Working Area Dynamics & Coupling

Progress Report

Prepared by:	Area Leader Petra Smolíková
Period:	July - December 2024
Date:	28/02/2025

Progress summary

This report summarizes the work done in the Area of Dynamics & Coupling of the RC LACE from July to December 2024. Three research stays were executed in this period. Other work was done locally. The work done was registered in the work packages DY1 - Improvement of SISL spectral dynamical core (H and NH), H1 – Turbulence and shallow convection and PH7 – On the interface between the surface and the atmosphere of the ACCORD registered workforce summary for the last two quarters of 2024 and partially also in the project DEODE_330. Some work was registered under DY3 – Development of methods for solving the implicit equation in grid point space, but the correct placement would be DY1.

We keep track of closed topics and subjects in the numbering and number the new topics and subjects with consecutive numbers. The closed topics and subjects are not listed any more in the report and thus the numbering may jump up several numbers.

1. Scientific and technical main activities and achievements

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.

Status: No progress was made.

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.

Status: No progress was made.

Executed efforts in Task 1: None

Task 2. Horizontal diffusion

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

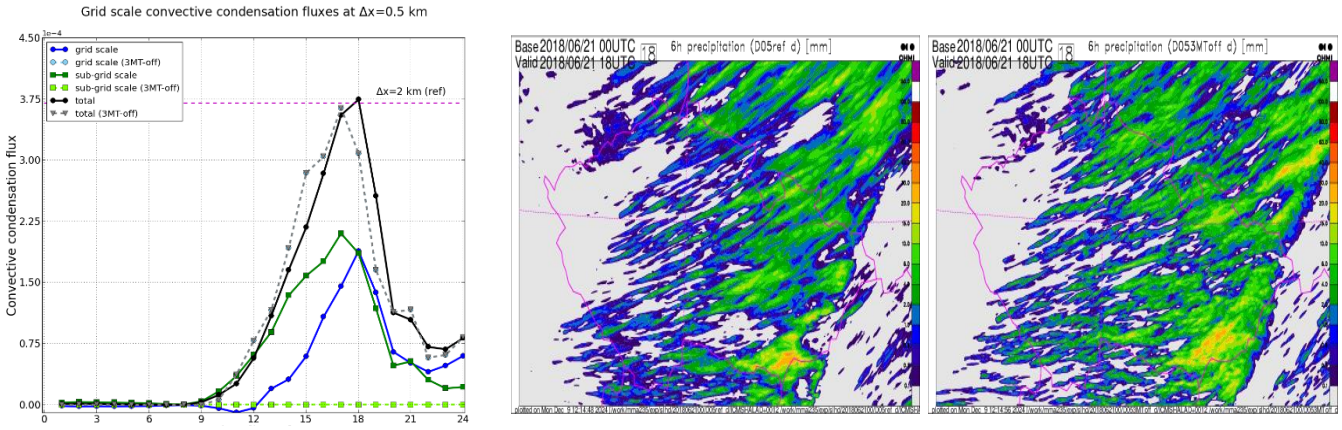

Figure 2: Left: Spatially averaged resolved, subgrid and total convective condensation flux for 21 June 2018 convective case for 500m horizontal resolution with and without 3MT. Precipitation cumulated between 12 and 18 UTC for the convective case, with 3MT (middle) and without 3MT (right).

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.

Status: The effect of 3MT scheme on the resolved, subgrid and total TKE was investigated in the experiments with the highest horizontal resolution of 500m. Even if the total convective condensation flux seems to have comparable time evolution of the spatially averaged value independently whether the 3MT scheme is applied or not (see Figure 1 in the left), the spatial distribution of cumulate precipitation is favorable to the necessity to use 3MT even in these high spatial resolutions (see again Figure 1). This is in accordance with the results presented by Wim de Rooij (KNMI) for the HARMONIE-AROME moist convection scheme applied in high resolutions.

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.

Status: This topic is tightly coupled with the Subject 2.2 and the results comes as the conclusions of it. Spatially averaged resolved, subgrid and total convective condensation flux for 21 June 2018 convective case were investigated in the cascade of resolutions. See Figure 2. A slight increase in the resolved flux and a slight decrease in the subgrid flux are observed with the total value of the spatially averaged

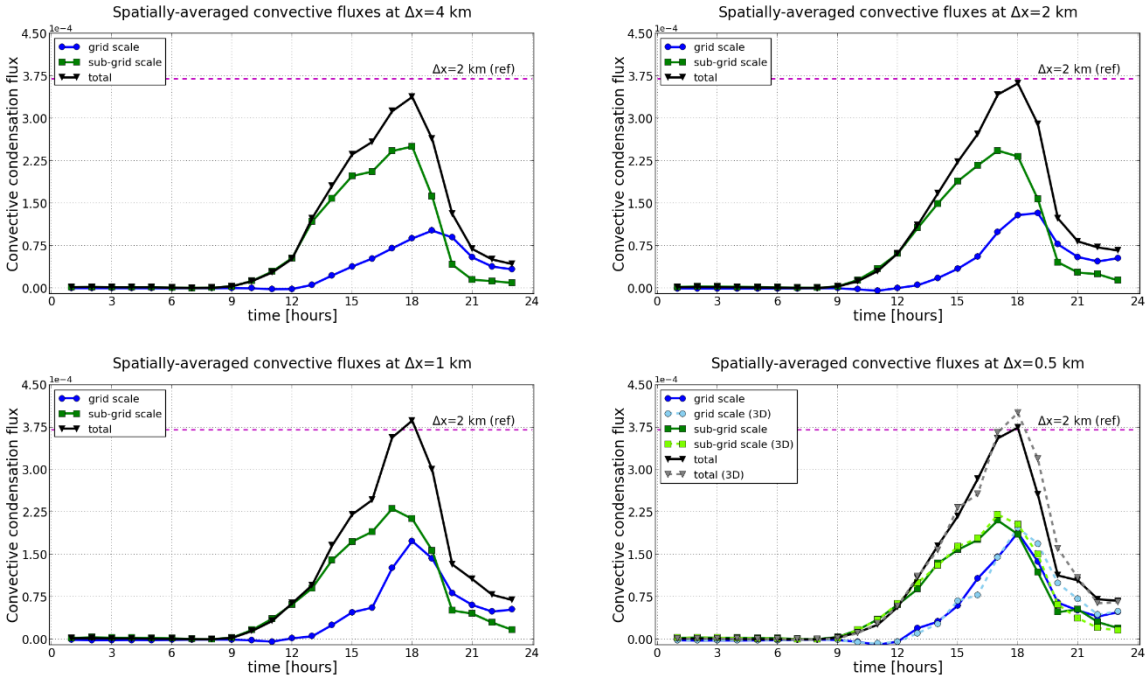

Figure 2: Spatially averaged resolved, subgrid and total convective condensation flux for 21 June 2018 convective case at the cascade of resolutions.

convective condensation flux being almost preserved throughout the resolutions. This seem to show that convection is designed already as scale aware. The future work will aim for more intensively pronounced effects.

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.

Status: The pseudo 3D turbulence code in the TOUCANS scheme of the ALARO CMC was revised and related experiments were performed at the cascade of resolutions (500m, 1km, 2km and 4 km). The current pseudo 3D turbulence scheme in the ALARO CMC introduces two effects, the horizontal effects in the production of turbulence energies and the additional 2D diffusion equation. Additionally, unified horizontal turbulence length scale is defined for both approaches. The computation of horizontal derivatives in the shear production term involved in pseudo 3D turbulence scheme is performed by SLHD either on η-levels or on z-levels. The impact of this choice on the averaged profiles of kinetic energy is very limited.

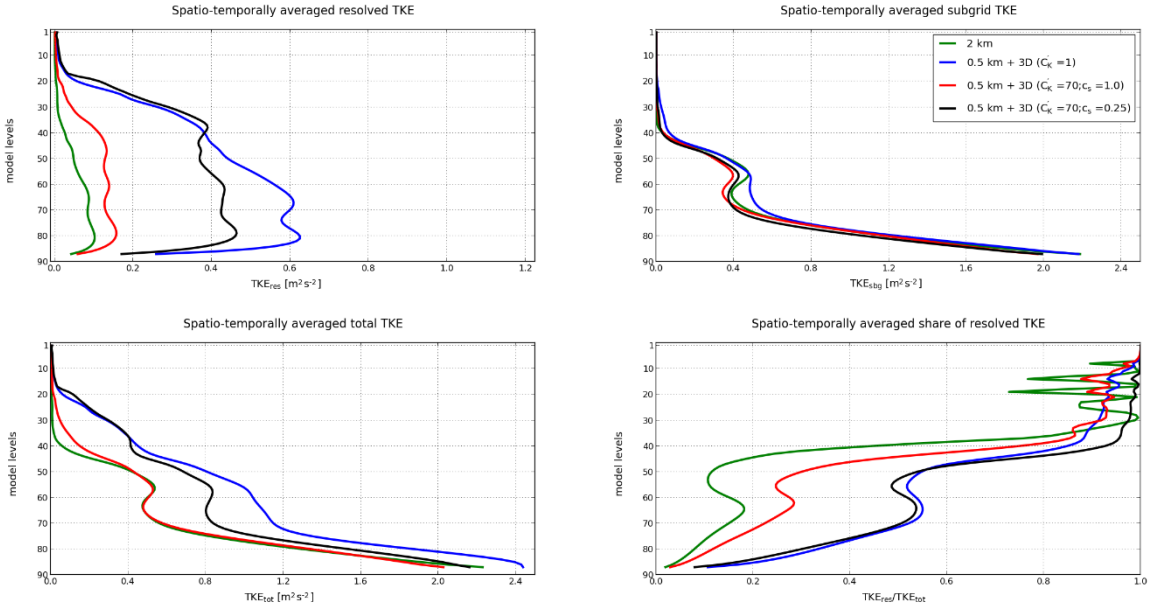

Figure 3: Spatially and temporally averaged resolved (top left), subgrid (top right), total (bottom left) TKE and the share of resolved versus total TKE (bottom right) for 500m resolution and several choices of pseudo 3D turbulence parameters; 2km resolution values are shown for comparison.

For the analysis of results, we use several diagnostic tools as chosen 3D prognostic fields (in particular wind components and pressure departure), kinetic energy spectra (KES) obtained with ECTO and averaged profiles of resolved, subgrid and total TKE. The latter are computed over a prescribed sub-domain. Further, the impact of various constants in the pseudo 3D turbulence parametrization was investigated with the aim to find the most influential and beneficial choice allowing for scale awareness. See Figure 3 for the illustration of results. The red curve shows the test matching the best the green curve for the total TKE, i.e. the total TKE is being preserved the best throughout the resolutions. This is the goal we would like to obtain. The pseudo 3D turbulence setting used for the experiment depicted with the red curve was then further investigated.

Contributors in Task 2: Mario Hrastinski (Cr), Petra Smolíková (Cz)

Executed efforts in Task 2: 0.5 PM – the second part of Mario‘s research stay at CHMI, Prague, 1.5 PM of local work

Deliverables: report published soon on RC LACE web pages

Task 3. Time scheme

Subject: 3.3 Dynamic definition of the iterative time scheme

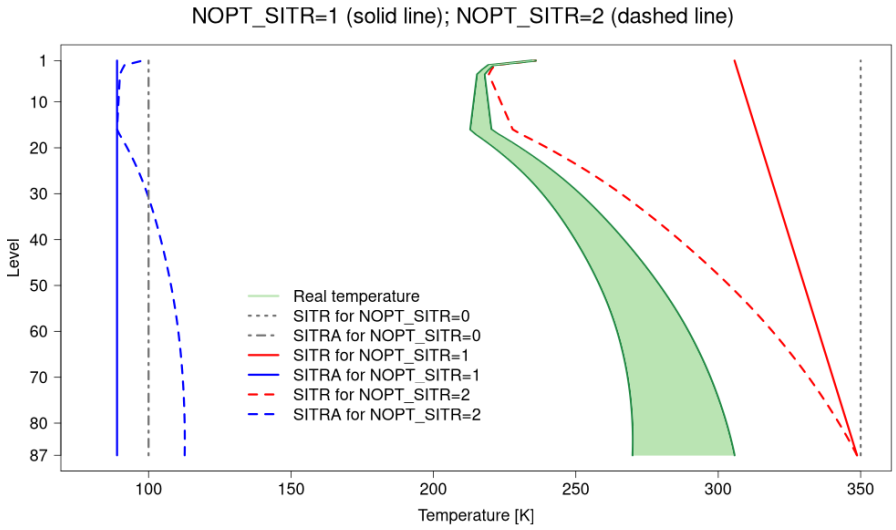

Figure 4: Vertical profiles of SI reference parameters connected to temperature.

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 additional iteration (corrector) 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.

Status: The new option NOPT_SITRA designed by Fabrice Voitus (Météo France) in CY48T3_deode branch was tested. It allows for the dynamically chosen SI reference state parameters SITR and SITRA

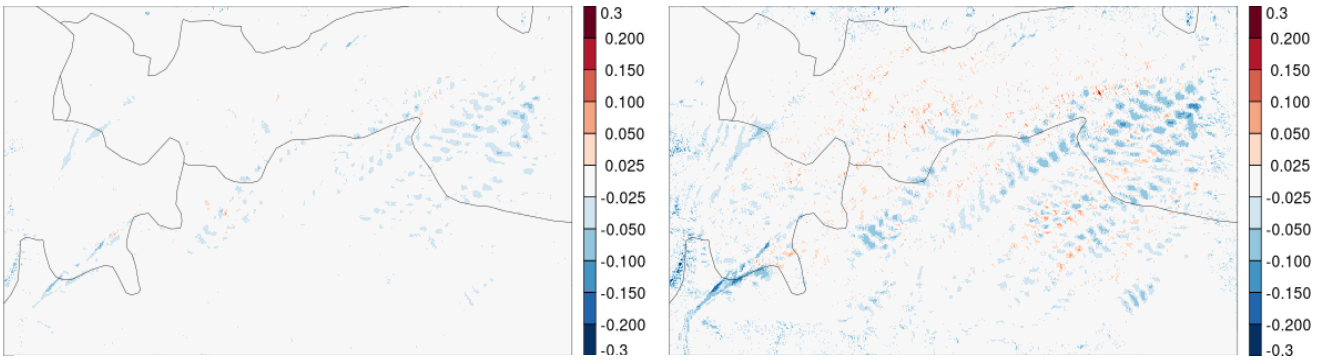

Figure 5: Differences between the non-linear residuals in the temperature equation. Left: NOPT_SITR=0 compared to NOPT_SITR=1, right: NOPT_SITR=0 compared to NOPT_SITR=2.

according to the current temperature value in the domain represented with the spectral norms of temperature. Moreover, a vertically non-constant profile of SITR and SITRA is allowed. See Figure 4 for the illustration of available profiles of SITR and SITRA. The previously used value was constant in vertical and during the whole integration with values SITR=350K and SITRA=115K.

The expected benefit of the modification is the reduced value of non-linear residuals in the prognostic equations for temperature, divergence and non-hydrostatic model variables. A diagnostic tool allowing to visualize the non-linear residuals was prepared. The model level 50 of the non-linear residual of the temperature equation in case of constant and dynamically defined SITR is available in Figure 5. Blue

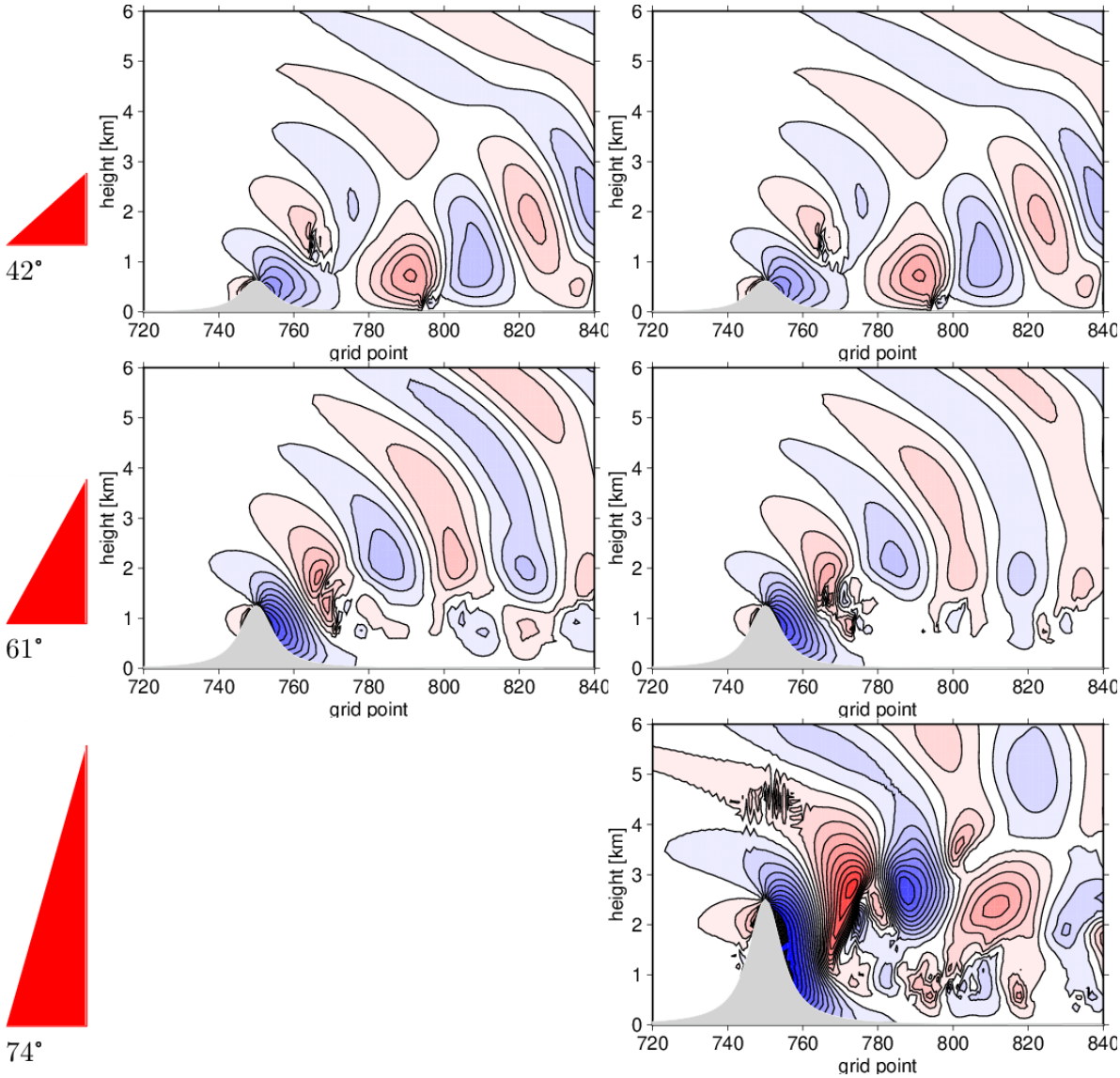

Figure 6: Idealised case of the uniform wind over the Agnesi shaped mountain with various steepness. The slope is demonstrated on the left with the right triangles. The left column shows results with zero reference slope in the SI scheme, right column shows result with constant slope of value 1.

colors show where the dynamically defined SI parameters result in smaller absolute value of non-linear residuals. The work will be continued.

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.

Status: The reference horizontal gradient of geopotential (related to the constant slope of orography) in the linear model was calculated for all vertical levels differently than in the previous attempt, based on surface values and the vertical profile of the linear model reference state after hints from Fabrice Voitus. The method results in new formulation of the vertical Laplacian operator in the linear model of the ICI time scheme. Then three different discretisations of this new linear vertical Laplacian were proposed and compared to the solution proposed by Fabrice Voitus in CY48T3_deode. Then several idealized 2D tests were prepared showing increased stability of integration with non-zero reference horizontal gradient of geopotential depending on the reference value RSLP of slope representing the given domain. For small values of the real slope of the mountain the stability is similar with non-zero reference slope as with the previous formulation not taking in account the orography in the linear model while for very high values of the real slope the stability of the numerical solution is clearly improved.

Figure 6 shows the idealised mountain slopes with red triangles and the solution of the idealised case with constant wind blowing over the Agnesi shaped mountain for the SI reference slope RSLP=0 (in the left) and RSLP>0 (in the right). For the highest mountain the case with zero RSLP was unstable and the integration crashed (bottom left picture is thus missing).

It shows that an appropriate value of the reference slope must be chosen. It was tested that noise is not generated over the flat terrain with a reasonable value of the reference slope. See Figure 7 illustrating what happens if the value of RSLP is too big – noise appears close to the ground for RSLP=4 at

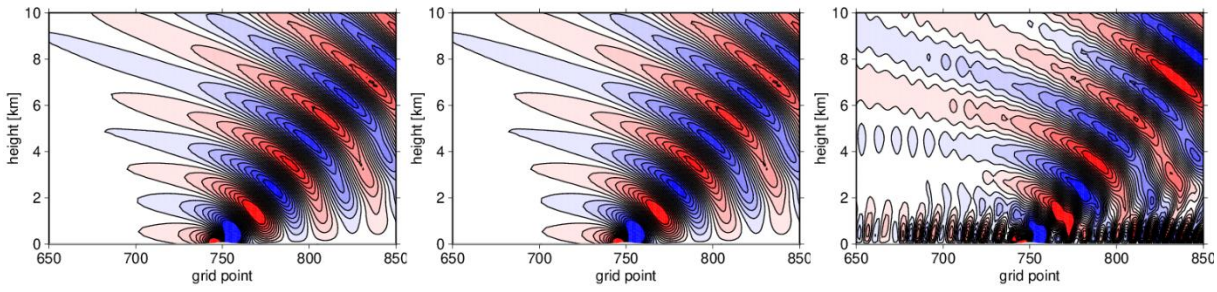

Figure 7: As Figure 6 but with very low mountain and the reference slope being 0 in the left picture, 1 in the middle and 4 in the right picture.

the bottom right picture. Then real 3D simulations with the Alpian domain in 200m horizontal resolutions were prepared and some tests performed. On top of that, a documentation describing the design of code modifications is in preparation.

Contributors of Task 3: ALEXANDRA Craciun (Ro), Nika Kastelec (Sl), Petra Smolíková (Cz)

Executed efforts in Task 3: 1PM of research stay of Alexandra at CHMI (partially remotely), 2.75 PM of local work registered to DY1 work package of the ACCORD workforce summary

Documentation: a new code design documentation is in preparation

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

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.

Status: A contribution describing the tests with several possible truncations in very high-resolution experiments was prepared for the DEODE_330 deliverable.

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?

Status: The code modifications prepared by Fabrice Voitus based on CY48T3 were phased to CY48T3_deode and tested. A recommended setting of new dynamics options was prepared and it is ready for long time verifications in DEODE_330 project.

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.

Status: No progress was made.

Subject: 4.7 Consecutive domain approach

Description and objectives: One of the goals of the DEODE_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.

Status: No progress was made.

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.

Status: The initialization through the blended approach allowing to start integration from the hydrostatic primitive equations and continue gradually towards the non-hydrostatic Euler equations was tested. The results are still preliminary.

Contributors of Task 4: Petra Smolíková (Cz)

Executed efforts in Task 4: 0.5 PM of local work

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-numbers 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.

Status: Compatibility of hydrostatic dynamics and VFE discretization with single precision was tested in CY48T3 and CY49T2. The problems found are connected to the number of vertical levels or its vertical distribution exhibiting big gaps between some layers. Thus, correct runs with 87 vertical levels used in the Czech Republic operationally contrast with crashing runs with 60 vertical levels of A-LAEF at 5km resolution. The sources of these problems were not yet tracked.

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.

Status: No progress was made.

Contributors of Task 5: Petra Smolíková (Cz), Oldřich Španiel (Sk)

Executed efforts in Task 5: 0.5 PM of local work.

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 control 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.

Status: The gradual transition from the HPE system to non-hydrostatic fully elastic (EE) system of equations was introduced by Fabrice Voitus. The crucial item here is the correct evaluation of the non-hydrostatic prognostic variables – the vertical divergence and the pressure departure. It is present in the code under the logical key LNHHY. On top of that, the logical key LNHHY_FIXED was reintroduced. This key allows for the fixed blended system of equations being used throughout the whole integration. Simplified approach with only one control parameter RNHHY_DELTA was prepared. The value of

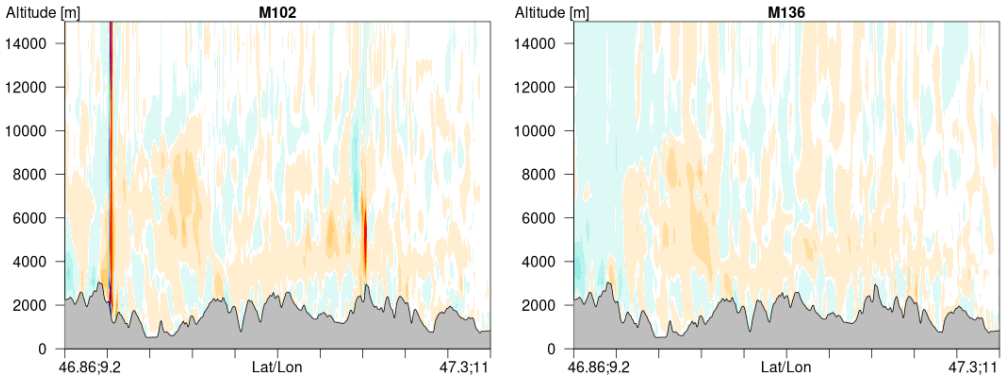

Figure 8: Vertical cross section through the field of vertical velocity over the mountain ridge for RNHHY_DELTA=1 corresponding to NH (in the left) and RNHHY_DELTA=0.002 (in the right) coresponding to the blended approach. Notice the removed chimney like pattern on the right picture.

RNHHY_DELTA between 0 and 1 ensures the usage of all possible blended systems. The results of integration with different values of this control parameter are demonstrated by Figure 8.

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. The transformation to spectral space guarantees some level of filtering and consistency of the calculations needed for the vertical motion variables conversion. We would like to investigate whether the current treatment of the X-term is the best choice in terms of accuracy and numerical stability of the time scheme, and what would be the influence of the recalculation of X in each place where it is needed without its transformation to spectral space.

Status: The code modification was prepared that enables to calculate the X term whenever needed from model variables without the need to transform the X term to the spectral space and back. The logical key LSPNHX was introduced for this purpose. The CPU time saving coming from this modification is about 7% for the whole model forecast. On top of that, when the X term is calculated directly and used for the transformation from vertical divergence variable to the vertical velocity variables without evaluation of the time evolution of X (under the key ND4SYS=0), the chimney patterns are removed from the vertical velocity field as demonstrated in Figure 9. Moreover, the time oscillations present in the solution are as well being removed. This is demonstrated by the time evolution of domain averaged spectral norms shown in Figure 10.

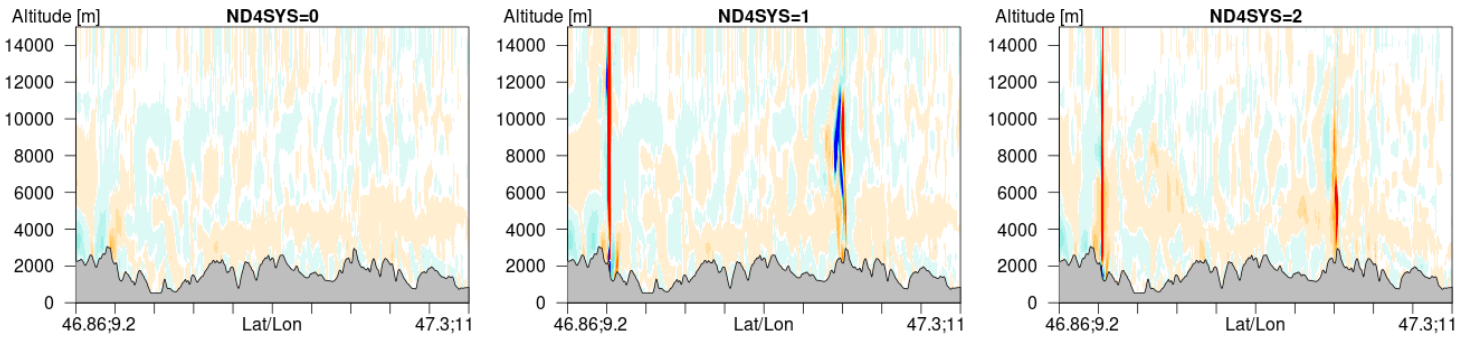

Figure 9: Vertical cross section through the field of vertical velocity over the mountain ridge for different values of ND4SYS. Left: ND4SYS=0, middle: ND4SYS=1, right: ND4SYS=2.

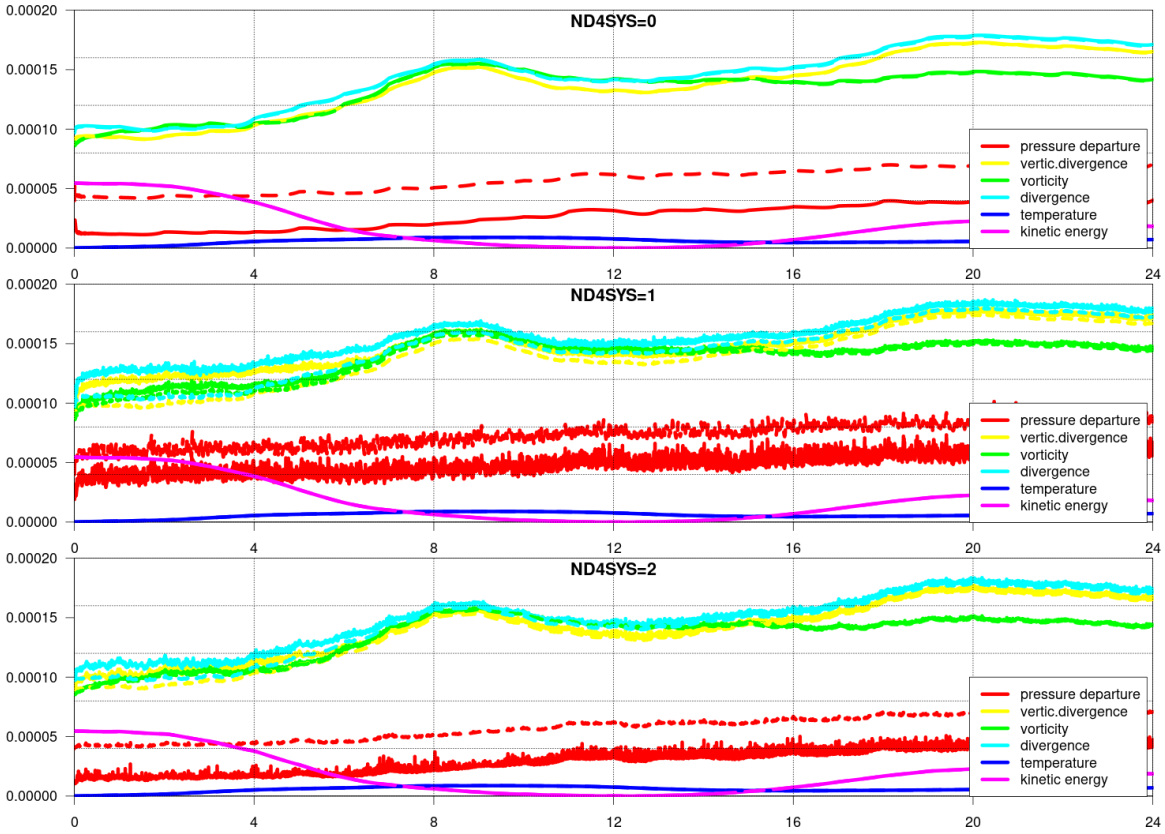

Figure 10: Domain averaged spectral norms of model variables for different values of ND4SYS.

Contributors of Task 4: Natalia Szopa (Pl), Petra Smolíková (Cz)

Executed efforts in Task 6: 1 PM – research stay of Natalia Szopa at CHMI, 1.5 PM of local work

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.

Status: No progress was made.

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 the new operations. Problems with the performance of the e903 procedure were detected and need to be solved.

Status: No progress was made.

Executed efforts in Task 7: None.

2. Documents and publications

Three reports from the executed research stays are in preparation:

1. Alexandra Craciun, *Dynamic definition of the iterative time scheme for the ACCORD system*, report from the stay at CHMI, October 2024, 4pp.
2. Natalia Szopa, *The X-term treatment for the vertical motion variable in the ICI time scheme of the ACCORD system*, report from the stay at CHMI, November 2024, 8pp.
3. Mario Hrastinski: *Optimizing the performance of sub-kilometer ALARO CMC*, report from the stay at CHMI, December 2024, 14pp.

On top of that, the documentation of the recently developed dynamics options is in preparation.

3. Activities of management, coordination and communication

1. 43th LSC, 18-19 September 2024, Wien, Austria
2. EWGLAM/SRNWP Meeting, 30 Sep – 3 Oct 2024, Prague, Czech republic, presentation of Petra Smolíková: *Dynamics for higher numerical consistency and stability*

4. LACE supported stays

Three research stays were executed in the second half of 2024:

1. Alexandra Craciun, Dynamic definition of the iterative time scheme, 0.5 PM in Prague and 0.5 PM remotely (Oct 2024)
2. Natalia Szopa, Options for calculation of the X-term in vertical divergence variable, 1Pm in Prague (Nov 2024)
3. Mario Hrastinski, Tuning and redesign of the horizontal diffusion depending on the scale, 0.5 PM in Prague (Dec 2024), the second part

5. Summary of resources/means

The efforts invested in the area of Dynamics & Coupling of RC LACE in the whole year 2024 reach three quarters of the efforts planned. Together 18 PM were reported in the area of Dynamics and Coupling. A lot of efforts was invested in the better design of the ICI time scheme of the ACCORD system and in the testing of the newly designed features in the model dynamics. These efforts are needed to fulfil the goals of the project DEODE_330 and mirror the engagement of the RC LACE member states in this project. The coupling strategy does not seem to call for urgent adjustments and may be seen as satisfactory for the current model applications. Four research stays were executed in the length of 4 PM in total which fully corresponds to the planned efforts. We contributed to the work packages DY1, PH1, PH7 and some work was committed as connected to DEODE_330 to the ACCORD work force statistics.

Task	Resources					
	Planned	First half 2024	Second half 2024	Total 2024	Stays	DEODE_330
1. Vertical discretization	3	0	0	0	-	-
2. Horizontal diffusion	3	1.5	2	3.5	1/1	0.5
3. Time scheme	4	2.5	3.75	6.25	2/2	-
4. Evaluation of the dynamical core in VHR	8	4.5	0.5	5	-	1.5
5. Optimization of the model code	1	0	0.5	0.5	-	-
6. Basic equations	3	0	2.5	2.5	1/1	-
7. Coupling strategy	2	0.25	0	0.25	-	-
Total manpower	**24**	**8.75**	**9.25**	**18**	**4/4**	**2**