Working Area Dynamics & Coupling

Progress Report

Prepared by:	Area Leader Petra Smolíková
Period:	January – August 2019
Date:	6/9/2019

Progress summary

This report summarizes the work done in the Area of Dynamics and Coupling of RC LACE from January to August 2019.

1. Scientific and technical main activities and achievements

Let us mention the biggest achievements in the tasks planned for the year 2019.

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 compatibility of VFE with direct inversion Helmholz solver is planned for the end of year since the elimination of variables implemented by Fabrice Voitus is now available in the official cycle CY46T1. On top of that the formulation of vertical discretization in case of VFE was revised. The explicit definition of vertical coordinate was modified with several new options enabling to choose the density of vertical levels close to the bottom and top domain boundary. See Figure 1 for an illustration. Then the definitions of A and B coefficients needed for pressure based vertical coordinate definition ensure mass conservation. It was shown experimentally that the proposed solution results in purely imaginary eigenvalues of the operator representing the linear model which property is a necessary condition for the scheme numerical stability.

The vertical FE discretization designed primarily for NH model version was tested in global hydrostatic model IFS. It was shown that even with B-splines of high order (7) used in the FE basis the proposed discretization results in stable integration.

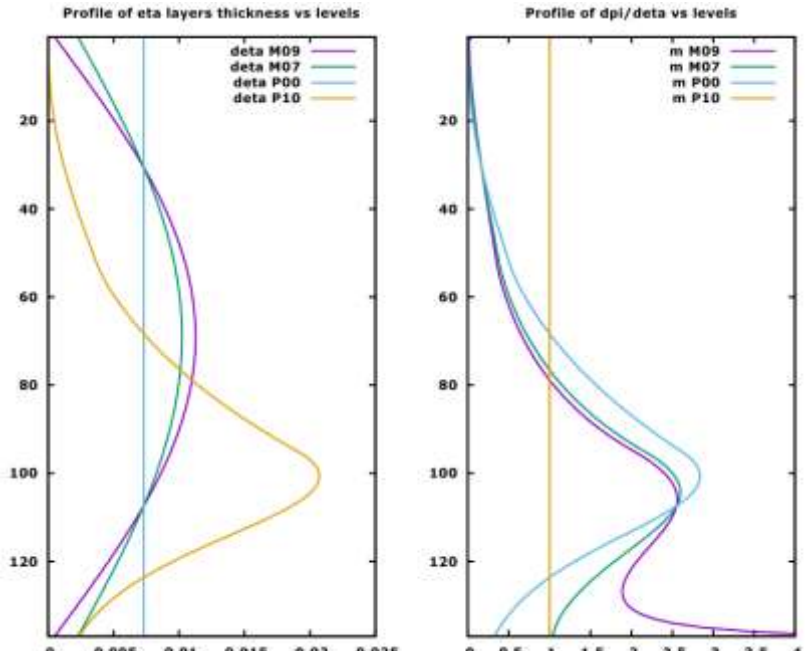

Figure 1: Vertical profile of the vertical layers thicknesses and of the hydrostatic pressure change across layers for several possible parameters settings.

Moreover, the full level variant of the vertical velocity was implemented on top of the already existing half level version. In both cases, the integral and the derivative in the vertical are not inverse of each other, but it does not seem to affect the results detrimentally. See Figure 2 for an illustration of results.

The topic is ONGOING.

Contributors: Jozef Vivoda (SHMU)

Executed efforts: 1 PM

Documentation: presentation

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 commu-

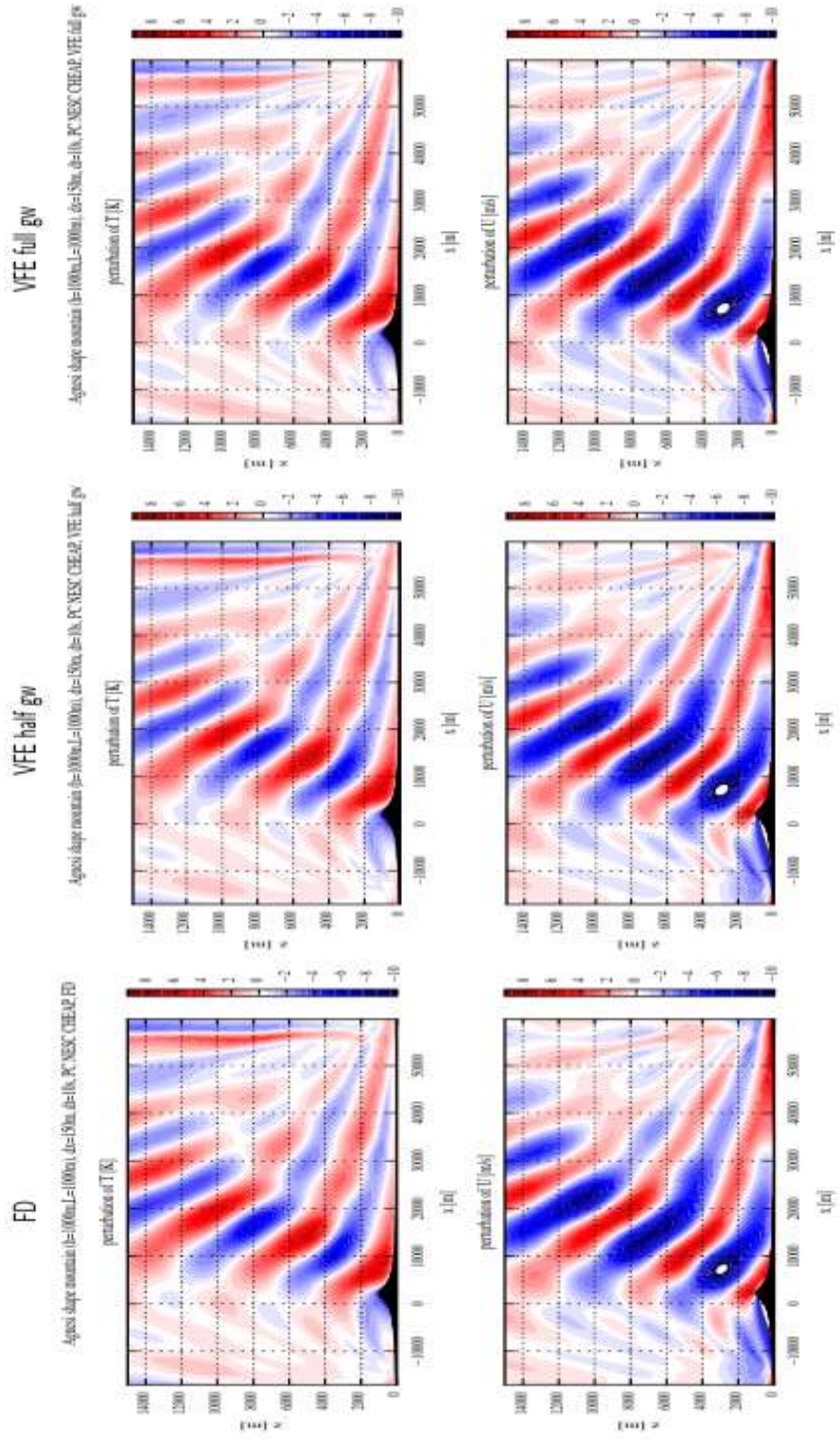

Figure 2: Non-linear non hydrostatic flow over Agnesi shaped mountain, 2D vertical slice simulation with FD discretization (left), FE discretization with full level w (middle) and FE discretization with half level w (right) in the vertical for temperature (top) and horizontal wind (bottom).

nity. 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 also 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: First, a sensitivity study for the available tuning parameters for SLHD was prepared in dependence on the horizontal resolution. The performance was tested in the cascade of resolutions: 4km, 2km and 1km on the domain covering Central Europe with Alps, and with 87 vertical levels. The experiments performed confirmed the correct behaviour of SLHD. However, it was shown that the sensitivity to available tuning parameters decreases with the increasing resolution and that it is very difficult to tune SLHD at 1 km resolution to properly diffuse energy at smaller scales. The proposed solution for future work could be to make grid-point part of SLHD vertically dependent.

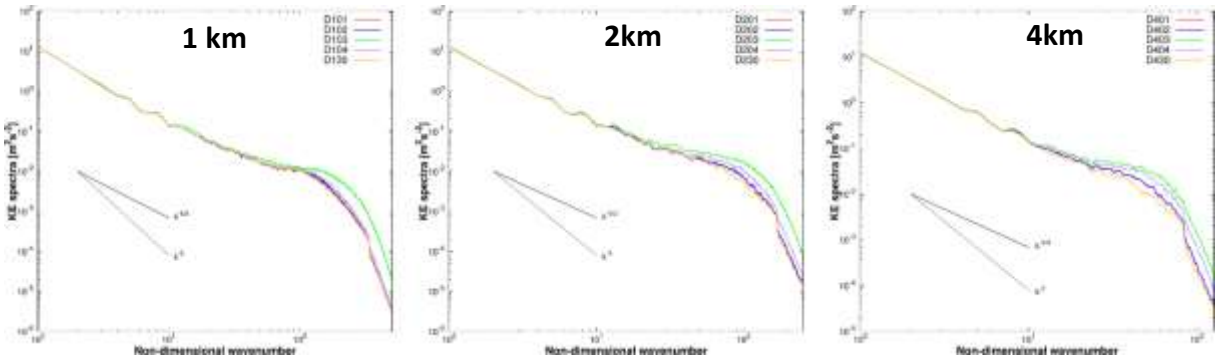

Figure 3: Sensitivity to SLHD tuning shown on kinetic energy spectra at 80th model level. Left: 1km, middle: 2km; right: 4km horizontal resolution. Experiments: Czech operational setting (red), parameter kappa=1 corresponds to maximal diffusion (yellow), parameter kappa=0 corresponds to SLHD grid-point part switched off (green).

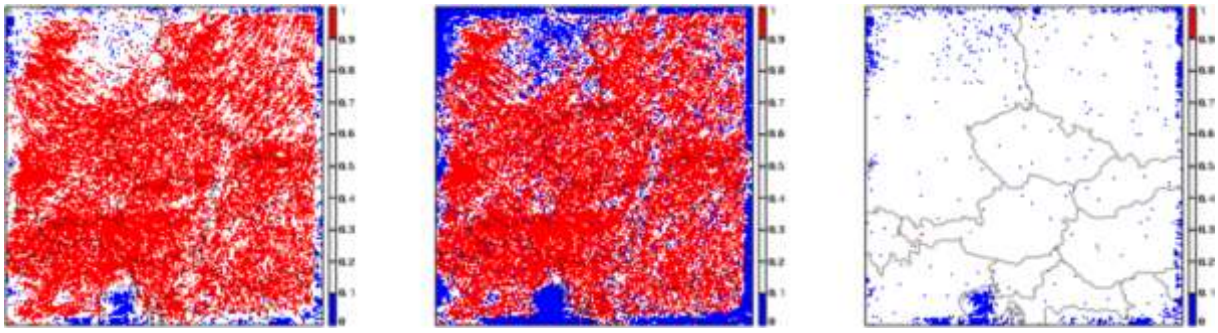

Figure 4: Kappa coefficient for several experiments at 1km horizontal resolution, 80th model level. Czech operational setting on the left.

More experiments were devoted to the sensitivity of the kappa parameter to different tunings and to the role of kappa in the diffusion process. See Fig.4 for illustration.

Further study was dedicated to the determination of the resolved versus subgrid part of the turbulent kinetic energy (TKE). The physical package ALARO-1 with the turbulence parametrization TOUCANS in the current Czech operational setting was used, based on the cycle 43t2. The experimental domains in the cascade of resolutions (4,2,1km) were used again. Original procedure was designed with the results shown on Figure 5 and 6. It has revealed that, at least in convective case, we enter the grey zone of turbulence at 1 km horizontal resolution. Hence, we should at least think about adaptation of ALARO-CMC for it. In order to achieve this goal, we prepared domain at 500m horizontal resolution on top of the three domains used in this study to serve as a basis for further research. Further details may be found in the report.

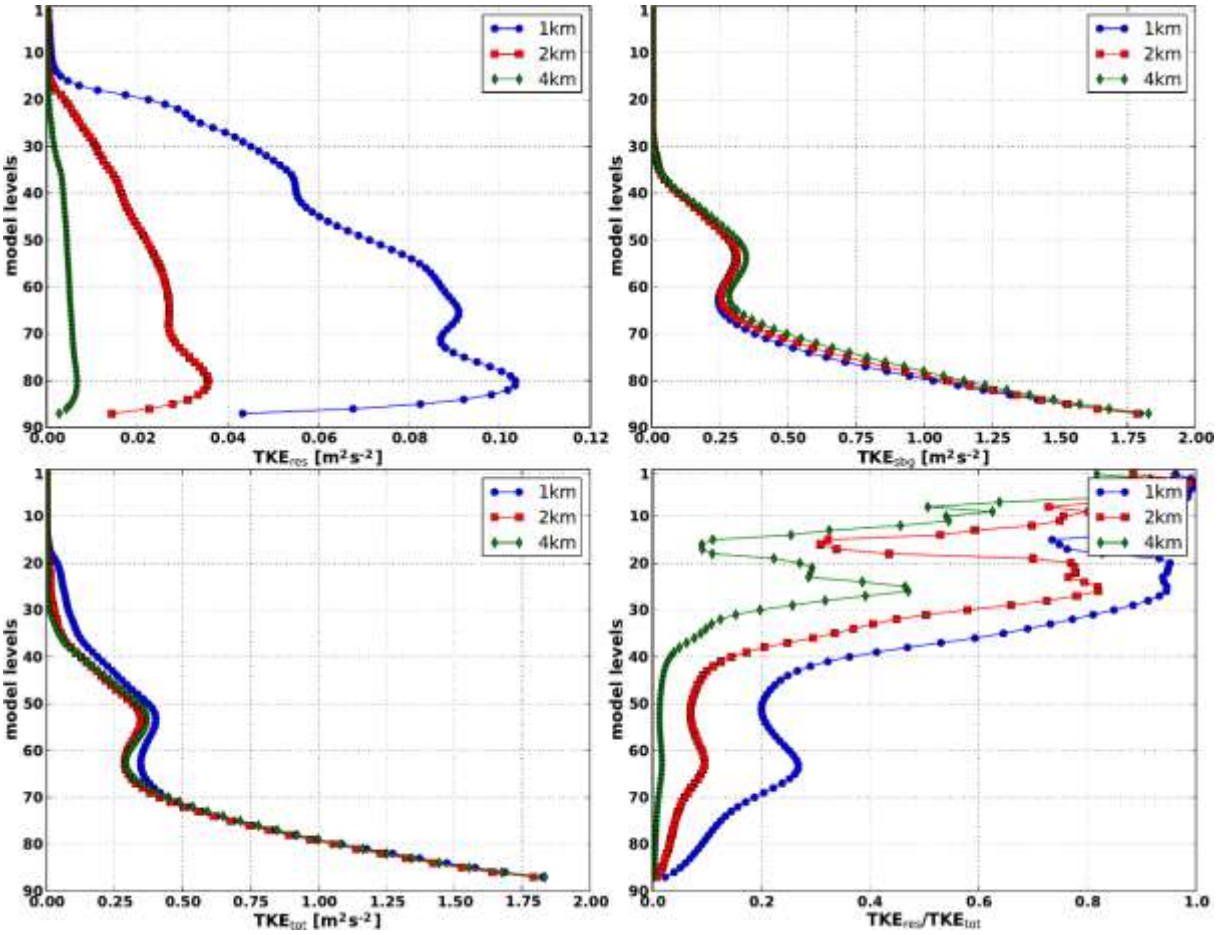

Figure 5: Spatially and temporally averaged vertical profiles of TKE. Top left: resolved part; top right: subgrid part taken from TOUCANS; bottom left: total; bottom right: percentage of resolved/total TKE.

The topic is ONGOING.

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

Executed efforts: 1 PM research stay at CHMI, 2 PM of local work

Documentation: report from the stay, appearing soon on the LACE web pages

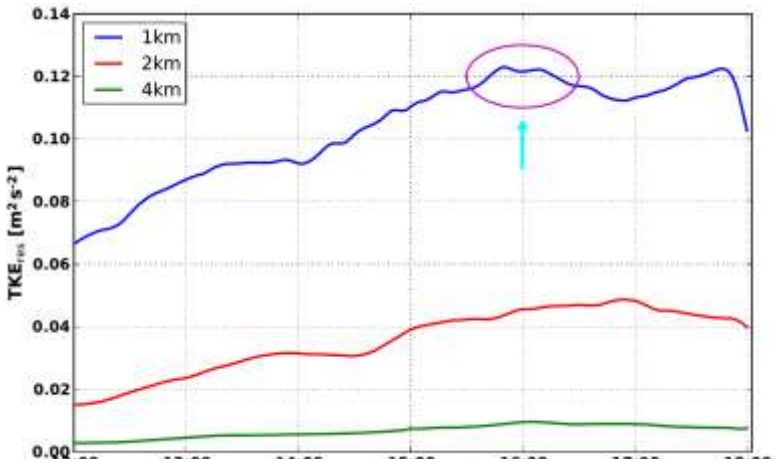

Figure 6: Time evolution of the spatially averaged (in horizontal) resolved TKE for ALARO at 1km, 2km and 4km horizontal resolution, at 80th model level, during summer convection situation. The arrow indicates a peak of convective activity.

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

Description and objectives: It was reported that LPC_FULL scheme with reiteration of SL trajectories produces noisy solution. We have confirmed these results. We tried to understand this phenomenon. As we increase the model horizontal resolution, the local divergence can increase significantly and the Lipschitz criteria may be broken locally. Then the trajectory search may become divergent and the increase in the number of iterations in the process to search for a SL trajectory may lead to even less accurate solutions. Similar problems have been identified at ECMWF in IFS and fixed by local change of the computation of the half level wind. First tests were started in 2017 which did not reveal any serious problem with the convergence. The prepared environment will be used for systematic testing on longer period.

Status: Last year we obtained the results which revealed that simple increase of the number of iterations used for the algorithm for the SL trajectory search may be sufficient to deliver precise position of the origin point. The problems with convergence of this iterative process were reported from the IFS. We have not diagnosed any problems when applied in LAM up to 1km horizontal resolution and decided to close the topic for the time being.

The topic is FINISHED.

Contributors: none

Executed efforts: none

Documentation: none

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 PENDING.**

Contributors: none

Executed efforts: none

Documentation: none

Subject: 3.4 Terms redistribution through new vertical motion variables

Description and objectives: Motivated by the work of Fabrice Voitus being 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.

Status: **The topic is ONGOING.**

Contributors: none

Executed efforts: none

Documentation: none

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.

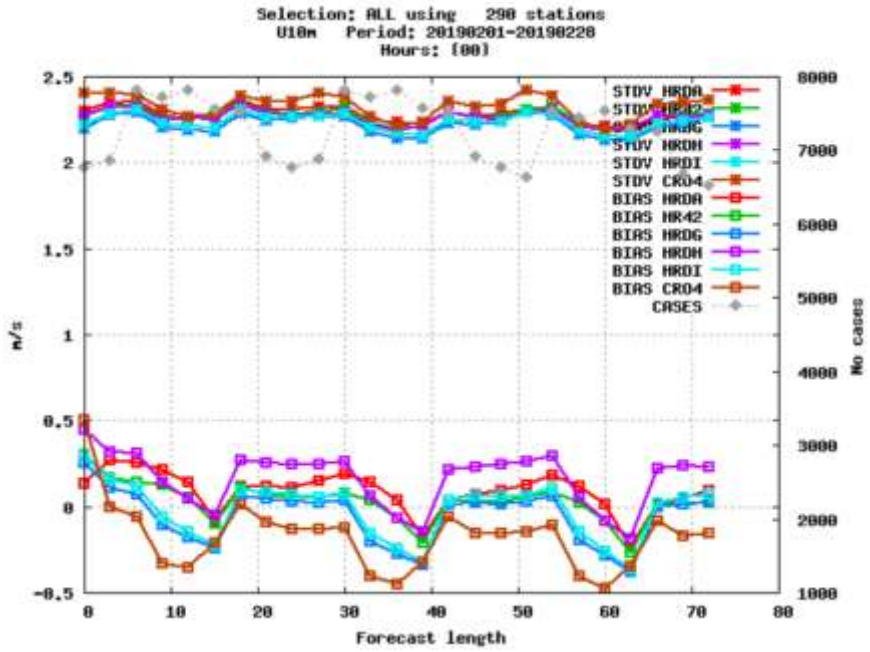

Figure 6: Objective scores (STDEV and BIAS) for several configurations of the dynamical adaptation being run at DHMZ; current operational version in red, proposed configuration in turquoise, operational ALADIN at 4km used as coupling model in brown.

Status: Since the operational configuration of ALADIN at 8 km resolution is going to be switched off at DHMZ, it will be replaced with ALADIN at 4 km resolution in the role of the coupling model for the dynamical adaptation which is run operationally 4 times a day for 30 time steps and only at vertically and horizontally restricted domain. New configuration of the dynamical adaptation run was prepared and several proposed settings were tested. In all proposals, still hydrostatic dynamics on cy29 is used and upgrade in this direction may be planned only depending on the available human resources. As a result of the balance between the cost effectiveness and performance, the configuration at 2km resolution with 32 vertical levels corresponding to ALADIN-HR4 up to roughly 1.5km was chosen. The 10m wind speed BIAS and STDEV for this configuration (HRDI, turquoise) may be compared to previous operational configuration (HRDA, red) on Figure 6.

Moreover, new climate files prepared by Suzana Panežić with orography determined from the finer database GMTED2010 were used, with the goal to have dynamical adaptation at

1 km resolution, keeping the same domain as at 2 km. Despite the objective scores for this configuration being slightly better than other configurations on the whole domain, they were

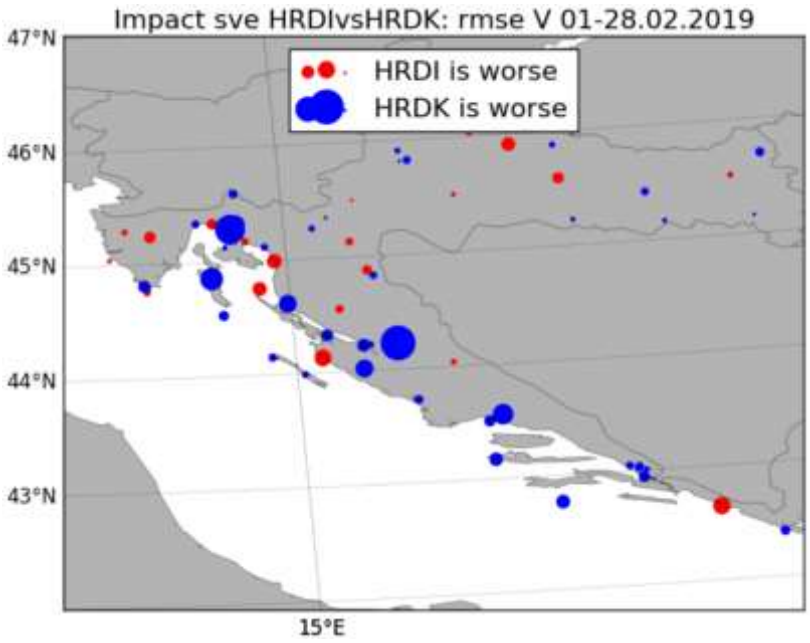

Figure 7: RMSE for the configuration HRDI with traditional climate files and for the configuration HRDK with climate files prepared from the finer database.

worse when verified on Croatian stations only as can be seen on Figure 7.

The topic is ONGOING.

Contributors: Mario Hrastinski (DHMZ)

Executed efforts: 1 PM of local work

Documentation: The report may be found on the LACE web pages.

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

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 have to start experiments in the very high resolution. For these goal the climate files have to be prepared from a fine database. We started with the domain covering Central Europe including Alps in 500m horizontal resolution. We solved problems connected to memory requirements in the procedure e923.

Status: **The topic is STARTED.**

Contributors: Petra Smolíková (CHMI)

Executed efforts: 0.5 PM of local work

Documentation: none

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.

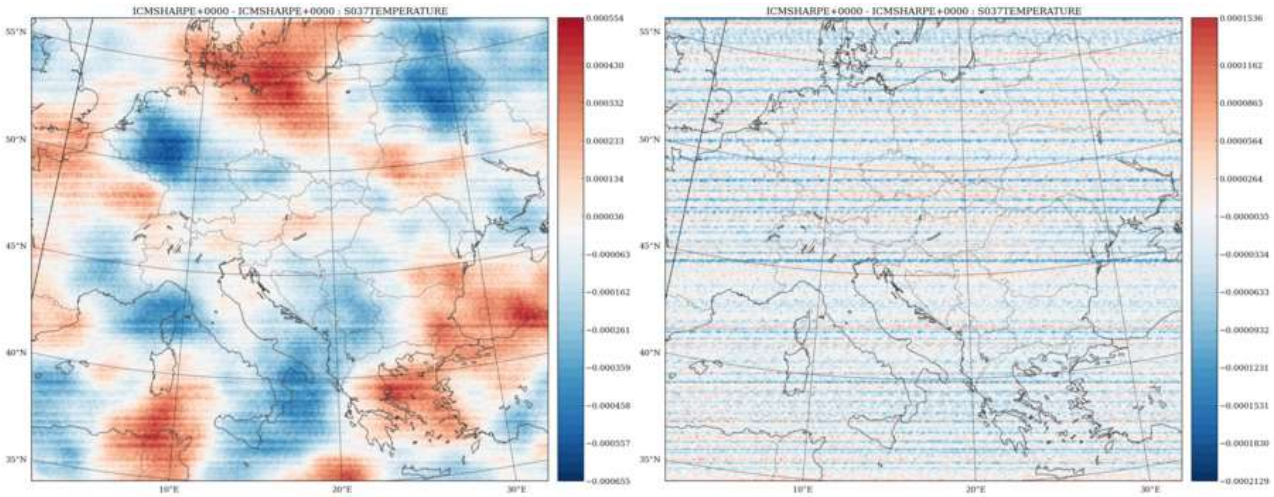

Figure 6: The difference in the files after reading initial files and writing in the model files (ICMSH+0000) between double and single precision runs; with default packing (left) and with 24 bits used for each spectral coefficient (right).

Status: The LAM model configuration CY43T2 was compiled and run in single precision. The experiments were started with basic configuration, in adiabatic regime and with hydrostatic dynamics. Huge differences (6K close to the ground, after 72 hours of integration) were found in the results. Then the procedure was examined and it was found that big differences are already in the files just after the initial conditions are being read into the model (and saved in ICMSH+0000). The reason is in the used packing procedure which was retuned to use 24 bits for each spectral coefficient. With this retuning, similar results were obtained at the beginning of integration for single and double precision runs. The structure of differences is subtler and the differences are smaller. Hence this packing is more suitable for comparison of model files with reduced precision. We got the lesson from this first step that one has to proceed carefully in small steps to reach satisfactory results.

The topic is ONGOING.

Contributors: Oldřich Španiel (Sk)

Executed efforts: 0.5 PM of local work

Documentation: none

2. Documents and publications

Several reports already are or will be soon published on the RC LACE web pages:

1) Mario Hrastinski, Testing the performance of Semi-Lagrangian Horizontal Diffusion (SLHD) at different horizontal resolutions, 16 pp.

2) Mario Hrastinski, Dynamical adaptation related work at DHMZ, 3pp.

Activities of management, coordination and communication

1) **Joint 29th ALADIN Workshop & HIRLAM All Staff Meeting 2019**, 1-5 April 2019, Madrid, Spain – presentation of Petra Smolíková "Dynamics in LACE"

2) **Dynamics Working Day**, 28 May 2019, Toulouse, France – presentation of Jozef Vivoda "Contribution of RC LACE into development of HY and NH dynamical core"

LACE supported stays in 2019

1) Mario Hrastinski (Cr) - Tuning and redesign of the horizontal diffusion depending on the scale, (May-June 2019 at CHMI)

Summary of resources/means

The effort invested into the area of Dynamics&Coupling in frame of LACE in the first eight months of 2019 is more restricted then in the previous years. Only one research stay was executed, another two are planned for the end of the year.

Task	Subject		Resources		
			Planned	Executed	Stays
1. Vertical discretization	1.1	Design of VFE in NH model	2	1	-
	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	3	1/1
3. Time scheme	3.1	Generalization of the semi-implicit reference state	2	0	-
	3.2	The trajectory search in the SL advection scheme	3	0	1/0
	3.3	Dynamic definition of the iterative time schemes	3	0	1/0
	3.4	Terms redistribution through new vertical motion variables	3	0	1/0
4. Evaluation of the dynamical core in very high resolutions	4.1	Tuning of dynamical adaptation of the wind field at different resolutions	2	1	-
	4.2	Upper boundary condition	2	0	-
	4.3	Experiments in very high resolution	0	0.5	-
5. Optimization of the model	5.1	Single precision	2	0.5	-
Total manpower			**24**	**6**	**4/1**

Problems and opportunities

This year even persistent contributors were occupied with other tasks connected to local operational activities, computer procurements etc. A substantial part of the work is planned for the end of the year and may be accomplished. We have to find an appropriate workforce for other planned topics otherwise we are not able to fulfil the plan.