Working Area Dynamics & Coupling

Progress Report

Prepared by:	Area Leader Petra Smolíková
Period:	2020
Date:	17/3/2021

Progress summary

This report summarizes the work done in the Area of Dynamics and Coupling of the RC LACE during 2020. Due to the epidemiologic situation in all the Europe the working conditions were limited, and several research stays have to be shifted or cancelled. Nevertheless, one research stay was executed in Prague. Valuable work was done as well locally. This report includes the work reported in the previous report being prepared for the LSC meeting held in September 2020.

1. Scientific and technical main activities and achievements

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). We plan to study the compatibility of direct inversion in the Helmholtz solver done after elimination of all variables but horizontal divergence (solution proposed by Voitus) with finite element vertical discretization.

Status: The cleaning and pruning of many existing code branches was done. The optimal configuration of VFE NH was chosen and several options which revealed obsolete were deleted. The code entered the cycle CY48t1 being prepared at the end of 2020 and expected to be declared in the first quarter of 2021. The compatibility of the newly proposed vertical velocity variable with VFE was not studied yet.

The topic is ONGOING.

Contributors: Jozef Vivoda (SHMU), Petra Smolíková (CHMI)

Executed efforts: 2 PM of local work

Documentation: short description for phasing

Subject: 1.2 Modularization of vertical discretization

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

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

The topic is PENDING.

Contributors: none

Executed efforts: none

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. For the start of the work, the diffusion coefficient used in SLHD and being a monotonic function of the total flow deformation along the terrain-following vertical levels was redesigned. Two domains were prepared for clean tests covering roughly the same territory and differing in the resolution. We will continue the work.

Status: Two research stays planned for the last quarter of 2020 (Mario Hrastinski, 0.5PM+0.5PM, at CHMI) were shifted to 2021.

The topic is PENDING.

Contributors: Mario Hrastinski (DHMZ), Petra Smolíková (CHMI)

Executed efforts: none

Documentation: none

Task 3. Time scheme

Subject: 3.1 Generalization of the semi-implicit reference state to include vertical profile of background variables and horizontal features as orography

Description and objectives: One of the possible ways to attack this subject is a direct inclusion of the tangent-linear approximated model in the semi-implicit time scheme. The stabilising effect of such method was identified at ECMWF for the hydrostatic IFS by Filip Váňa, and the potential of the new design of SI scheme has been exploited in low spatial resolution (corresponding to usual values in global applications). The most interesting point is the incorporation of orography and real vertical profiles into the linear model, while in the existing reference state for linearization no orography and only constant vertical profiles are present. The consequence of this new design of SI scheme would be no need of the spectral space representation of model variables and of transformations between spectral and grid-point spaces once the horizontal derivatives are calculated in a local way (for example through finite differences). The crucial point is here the iterative method used to solve the Helmholtz problem and its convergence behaviour in higher spatial resolutions (with steeper slopes). There are other less ambitious ways how the vertical profile of the reference state could be incorporated in the semi-implicit scheme which may be also investigated.

Status: **The topic is PENDING.**

Executed efforts: none

Documentation: none

Subject: 3.2 The trajectory search in the SL advection scheme

The topic is CLOSED.

Subject: 3.3 Dynamic definition of the iterative time scheme

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 topic is ONGOING. One research stay planned for this year was cancelled due to the covid-19 restrictions.

Contributors: Alexandra Craciun (ANM), Petra Smolíková (CHMI)

Executed efforts: 1 PM local work

Documentation: none

Subject: 3.4 Terms redistribution through new vertical motion variables

Description and objectives: Motivated by the work of Fabrice Voitus which was presented at the ALADIN Workshop in Toulouse in April 2018 we started this new subject. The aim is to reformulate the nonhydrostatic nonlinear model to obtain simple bottom boundary condition which is easily fulfilled. This aim may be reached only for restricted choices done in the dynamics of the ALADIN system. In particular, only the case when vertical velocity variable is

used in the nonlinear nonhydrostatic model in the two-time level SI SL scheme. The bottom boundary condition was proven to be very important for the stability and accuracy of the whole discretization of the system of prognostic equations. Several new formulations of vertical velocity were already proposed in 2018 and implemented in the model code. The work will continue.

Status: The cooperation with Fabrice Voitus has been established and the implemented options were tested in 3D experiments. It includes the w5 variable designed under the key NVDVAR=5 in CY46t1.bf02 and vertical discretization refinement implemented under the keys LNHEE_REFINE_SILAPL, LNHEE_REFINE_GRP, LNHEE_REFINE_PREHBBC in CY46t1.bf02. First, we run the forecast for 24 hours in the dynamical adaptation for 30 Oct 2017 00UTC, in the setting of the Czech operational suite. It has 2.325km horizontal resolution, 87 vertical levels, domain covering Alps, full ALARO-1 physics. The very good correspondence was found in the objective scores of all prognostic variables (wind field, temperature, relative humidity) for both vertical motion variables (w4 and w5) and very similar stability regions were detected. These regions are given by the range of timesteps and by the range of SITRA values which may be used to get 24 hours forecast without crash. The results are summarized in Table 1.

To demonstrate better stability properties of the scheme with the new w5 vertical motion variable compared to the previously implemented w4, we run experiments in higher horizontal resolution of 375m, the domain of Occitania partially covering Alps and reaching the Mediterranean See; see Fig.1. We run forecast from 3 Oct 2015 00UTC for 24 hours in dynamical adaptation with ALARO-1 physics without 3MT. The calculation is again considered stable if the run finishes. The results are summarized in Table 2.

Some problems were detected in the new w5 formulation with vertical discretization refinement, observable as the noise pattern in the prognostic variables fields. These problems were reported to Fabrice Voitus.

The topic is ONGOING.

Contributors: Petra Smolíková (CHMI)

Executed efforts: 2 PM of local work

Documentation: none

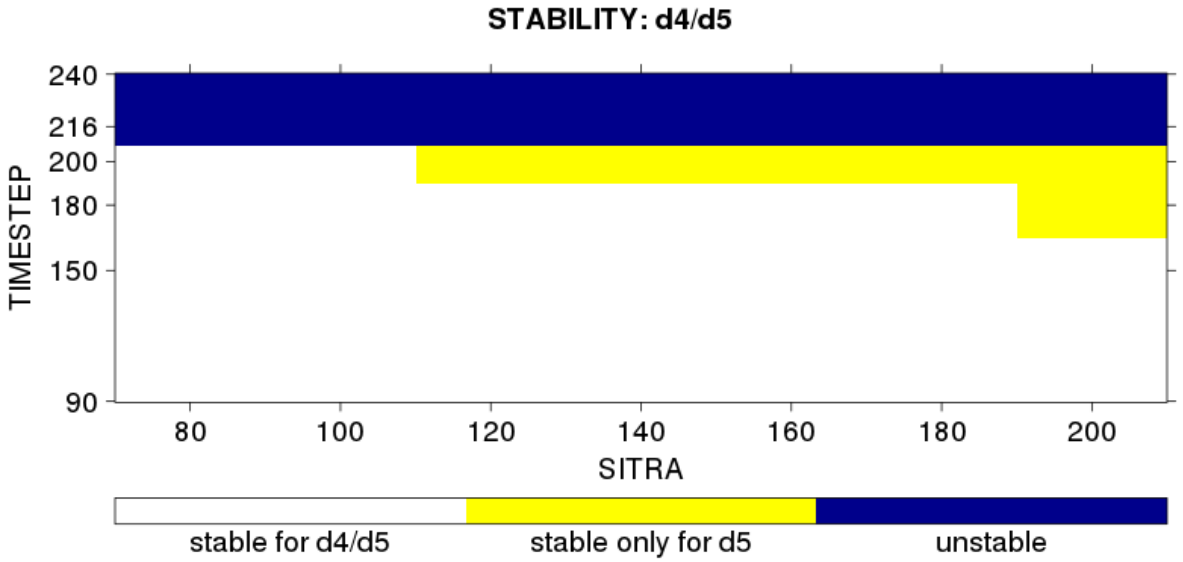

Table 1: Stability of experiments in 2.325km horizontal resolution.

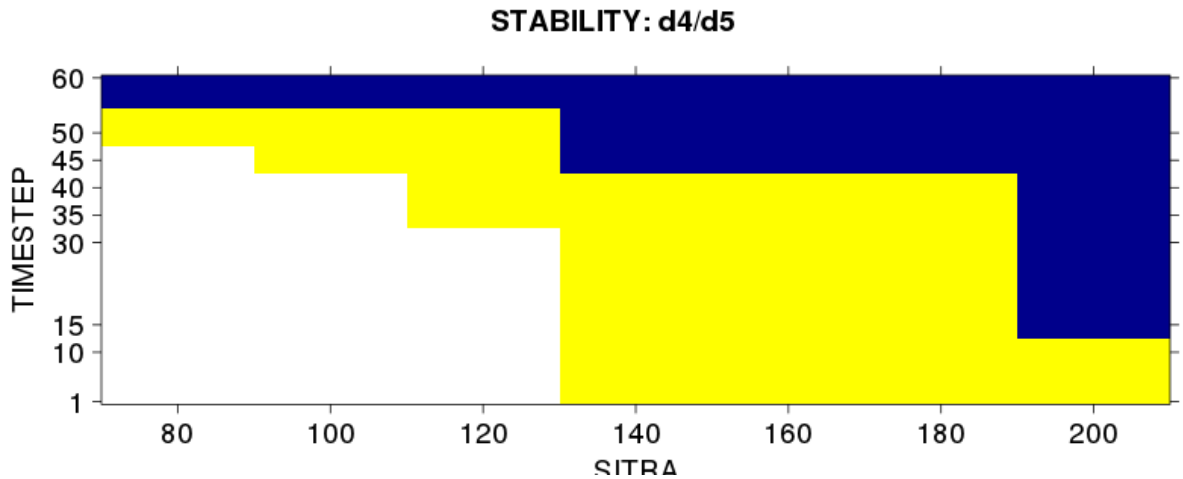

Table 2: Stability of experiments in 375m horizontal resolution.

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 on 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 non-hydrostatic 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.

Status: **The topic is PENDING.**

Contributors: Mario Hrastinski (DHMZ)

Executed efforts: none

Documentation: none.

Subject: 4.2 Upper boundary condition

Description and objectives: There are some indications that upper boundary may cause a problem in higher resolutions. There could be a big jump in vertical levels needed which may destabilize the whole model as it was observed for finite elements used in the vertical discretization of ALADIN-NH.

In general, on the top boundary there is no material surface contrary to the bottom boundary and vertically unbounded atmosphere may be undesirable in some applications. In practice, velocity normal to the upper boundary is set to zero causing wave reflection similar to lateral boundaries. Free-slip conditions are used for other variables. This means that the vertical derivatives of these variables are equal to zero and there is no mass and heat transfer across the boundary. Radiation boundary condition can be imposed by diagnostic relationship between pressure and vertical velocity at the top (Klemp, Durran 1983; Bougeault 1983). However, it is formulated in terms of vertical wavenumbers and frequencies and is difficult to be implemented. To overcome this problem an explicit absorbing layer is applied for example in SLHD (semi-Lagrangian horizontal diffusion) where spectral diffusion works only when approaching to the top, and an implicit absorbing layer is applied through the coarsening of the vertical resolution when approaching to the top. It should be investigated if there are some new or enhanced problems at the model top in horizontally or vertically higher resolutions and solutions could be proposed if needed.

Status: **The topic is PENDING.**

Executed efforts: none

Documentation: none

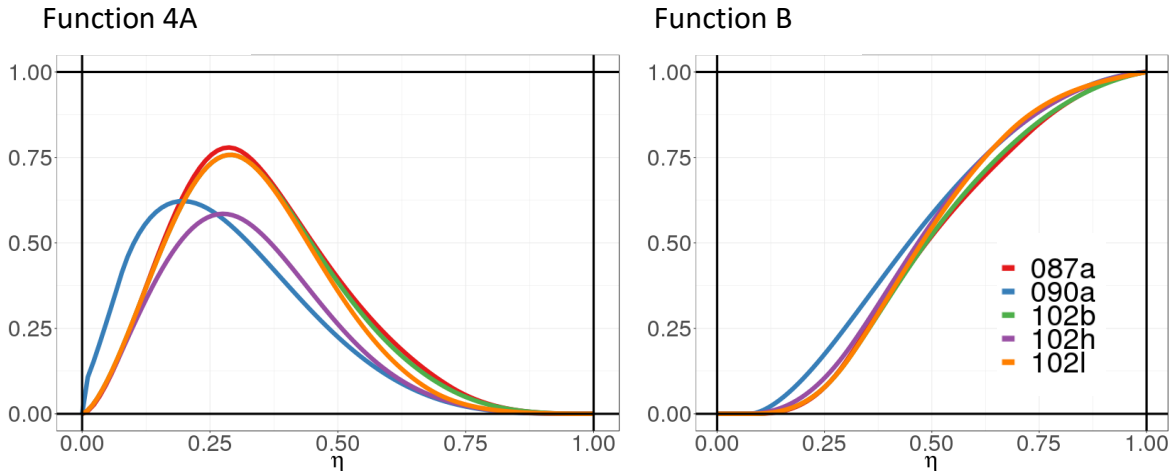

Figure 2: Distribution of A and Bs in experiments for 4.3.

Subject: 4.3 Experiments in very high resolution

Description and objectives: As reported by Fabrice Voitus (Météo France) the numerical stability of the ALADIN nonhydrostatic dynamical core is endangered as soon as the horizontal resolution of 350m is approached above steep orography. To be able to test this statement and to analyse the model dynamical core behaviour we must to start experiments in the very high resolution. For these goals the climate files must be prepared from a fine database.

Status: This year the study of increased vertical resolution was prepared. We tested the impact of the increase in the number of vertical levels from 87 to 102. Since the algorithm for the vertical levels distribution through the parameters A and B is parametrized with many parameters, we designed several possible vertical levels distributions which were then tested. We controlled the density of vertical levels in PBL layer, middle layer or troposphere layer. We started with two distributions simulating the density of vertical distribution of the Czech operational suite (87 levels) and Météo-France operational suite (90 levels). The best scores were obtained whenever the first level was placed closer to the surface (5m) compared to 10m of the Czech operational suite. In this case the screen level for wind is above the first model layer and the calculation must be revised. See Figure 3 for an illustration of scores for cloudiness and Figure 2 for A and B distribution. We will continue in the work started.

The topic is ONGOING.

Contributors: Petra Smolíková (CHMI)

Executed efforts: 2 PM of local work

Documentation: experiments results, report will be prepared

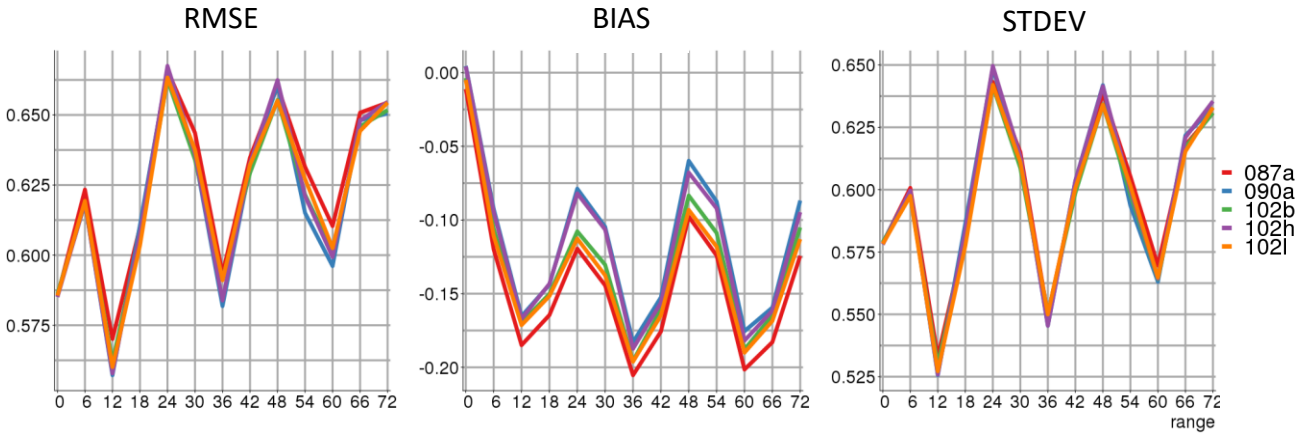

Figure 3: Objective scores of cloudiness for several experiments with various vertical levels distribution. Notation: 087a – 87 vertical levels of the Czech operational domain; 090a – 90 levels of AROME Météo France operations; 102b,102l – other proposals with 102 vertical levels and the first level in 10m; 102h – 102 vertical levels with the first level in 5m.

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: The single precision code under cy46t1.bf05 was investigated and problems with compilation were solved.

The topic is ONGOING.

Contributors: Oldřich Španiel (Sk)

Executed efforts: 0.25 PM local work

Documentation: none

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.

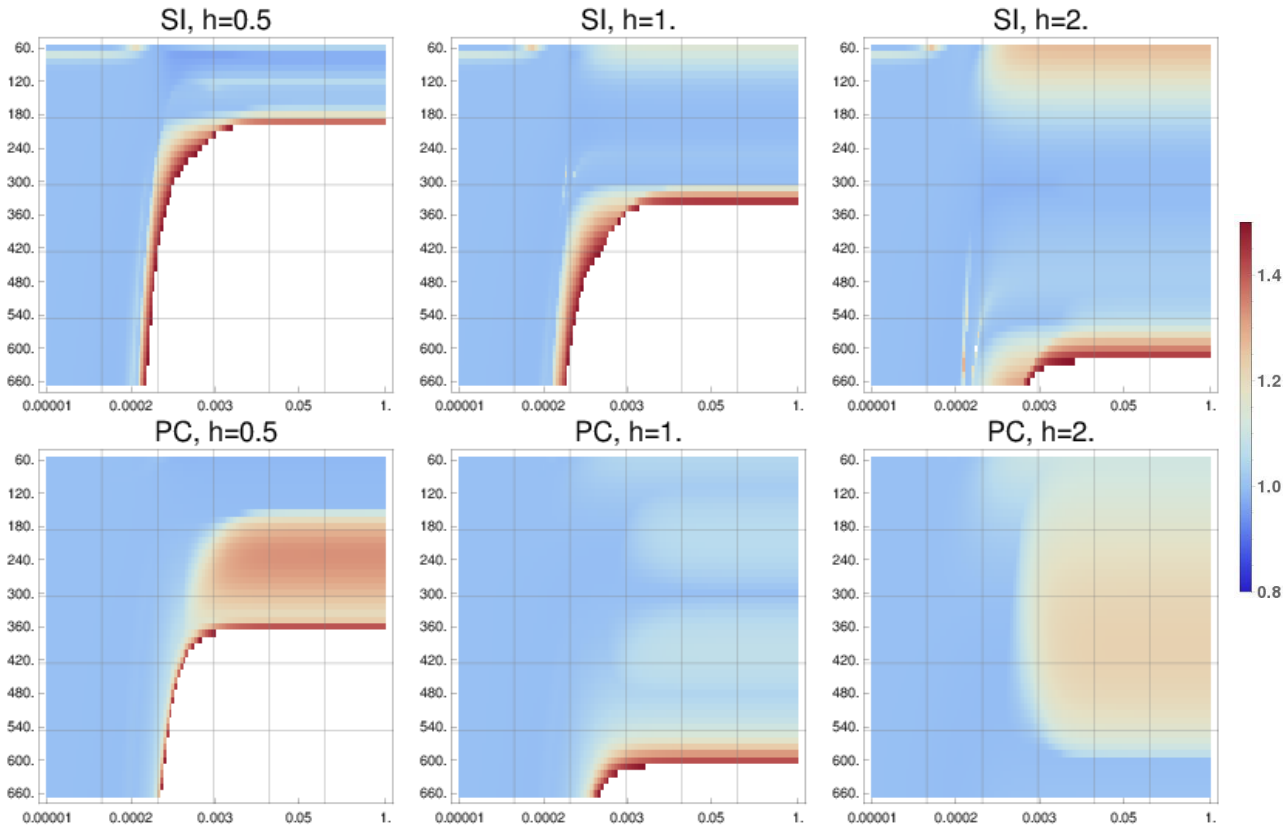

Figure 4: The amplification factor for SI and PC time schemes with different values of the wave number (horizontal axis) and different background temperature in the non-linear model (vertical axis). The time step is 15s and h is changed in the linear model only.The stability is achieved for values at most 1 (blue colors). White regions indicate very poor stability with values out of the scale.

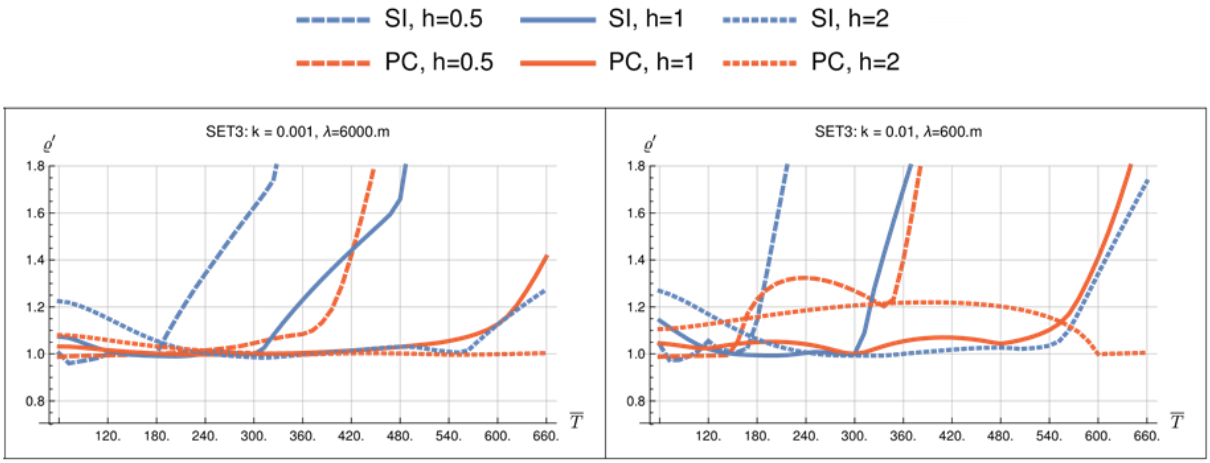

Figure 5: The amplification factor for Si and PC time schemes and several values of h used in the linear model only. Each graph is valid for one value of the wave number indicated at his top.

Status: The set of control parameters was introduced in the full Euler system of equations that master separately the nonhydrostatic terms. If all the parameters are set to 0, the system collapses to the hydrostatic primitive equations, while setting all parameters to 1 gives Euler equations. Relations between these parameters were found that ensure the characteristic equation of the hybrid linear system to have the same property (0 gives HPE solution, 1 gives EE solution). In the discretised context, the control parameters may be independently changed in the linear model and in the non-linear residual. In case of only linear model being modified with the control parameters distinct from 1, the solved equation system remains the set of full Euler equations. On the other hand, as soon as the control parameters are modified in the non-linear residual, the solved set of equations is affected, and we must carefully check if the nonhydrostatic features of the motion are still kept in the numerical solution.

The stability analysis of the SHB type was performed in the simplified context with only one control parameter being changed and all the other control parameters being evaluated according to it. We denote this parameter *h*. This analysis indicates which values of the control parameter *h* may possibly have the stabilization effect on the integration scheme. The results are illustrated in Figures 4,5 for the time step of 15s and the SI background temperature of 300K in the linear model. One may conclude that values of *h* slightly higher than 1 are beneficial for the stability while values smaller than 1 are destructive. The behaviour depends on the wave number and the chosen time scheme. Here, we denote SI the one step SETTLS time scheme, while PC means the predictor corrector scheme with one iteration of the non-linear solver.

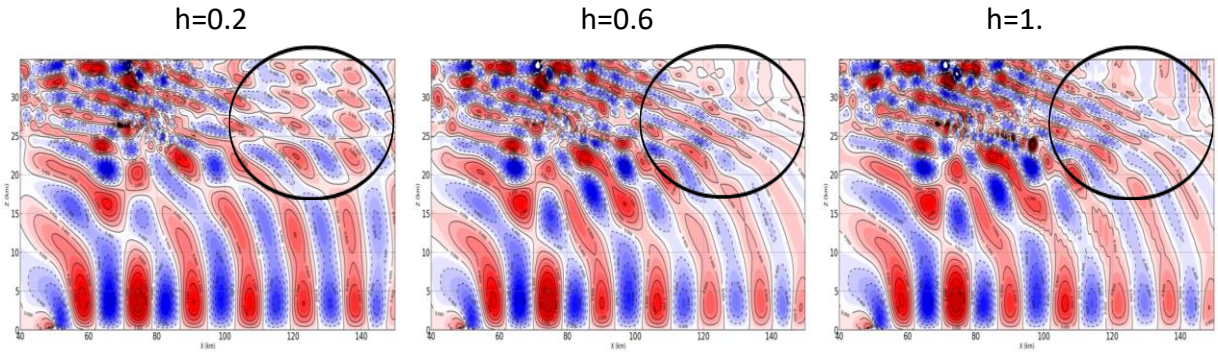

Figure 6: Vertical velocity w[m/s] in Keller trapped lee wave test case after 1000 steps.

The proposed ideas were implemented in the recent cycle CY46t1.bf02 and merged with other changes in dynamics, mainly the elimination of all variables except the horizontal divergence in the Helmholtz solver. Then idealized experiments in the vertical slice 2D model were prepared. We illustrate the results in Figure 6 for Keller trapped lee wave. The parameter *h* was changed in both the linear and the nonlinear model parts in this case. One may notice that small values of *h* give significantly different results then higher values of *h* and *h*=1. (See the top right corner.) We believe that the "nonhydrostatic behaviour" is kept for *h* close to 1 while there is a jump to "hydrostatic behaviour" if the control parameters are small.

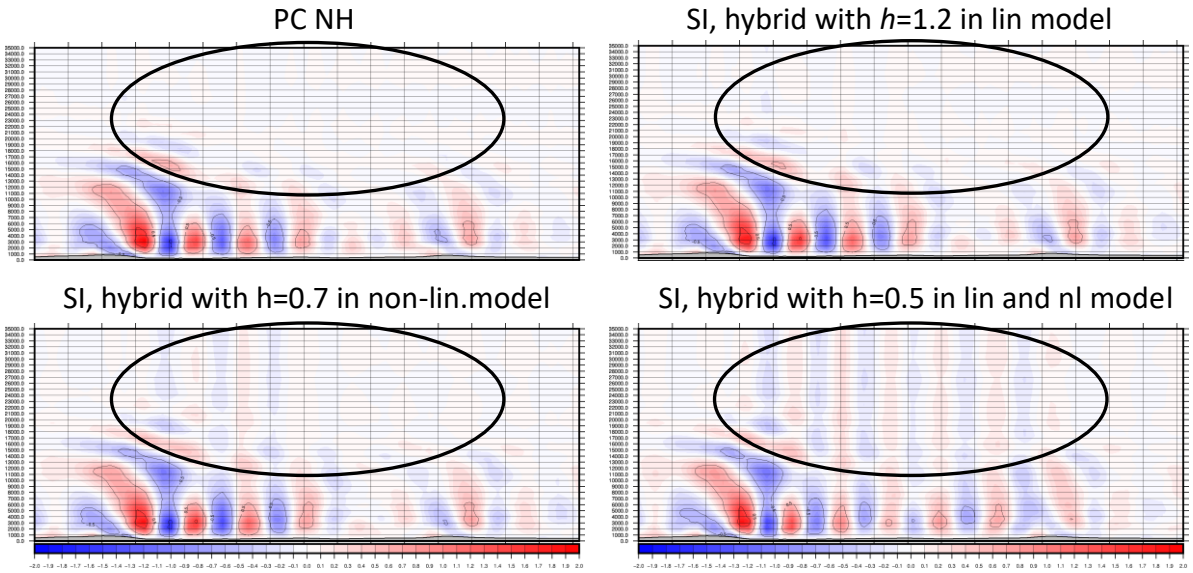

Figure 7: True vertical velocity w [m/2] in a cross section over Krušné Hory forecasted from 12 February 2019 00UTC for 11 hours. The ellipsis indicates the region of the biggest differences.

Further, real simulations were run for two datasets. The first corresponding to the Czech operational setting and the Czech operational domain in 2.325km, dynamical adaptation for a case of strong wind over Krušné Hory from 12 February 2019 00 UTC integrated for 11 hours. The second simulation was run for Occitania domain in 375m and modified setting of physics. See Figure 1 for domains definition. In both cases the horizontal diffusion was consistently set for vertical and horizontal divergence. The results are illustrated in Figure 7. A spurious pattern is created behind the mountain ridge for control parameters smaller than 1. For values higher than 1 applied only in the linear model we obtained solution close to the full NH solution (the top right panel compared to the top left panel).

The topic is ONGOING.

Contributors: Jozef Vivoda, Petra Smolíková

Executed efforts: 2 PM research stay in Prague, 4 PM of local work

Documentation: report from the stay, stability analysis results, published soon on the RC LACE web pages

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 asses 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: none

Executed efforts: none

Documentation: none

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.

Proposed contributors: none

Executed efforts: none

Documentation: none

2. Documents and publications

Three reports will soon be published on the RC LACE web pages:

1) Jozef Vivoda, *Stabilization of the time stepping for the ALADIN NH model. Transition of the EE system into the HY system using a set of constant parameters,* 2020, 17 pages.
2) Petra Smolíková*, Increasing vertical resolution for the operational suite at CHMI*, 2020.
3) Petra Smolíková*, Stability analysis for iterative centered implicit scheme with parameters, 2020, 28 pages.*

Activities of management, coordination and communication

1) **ALADIN/HIRLAM Strategy meeting**, 3-5 February 2020, Toulouse, France
2) **Tribute to Jean-Francois Geleyn**, 6 February 2020, Toulouse, France
3) **34th LSC Meeting**, virtual, 11-12 March 2020
4) **Joint 30th ALADIN Workshop & HIRLAM All Staff Meeting 2020**, virtual, 30 March – 2 April 2020 – presentation of Petra Smolíková "Dynamics in LACE"
5) **35th LSC Meeting**, virtual, 16-17 September 2020
6) **Annual Seminar ECMWF,** Numerical methods for atmospheric and oceanic modelling: recent advances and future prospects, virtual, 14-18 September 2020

LACE supported stays

Two research stays were cancelled due to the covid-19 restrictions. One research stay was executed as planned even if the circumstances were difficult:

Reformulation of the NH system as a departure from HPE - Jozef Vivoda (SHMI), 2 PM in Prague

Summary of resources/means

The efforts invested in the area of Dynamics&Coupling in 2020 were limited, partially due to restrictions connected to the epidemy of covid-19, partially for unavailability of needed workforce due to other reasons. We were able to commit slightly more than half of the work we planned for the whole year. We hope in better future.

Task	Subject		Resources		
			Planned	**Executed**	**Stays** Plan/Exec
1. Vertical discretization	1.1	Design of VFE in NH model	2	2	-
	1.2	Modularization of vertical discretization	2	0	-
2. Horizontal diffusion	2.1	Tuning and redesign of the horizontal diffusion depending on the scale	3	0	1/0
3. Time scheme	3.1	Generalization of the semi-implicit reference state	2	0	-
	3.2	The trajectory search in the SL advection scheme	0	0	-
	3.3	Dynamic definition of the iterative time schemes	3	1	1/0
	3.4	Terms redistribution through new vertical motion variables	2	2	-
4. Evaluation of the dynamical core in very high resolutions	4.1	Tuning of dynamical adaptation of the wind field at different resolutions	0	0	-
	4.2	Upper boundary condition	2	0	-
	4.3	Experiments in very high resolution	2	2	-
5. Optimization of the model code	5.1	Single precision	1	0.25	-
6. Basic equations	6.1	Reformulation of the NH system as a departure from HPE	2	6	2/2
7. Coupling strategy	7.1	The impact of higher coupling frequency	1	0	-
	7.2	Frame approach in the LBC files	2	0	-
Total manpower			**24**	**13.25**	**4/2**