A high-order back-ward forward sweep interpolating algorithm for semi-Lagrangian method*, Int. J. Num. Meth. Fluids, 84, 584–597,doi: 10.1002/fld.4362

[2] Mortezazadeh, M. and coauthors., 2024, *Sweep interpolation: a cost-effective semi-Lagrangian scheme in the GEM model*, Geosc. Model Develop. 17/1, 335–346, doi: 10.5194/gmd-17-335-2024

Proposed contributors: Petra Smolíková (Cz), Natalia Szopa (Pl)

Estimated efforts: 3 PM of local work, 1 PM research stay at CHMI

Planned deliverables: 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.

Subject: 7.4 Preparation of new LBC files from IFS

Description and objectives: Since in DE_330 project, LBC files are created either from the HR IFS or from DT based again on IFS, the design of coupling must be evaluated and some conclusion for the DE_330 project must be taken. Similar considerations are necessary for the preparation of new operations which are in progress in several RC LACE member states.

Proposed contributors: if available

Estimated efforts: 0 PM so far

Task 8. Documentation

Subject: 8.1 Documentation for recently developed dynamics options

Description and objectives: There is an urgent need for concise documentation of the recently developed Dynamics features to facilitate understanding of the implementation of new methods in the code, potentially, its further development. This need has been recognised at ACCORD consortium level, and efforts in this direction at RC LACE will be coordinated with the ACCORD documentation officer and Dynamics area leader. Such documentation should comprise a scientific section containing equations and explanations, and a technical section containing descriptions of relevant routines in the code, names of variables, arrays and logical keys, and descriptions of namelist parameters.

Proposed contributors: Petra Smolíková (Cz),???

Estimated efforts: 4 PM of local work

3 Summary of resources

The total effort invested into the area of Dynamics & Coupling in the frame of RC LACE during 2026 is expected in the amount of 24 person/months, only 3 person/months from that supported by RC LACE budget directly. The planned efforts are kept roughly on the level of the previous years, the Task 7: Coupling strategy is not being felt as urgent currently and no efforts are planned for it. On the other hand, a new Task 8: Documentation is proposed.

Task	Resources	
	Total	Stays
1. Vertical discretization	2	1
2. Horizontal diffusion	2	0
3. Time scheme	4	1
4. Evaluation of the dynamical core in VHR	6	-
5. Optimization of the model code	2	-

6. Basic equations	4	1
7. Coupling strategy	0	-
8. Documentation	4	
Total manpower	**24**	**3**

4 LACE supported stays

We plan the following research stays for 2026:

1) Vertical resolution increase, consequences in turbulence – Mario Hrastinski, 1 PM in Prague
2) Orographic terms in the linear part of the ICI time scheme – Nika Kastelec, 1 PM in Prague
3) Sweep interpolations in the SL advection – Natalia Szopa, 1 PM in Prague

5 Meetings and events

We plan to attain the following events:

1) Dynamics Days, January 2026
2) LSC Meeting, March 2026
3) 6th ACCORD All Staff Workshop , April 2026
4) 3D Turbulence Working Days, June ??? 2026
5) LSC Meeting, September 2026
6) 48th EWGLAM and 33rd SRNWP joined meetings, September 2026

6 Risks and constrains

There is a lot of tasks aiming on testing several configurations and model features in high resolution experiments. These tasks are a part of the DE_330 project or possibly other projects. The focus on such tasks may prevent people from being able to do new code development and research aiming to propose new methods.