Working Area Dynamics & Coupling

Progress Report

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Progress summary

This report summarizes the work done in the Area of Dynamics and Coupling of RC LACE between October 2015 and December 2015. Despite of the reporting time being quite short the progress has been achieved in several subjects and one month research stay of David Lancz has been realized in Prague on "Feasibility study to add the physical tendency of vertical velocity to the adequate prognostic NH variable".

Scientific and technical main activities and achievements, major events

Let us mention the biggest achievements in the planned topics and illustrate them by several figures. We list all tasks planned for the year 2015. Several of them have been fully or partially solved during the previous reporting period January 2015 – September 2015 and the progress in these topics is summarized in the previous report.

Task 1. VFE NH

Subject: 1.1 Design of vertical finite elements scheme for NH version of the model

Description and objectives: The main objective of this task is 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 differences (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).

Executed efforts: none

Status: **The subject was not touched during the reporting time period. See report for the first part of 2015 for details.**

Task 2. SL scheme

Subject: 2.1 Application of ENO techniques to semi-Lagrangian interpolations

Description and objectives: High order semi-Lagrangian interpolations, in 1D typically represented by cubic Lagrange polynomial on 4-point stencil, are not monotonic and produce spurious overshoots in the vicinity of discontinuities or sharp gradients. Their quasi monotonic version exists, but simple cut off procedure reduces accuracy dramatically. However, if interpolation stencil is extended to 6-points, 3rd order ENO (Essentially Non-Oscillatory) interpolation could be applied. It is able to reduce spurious oscillations/overshoots while keeping high order of accuracy uniformly. Aim of the work is to implement ENO interpolation technique in ALADIN and evaluate its performance/cost. A first study of the problem has been already done in 1D – linear advection toy model, and for quadratic interpolators in 2D vertical plane model. Quadratic interpolators have been found too smoothing, but 1D experiments show promising results for cubic interpolators, or WENO technique in which two interpolators are combined depending on the advected field. We continue in the already started work.

Executed efforts: none

Status: **The subject was not touched during the reporting time period. See report for the first part of 2015 for details.**

Subject: 2.2 COMAD weights for SL interpolations

Description and objectives: The COMAD weights have been designed at ECMWF (Sylvie Malardel). The linear and cubic semi-Lagrangian weights are modified to take into account the deformation of air parcels along each direction, with deformation factor defined with the respect to the local velocity in the given direction and the time step used. The proposed modification had a positive impact on the objective scores of the IFS runs and on the AROME 1.3km runs. We would like to know if we may get some benefit from this modification for the local model ALARO.

Executed efforts: none

Status : **The subject was not touched during the reporting time period. It was postponed to the next year.**

Task 3. Physics-dynamics interface

Subject: 3.1 Feasibility study to add the physical tendency of vertical velocity to the adequate prognostic (NH) variable

Description and objectives: For parameterization schemes used in HPE systems, the horizontal momentum 'feels' the sub-grid effects of mountain drag, turbulence and convection. The impact of these processes on the vertical momentum in the case of NH dynamics has to be reconsidered.

Contributors: David Lancz (Hu), Petra Smolíková (Cz)

Executed efforts: 1 month of research stay (D. Lancz); 0.5 month of local work

Documentation: **report from the stay published on the RC LACE web pages**

Status: The turbulent tendency of vertical velocity was implemented in the ALADIN-NH CY38t1 in which the physical parametrization of turbulence (TOUCANS) is already a mature and tuned part of the physical parametrization package ALARO-1. The turbulent diffusion flux of the vertical velocity is calculated as a part of TOUCANS from the turbulent kinetic energy and used to calculate the turbulent tendency of vertical velocity. This tendency is passed to the dynamics part of the model and added to the total tendency of vertical velocity. The effect of this modification was studied on vertical plane 2D tests and in real simulations.

In the vertical plane 2D experiments we simulated lee waves behind a hill. In the initial profile of temperature there were two isothermal layers divided by a strong inversion. The initial profile of the horizontal wind was homogenous. The physical parametrization package ALARO-1 was set according to the actual Czech operational setting (2015). As a consequence a convective updraft was generated in the middle of the domain and a nice turbulent rotation established behind the hill. Such simulation is not possible without working parametrization of turbulence.

While the initial value of the horizontal wind was 3m/s, the mean horizontal wind near the ground was 8m/s in the opposite direction while in the middle of the lower isothermal layer the mean horizontal wind was close to 10m/s. Hence, we may say that the created vortex was quite strong. The maximum change in the potential temperature after the vertical velocity turbulent tendency was added approaches 3K. We conclude that the simulation is working in the right direction and the influence of the added vertical velocity turbulent tendency is significant.

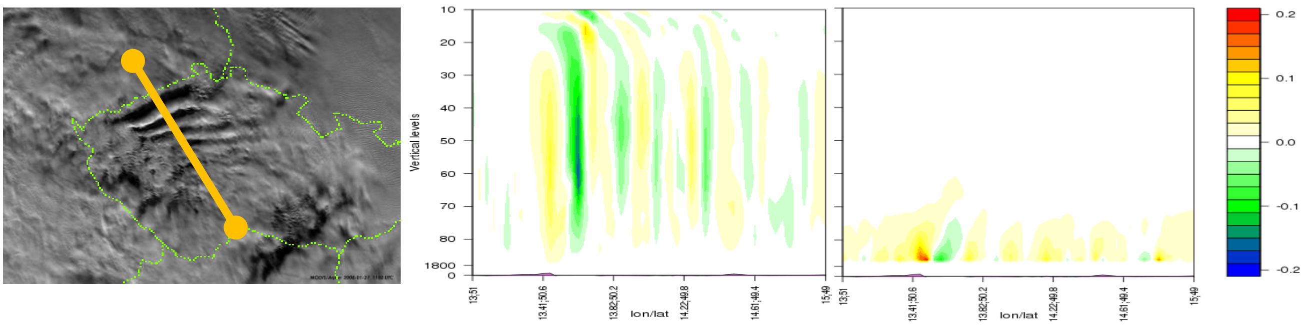

Figure 1: The vertical cross section through the orange line on the left picture. Left: satellite image of cloudiness; middle: difference in the vertical velocity between the experiment with and without w-tendency calculated; right: the tendency of vertical velocity multiplied by the factor of 4.

For real simulations we have chosen three different real cases and examined their vertical velocity fields. We show the results for the case of the orographic wave created in the flow over the western boundary of the Czech Republic on 27 January 2008. The used horizontal resolution is 1km, 87 vertical levels and the time step of 20s. The damping effect of the vertical diffusion of vertical velocity is demonstrated in Fig.2, while the vertical cross sections of differences created in vertical velocity field and the field of turbulent tendency of vertical velocity are shown in Fig.1.

The differences in the vertical velocity fields are in average small and exceed 0.2 m/s only occasionally near high topography (e.g. Alps), while w reaches values of 6m/s in the absolute maximum. The highest detected difference was around 0.8 m/s occurring only in few grid-points. The maximum temperature differences in the real cases are around 1-2K.

One may notice that despite of turbulent tendency of vertical velocity being created only in the lower part of the atmosphere (right picture on Fig.1) during one time step, the effect after several hours of integration may be similarly intensive in the whole extent of the atmosphere and the field of vertical velocity may be changed significantly in higher atmosphere as well. Notice that the turbulent tendency ranges in the same values as the difference in vertical velocity fields with and without the tendency added when the turbulent tendency is 4 times multiplied. The absolute values of vertical velocity in one experiment are approximately 20 times bigger. Hence, the tendency gives about 1% of the absolute value of vertical velocity in one step and the final change may be around 5% in the maximum.

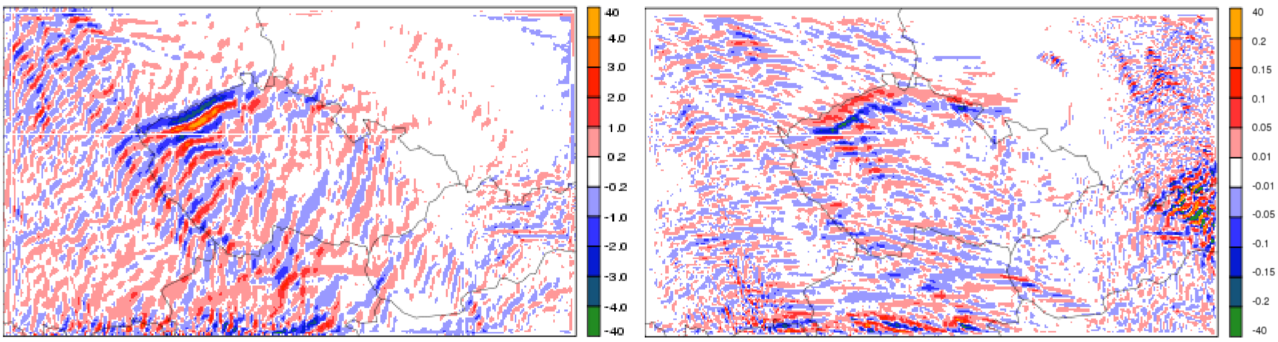

Figure 2: The vertical velocity field in the 50th vertical level. Left: for the experiment without w-tendency calculated; right: the difference of the two experiments (with w-tendency minus the reference without w-tendency).

Generally we can say that the impact of the vertical diffusion on vertical velocity corresponds to the expected trend (the damping of an orographic wave as an example) and the observed effect on vertical velocity field is modest. Nevertheless, we have proposed an original solution for this process which could be further developed, used and tested.

Subject: 3.2 Design of the ideal share between the horizontal turbulence and numerical 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 is a flexible tool to represent the numerical diffusion in the model. On the other side there is the horizontal extension of the scheme for vertical diffusion called TOUCANS as a tool for the horizontal turbulence control. 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.

Executed efforts: none

Status: The subject was not touched in the reporting time period. See report for the first part of 2015 for details.

Task 4. 1D2D turbulence scheme for ALARO

Subject: 4.1 Scientific validation

Description and objectives: Scientifically correct behaviour of the whole 1D2D system is a necessary condition needed to be satisfied to be able to fulfil further tasks. The vertical part has been prepared in the scheme TOUCANS, while the horizontal part has to be redesigned and modified to get consistent system on the latest model cycle. It follows that the compliance of the whole 1D2D turbulence scheme behaviour with the laws for transport of energy from bigger to smaller scales has to be carefully examined. Energy spectrum study is foreseen as an instrument for such validation. Preparation of a testing environment is considered as a part of the issue.

Executed efforts: none

Status: The subject was not touched during the reporting time period. See report for the first part of 2015 for details.

Subject: 4.2 Tests in <1 km resolutions

Description and objectives: As soon as the previous task is successfully finished, academic tests with the full model may be targeted to further study scheme behaviour and its interconnection with other model parts. Very fine horizontal resolutions (subkilometric) are needed for such tests.

Executed efforts: none

Status: The subject was not touched during the reporting time period. See report for the first part of 2015 for details.

Task 5. Evaluation of the model dynamical core in very high resolutions

Subject: 5.1 Namelist dynamic parameters for high resolution experiments

Description and objectives: Since in the recent past and in the future more and more people in the LACE community are interested in higher resolution (<2km) experiments, we are forced to find a list of dynamic parameters which may ensure a robust and stable forecast for these resolutions. We focus on experiments with the ALARO physics for which we do not know about previous extensive testing of dynamical choices in high resolutions.

Contributors: Petra Smolíková (Cz)

Executed efforts: 1 month of local work

Documentation: **report published on the RC LACE web pages**

Status: We have been running a serie of experiments in the aim to find a set of dynamic parameters for robust and stable forecast in horizontal resolutions around 1km. We use 87 vertical levels of the current Czech operational setting and 1km horizontal resolution over the domain covering the Czech Republic with small surroundings. The studied experiment is an orographic wave created over the western mountainous boundary of the Czech Republic on 27 January 2008. The simulation for 24 hours starts at 00UTC.

There are three sets of dynamic parameters we have been varying in the experiments:

1. spectral horizontal diffusion and SLHD
2. the time scheme (including SI reference state and X-term discretization)
3. the decentering through VESL

We have found several conclusions and recommendations for the dynamic parameters in high resolution experiments using ALARO physics which are summarized in the report.

Subject: 5.2 Clear comparison of SETTLS and ICI time schemes

Description and objectives: On workshops, during meetings with our colleagues from ALADIN, HIRLAM and ECMWF, in email exchanges, we are facing complaints on the speed, affordable timestep, computational time requirements and stability properties of the centred iterative time schemes (called PC scheme) developed under the RC LACE auspices. In 2011, a study of Filip Váňa has shown problems which may be faced when using alternative non-iterative 2-time-level scheme called SETTLS. From our case studies we believe that iterative schemes offer better stability properties than SETTLS without danger of creating spurious oscillations. We would like to compare time schemes available in the code of ALADIN/ALARO/AROME model and show benefits and drawbacks of them in a clear and convincing way.

Contributors: Petra Smolíková (Cz)

Executed efforts: 1 month

Documentation: **report published on the RC LACE web pages**

Status : We have evaluated the stability of pure SETTLS (Stable Extrapolating Two Time level Scheme) in comparison to iterative time schemes (called PC schemes) designed in the ALADIN/AROME/ALARO model in high resolution experiments. We have restricted our study to semi-Lagrangian (SL) advection and semi implicit (SI) time discretization for linear terms. To set the time scheme it remains to choose the time discretization used in the research of SL trajectory (SETTLS or NESC) and to choose the time discretization of non-linear terms used in

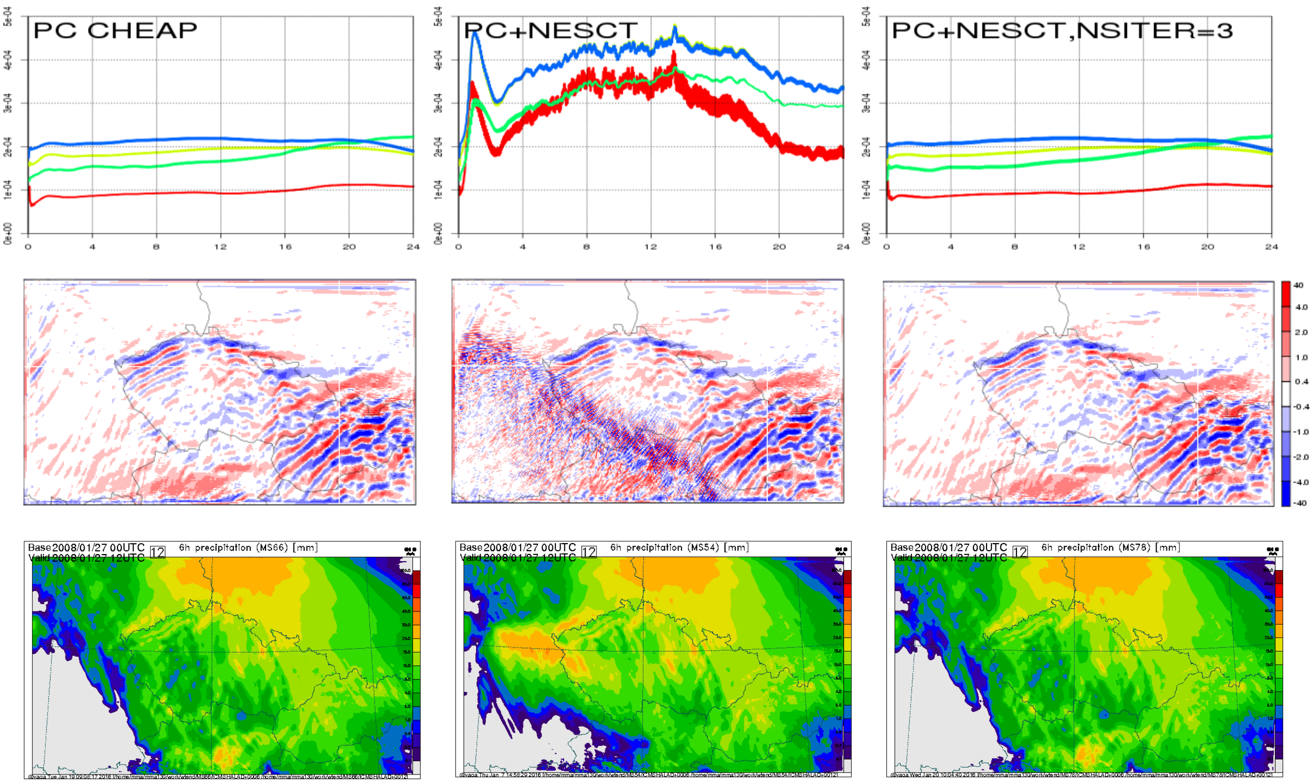

Figure 3: The choices in the iterative time scheme – time evolution of spectral norms averaged over the whole domain; green: vorticity; blue: divergence; yellow: vertical divergence; red: pressure departure (top); vertical velocity at 200hPa and 22UTC (middle); cumulated precipitation from 06UTC to 12UTC (bottom). Left: cheap version of PC scheme - SL trajectories calculated only in the predictor step (SETTLST=true); middle: SL trajectories calculated in all steps with NESC (NESCT=true) with 1 iteration of the PC scheme; right: SL trajectories calculated in all steps with NESC (NESCT=true) and 3 iterations of PC scheme applied.

the predictor step (the only step achieved if no iteration applied), while in all corrector steps of iterative time schemes the non-extrapolating (NESC) discretisation is used. Furthermore, we may decide if the SL trajectories will be recalculated in corrector steps or not. The trajectories are kept for corrector steps unchanged in case the “cheap” version of the iterative scheme is used.

We have simulated an orographic wave over the mountainous Czech western boundary on 27 January 2008 using 1km horizontal resolution over the domain covering the Czech Republic and small surroundings and 87 vertical levels by integrating for 24 hours from 00UTC. To see the difference in the stability and accuracy of distinct configurations, we have used an enhanced time step of 50s. The appropriate choice would rather be 40s, but the differences are then less pronounced. As the control experiment we have used the same setting with the time step of 20s.

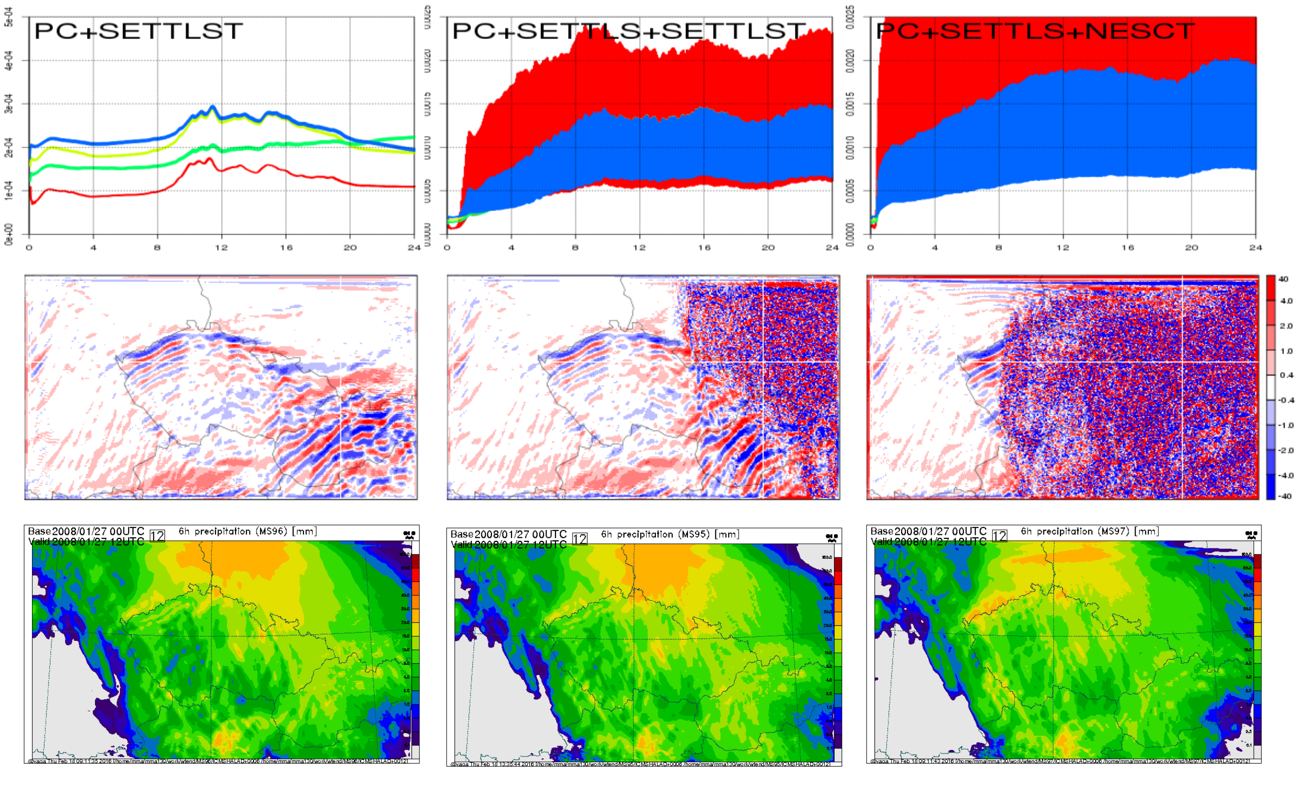

Figure 4: As figure 3 with different settings of iterative time schemes. Left: LPC_NESC, LSETTLST; middle: LSETTLS, LSETTLST; right: LSETTLS, NESCT. Notice 5 times larger scale for spectral norms evolution charts and PC+SETTLS experiments.

We may see from the experiments series that the SETTLS scheme may be beneficial in the trajectory calculations while the choice which enables to recalculate SL trajectories in the corrector steps through NESC formulae could be dangerous since serious oscillations in the prognosted fields may occur. As a consequence, other meteorological parameters may be influenced. See the bottom middle chart on Fig.3 for the cumulated precipitation field between 6UTC and 12UTC where 40mm of spurious precipitation appear close to western boundary of the Czech Republic. These oscillations may be damped by additional iterations of the PC scheme. In the presented case, NSITER=3 was needed to remove all the noise. See the right charts of Fig.3 for an illustration. Obviously, to reduce the timestep is as well going in right direction to get rid of these oscillations. Such solutions are unfortunately computationally expensive. For SL trajectories calculation using SETTLS, we got stable solutions. See the left charts of Fig.4 for an illustration.

For the sake of completeness, we have explored the choice of iterative time schemes with SETTLS discretization used in the predictor step for the discretization of non-linear terms. The second order first guess is then iterated to get again a second order result which does not seem to be a well-designed procedure. Moreover, the inconsistency between predictor and corrector step (using NESC) is enormous and the resulting fields are destroyed through the noise. See the middle and the right charts of Fig.4 differing in the way the SL trajectories are calculated. Precipitation charts are then influenced as well. For shorter time step of 20s we got reasonable results for all the configurations.

For iterative time schemes, one may choose furthermore when the horizontal diffusion is applied. By default, the horizontal diffusion is applied only once: at the last corrector iteration if SL trajectories are recalculated in corrector steps, or in predictor only if SL trajectory recalculation is not done since the whole advection is calculated in predictor in this case. Or, one may choose to apply the horizontal diffusion in all iterations (predictor and all correctors). We have found only a weak sensitivity to this choice. Hence, one may stick on the default setting.

The pure SETTLS scheme (without iteration) was also tested and appeared unstable. The study will continue in frame of Subject 5.3.

We may conclude that the most stable configuration of the time scheme available in ALADIN/AROME/ALARO model consists in the iterative procedure (with 1 iteration) without SL trajectories recalculation. We expect to continue in the study next year.

Subject: 5.3 Upper boundary conditions

Description and objectives: Mariano Hortal (HIRLAM, Spain) has introduced upper boundary nesting based on Davies relaxation similar as it is used on lateral boundaries. He has shown that this relaxation helps to get rid of upper level explosions observed in real cases for SETTLS time scheme. We would like to understand better the behaviour on the upper boundary and its interaction with PC time scheme used in most operational applications.

Executed efforts: none

Status: The subject was not touched in the reporting time period. It was postponed to the next year.

Task 6. LBC coupling strategy

Subject: 6.1 Rapid changes in surface pressure field

Description and objectives: Interpolation in time applied on LBC data of the large scale model to get the data on lateral boundaries for each time step of a LAM distorts the model fields and can lead to LAM forecast failures in case of fast propagating storms. The analysis of the MCUF (Monitoring the Coupling-Update Frequency) field from ARPEGE coupling files for the common LACE coupling domain may help to monitor the occurrence of such storms to draw conclusions on coupling zone positioning etc. Distinct warning index could be designed to capture high precipitation events again with consequences on LACE domain boundaries. It is a continuation of work from 2014.

Executed efforts: none

Status: The subject was not touched during the reporting time period. See report for the first part of 2015 for details.

Documents and publications

Three reports have been published on the RC LACE web page between October 2015 and December 2015:

1) Jozef Vivoda, Vertical finite element discretization in NH kernel of model system AAA

2) David Lancz, Examination of vertical diffusion of vertical velocity with ALADIN-NH CY38

3) Petra Smolíková, Namelist dynamic parameters for high resolution experiments

Activities of management, coordination and communication

Activities between October 2015 and December 2015:

1) 37th EWGLAM & 22th SRNWP joint meetings, 5 October - 8 October 2015, Belgrade, Serbia: participation of Petra Smolíková – presentation „Dynamics in RC LACE“

LACE supported stays (October 2015 – December 2015)

1) David Lancz (OMSZ, Hungary) - 1 month in Prague (CHMI), Nov-Dec 2015

Summary of resources/means for the whole year 2015

The total effort invested into the area of Dynamics&Coupling in frame of LACE in 2015 is 15 person/months, 4.25 person/months from that as scientific stays in Prague and in Ljubljana. The plan for 2015 was 14 person/months and 4 person/months on research stays. Hence we have fulfilled the plan on 107% and may be proud to follow the nice tradition of hard workers in our region of Europe. Concerning topic solved, there has been a shift from less urgent topics to more urgent ones or to topics whose solution has shown to require more time than expected.

Task	Subject		Resources		
			Planned	Executed	Stays
1. VFE NH	1.1	Design of VFE in NH model	4	4	1.25
2. SL scheme	2.1	Application of ENO technique in SL interpolations	1.5	3	1
	2.2	COMAD weights for SL interpolations	0.5	0	0
3. Phys-dyn interface	3.1	Physical tendency of w	1.5	1.5	1
	3.2	Ideal share between horizontal turbulence and numerical diffusion	2.5	0.5	0
4. 1D2D turbulence	4.1	Scientifique validation	0.5	0.5	0.5
	4.2	Test in <1km resolutions	0.5	0.5	0.5
5. Evaluation of the dynamical core in very high resolutions	5.1	Namelist dynamic parameters for high resolution experiments	0	1	0
	5.2	Clear comparison of SETTLS and ICI time schemes	1	1	0
	5.2	Upper boundary conditions	1	0	0
6. Coupling strategy	6.1	Rapid changes in surface pressure field	1	3	0
Total manpower			**14**	**15**	**4.25**

Problems and opportunities

It would be nice to have a bigger team for the tasks planned for the area of Dynamics and Coupling. It would be nice if people involved in this research could use their capacities for local work on research topics instead of being engaged in operation and other duties. But the world is not perfect.