Working Area Dynamics & Coupling

Work Plan Proposal

Prepared by:	Area Leader Petra Smolíková
Period:	2024
Date:	08/09/2023

1 Introduction and background

In 2024 we propose a restructuralization of several tasks and more detailed structure of the subjects being proposed to be solved. We try to get closer to the structure of the ACCORD Work Plan for 2024. New topics get new numbers in the RC LACE subject numbering being held since 2013 to keep track of all topics we were interested in. We estimate the workforce per task.

After the activity in the area of coupling in the few last years several topics were finished (as the testing of new LBCs prepared from IFS) or closed for non-availability of a dedicated workforce.

This plan is reflected in the ACCORD Work Plan for 2024 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). Several RC LACE members participate as well in the project DE_330.

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

The topic is CLOSED.

Subject: 1.2 Modularization of vertical discretization

The topic is CLOSED.

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.

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), Bruno Ćurjurić (Cr)

Estimated efforts: 3 PM of local work

Planned deliverables: report, code changes

Task 2. Horizontal diffusion

Subject: 2.1 Tuning and redesign of the horizontal diffusion depending on the scale

The subject was CLOSED and its goals were redistributed to the subjects 2.2-2.4 to better coincide with the ACCORD Work Plan.

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), Bruno Ćurjurić (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 is CLOSED.

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: Iterative centered 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.

The "on demand" ICI scheme was implemented in 2021 based on CY46T1. Here 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 scheme with NESC predictor is applied, a cheaper SI time scheme (only predictor) 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. The detailed plan depends strongly on the results obtained in the last part of 2023.

Unfortunately, in CY49T0 the routines used for the implementation of this method were significantly changed and the implementation must be reconsidered. Moreover, the time scheme combining SETTS and NESC treatments separately in each grid point based on a stability condition being satisfied for this grid point or not – the so called "mixed scheme" – was broken in CY49T0 as well and its implementation must be also adjusted.

Subject: 3.4 Terms redistribution through new vertical velocity variables

The topic is CLOSED.

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.

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

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

Planned deliverables: report, code changes

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

The topic is closed.

The dynamical adaptation application is not used anymore in the Croatian operations.

Subject: 4.2 Upper boundary condition

The topic is CLOSED.

Subject: 4.3 Experiments in very high resolution

The subject was CLOSED and its goals were redistributed to the subjects 4.4-4.7 to better coincide with the ACCORD Work Plan.

Concerning the participation of several RC LACE members in the project DE_330 our focus must be in hyper-resolution applications. Hence, several test cases with the horizontal resolution under 1km were prepared expected to be run first 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 have to 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 technique increase the numerical stability achieved in VHR experiments?

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: 4.7 Consecutive domain approach

Description and objectives: One of the goals of the DE_330 project is the application of the so called "consecutive domain approach". A LAM in a dynamical adaptation is first run on a bigger domain and then several high-resolution LAM runs are nested inside and coupled to the lower resolution run on a bigger domain. These domains may be partially overlapping and are supposed to follow the trajectory of meteorological structures (as convective storms). The approach is new and many new questions are emerging around.

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.

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

Estimated efforts: 4 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.

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), Oldřich Španiel (Sk)

Estimated efforts: 1 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 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, these parameters 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: 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 the next cycle CY49T1. The main key controlling the usage of the method is LNHHY in namdyna.

We will test the existing implementation in high resolution experiments, partially fulfilling the goals of the DE_330 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 assess the behavior of the scheme in relation to steep slopes present in the domain in real simulations.

Proposed contributors: Petra Smolíková (Cz)

Estimated efforts: 3 PM of local work

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: 7.2 Frame approach in the LBC files

The topic is CLOSED.

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

The topic is CLOSED.

Proposed contributors: Ana Šljivić (Cr)

Estimated efforts: 2 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 2024 is expected in the amount of 20 person/months, 3 person/months from that supported by RC LACE budget directly. The planned efforts are kept roughly on the level of the previous years, but the plan is made more realistic by removing pending topics and focusing on the topics which are ongoing.

Task	Resources	
	Total	Stays
1. Vertical discretization	3	-
2. Horizontal diffusion	3	1
3. Time scheme	4	2
4. Evaluation of the dynamical core in VHR	4	-
5. Optimization of the model code	1	-
6. Basic equations	3	-
7. Coupling strategy	2	-
Total manpower	**20**	**3**

4 LACE supported stays

1) Tuning and redesign of the horizontal diffusion depending on the scale – Mario Hrastinski, 1 PM in Prague
2) Dynamic definition of the iterative time schemes - Alexandra Craciun, 1 PM in Prague
3) Orographic terms in the linear part of the ICI time scheme – Nika Kastelec, 1 PM in Prague

5 Meetings and events

1) 3D Turbulence Working Week, Toulouse, France, January 2024, attended by 2 RC LACE colleagues
2) LSC Meeting, March 2024
3) 4th ACCORD All Staff Workshop 2024, March 2024
4) LSC Meeting, September 2024
5) 45th EWGLAM and 30th SRNWP joined meetings, September 2024

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.