Toward an operational implementation of the NH dynamics

RC LACE project summary

Responsible person: Filip Váňa, Area Leader for Dynamics and Coupling
Institution responsible for the project: CHMI
Project duration: 2008-2010
Main objective: The aim of this project was to deliver stable, accurate and efficient NH dynamics, ready for operational implementation in the model Aladin. With such a focus the special attention has been paid to test not only the NH dynamics itself. The interactions of model dynamics with the other model components within the full complex operational system have been studied. The project was also supposed to eliminate the true added value of the NH dynamics for the targeted LACE operational resolution being 4-5 km along horizontal with at least 60 vertical levels. This in a way means to give an answer to the question whether it is worth to activate NH dynamics at that scales.
Sub-objectives:
1. Validation of the current NH dynamics
2. Additional development or validation
3. Comparison of the NH and hydrostatic dynamics
4. Code optimization of the NH dynamics (optional)
5. Operational implementation

Project results/Achievements/Challenges:
Following the sub-objectives the work has been organized into five working packages (some were only optional):

1. Validation of the existing NH dynamics code
The aim of this working package was to validate the existing NH code by testing it at the code level, within academic benchmarks and parallel tests with full model. A successful fulfillment of this working package was the necessary precondition for any NH model operational installation and its additional development.
The NH dynamics has been proven to deliver reasonable performance. The academic tests and parallel runs indicated that the NH dynamics behaves as expected (see for example left panel of Figure 2). At the same time the global counterpart of the same NH dynamics was independently tested at ECMWF (Wedi, Yessad & Untch, 2009 and Wedi & Malardel, 2010). Also there no apparent problem has been detected. The transition from the hydrostatic dynamics to the NH one is smooth, causing no jump in the model scores (at the scales where the NH effects play negligible role like domains over Europe with horizontal resolution of around 9 km). Thanks to those results, the NH dynamics was concluded to be ready for operational tests.

2. Additional development or validation
This working package relatively independent to the rest of the project was aimed to maintain continuous research activities related to the NH model dynamics. Despite the known areas of potential research, some manpower was also allocated to new problems potentially appearing during the fulfillment of the other project packages.
The research in dynamics is usually of long-term character. It logically was not expected to finish any such task like the new vertical discretization within the limited life time of the NH

project. The important point however was that the research was not interrupted by allocating the already limited staff available to dynamics for the other project tasks. A significant effort has been invested to subjects like vertical finite element scheme, physics-dynamics coupling and mainly to the new issues appearing with the increased model resolution: improved formulation of the pressure gradient term, better representation of the model orography and revision of the used method for the convection triggering based on the moisture convergence.

Following more detailed description of studied tasks:

Second order accurate coupling of physics to dynamics – the general code is ready for tests. There seems to be still issues related to the turbulence scheme and resolved precipitations requiring special treatment different from the other parameterizations.

Consistent coupling of physics to the fully elastic dynamics – the experimental branch was prepared based on the theoretical work of Catry et al. (2007). The results of this new approach at the scales where NH effect plays negligible role are bit ambiguous. Additional research will be focused to better understand the mechanism of this phenomenon.

VFE NH – a set of general routines defining the VFE bases with respect to actual number of available boundary conditions has been prepared. Using those bases with not necessary same parameters for every model variable the NH VFE scheme is supposed to be designed.

Pressure gradient term – an academic 2D tool has been designed for identification of the sources of the pressure gradient term inaccuracy. The error has been recognized to come from vertical and horizontal discretizations. There are various approaches how to improve the vertical discretization of the pressure gradient force. Most of them are however only helping in specific stratifications or atmosphere in resting state. Their impact to the real flow is negligible if not detrimental. The only general and thus preferable solution is then through increase of the accuracy of the vertical model discretization, like the one offered by VFE scheme. The other source of pressure gradient term error comes from the inaccuracy of the horizontal discretization namely from the horizontal derivatives of orography. But again thanks to the mainly spectral representation of model field and with help of weak filter of the model orography, this error can be greatly suppressed (see for example Figures 1 and 2).

Horizontal shear terms for the 3D TKE equation – an example of extra benefit from the more complex NH approach. Unlike it is the case for hydrostatic approach, the NH dynamics naturally offers horizontal derivatives of all three wind components required for the complete shear term of the 3D TKE equation. As the NH effects has to be already considered at the scales where effects of horizontal turbulence can be see, it is not felt as a problem to allow 3D turbulence only in the NH case.

Retuning of the model diffusion – this subject (not entirely related to the NH dynamics) just illustrates the potential of research team to deal with the unexpected problem. By increasing the horizontal resolution of the Aladin/CE operational application from 9km to 4.7km some strange granularity patterns started to be frequently observed in specific weather types mainly in the precipitation fields and 2m temperature. By closer investigation that it originates by noise from the spectral linear diffusion generated in terrain following coordinate above orography. Fortunately with the existence of the non-linear semi-Lagrangian horizontal diffusion scheme (SLHD) the linear diffusion could be completely suppressed for the atmosphere bellow 100 hPa as a cure for this phenomenon. This is well illustrated by the Figure 3.

3– Comparison of the NH and hydrostatic dynamics

The key package of the project supposing to give an answer whether it is worth to switch the present model dynamics based on the hydrostatic assumption into the less restrictive (but more complicated) NH framework for the targeted scales between 4-5 km of horizontal mash and over 60 levels of vertical resolution.

Following the tests at 9km with 43 model levels showing neutral behavior of the NH dynamics with respect to the hydrostatic one, the similar parallel tests were performed for 4.7 km and 87 levels model at targeted resolution. The results just confirm once again the neutrality of the NH dynamics with respect to the hydrostatic reference (Figure 4). This indicates that with the 4-5 km of horizontal resolution (and orography similar to the one of Europe) the hydrostatic dynamics remain to be fully adequate and thus preferable (from the efficiency reasons) for the operational use. The only seen difference was observed in intensive precipitation over mountainous areas tending to offer slightly better signal. The precipitation also looked more peaked or locally structured compared to the smoother looking structures from hydrostatic model. For the other scores the two dynamics perform nearly identically. The wind field tends to get more variability in PBL (improving slightly bias worsening standard deviation). Iterative scheme brings purely benefit for the scales of 9km/L43 (similar to experience from ECMWF). With the increased resolution to 4.7km/L87 the iteration technique was found detrimental (similar experience is reported from Arome on 2.5 km).

4 – NH code optimization

This optional package was aimed to improve the NH dynamics performance in the case it is i/ found beneficial for the targeted scales and ii/ its activation requires significant increase in cost. Also the portability of the NH dynamics with respect to various computing platforms and parallelization techniques had to be ensured within this package.

To activate the NH hydrostatic dynamics for limited area model (LAM) implies additional 8% of CPU time in terms of the whole Aladin/CE model cost as measured on vector computer (NEC SX9) using exclusively share memory parallelization (OpenMP). The scalar architectures and distributed memory parallelization would possibly make this number less favorable by adding few more percent. This increase of cost is mostly related to the additional cost for the advection and spectral transformation of the additional two NH variables. The iterative scheme then for the same model implies further increase of around 46% of CPU. None of those numbers is very surprising, hence offering only small potential to gain there from any optimization. As in addition the NH dynamics was not found really profitable for the targeted resolution, this working package was skipped as unnecessary.

The NH dynamics has been successfully ported to various computing platform. This confirms its seamless portability.

5 – Operational implementation

This package ensured a support to any local installation of the NH dynamics in the national weather services. It was also assuming to deliver a guidance with respect of the hydrostatic approach limits.

To activate the NH dynamics is achievable by namelist modifications eventually by extension of initial file (after data assimilation) by two non-hydrostatic prognostic variables. All those necessary changes are documented and described on RC LACE web forum.

The impact of the NH dynamics at the horizontal scales of 4-5km is very weak. Most of the investigated cases give very similar meteorological results. There are few cases, especially associated with precipitation over mountains where it is possible to detect some differences. But still even there it is very difficult to judge meteorologically which scheme offers more realistic results. Naturally one would expect the more general approach of NH dynamics to deliver at worst equal results with the hydrostatic approximation. But the simplicity of the latter seems to also bring some non negligible value to the quality of the forecast (among the reduced cost).

Implementation:

Based on the parallel tests and specific case studies the NH dynamics brings no extra benefit for the models with resolution between 4-5 km and +60 vertical levels. The only noticeable improvement of the NH dynamics in terms of added model skills was seen in slightly reduced error for strong precipitation over mountainous regions. All the other scores are neutral or weakly worse. This can be explained by numerical error of more complex NH dynamics which is not compensated by any added value at those scales. Than at best the NH model is for higher computational cost delivering the same results. The pragmatic approach then seems to remain hydrostatic and invest the additional 8-12% of model cost to any other scheme bringing more benefits at those scales simulated by model. Those can be for example better vertical discretization or more sophisticated physical parameterization.

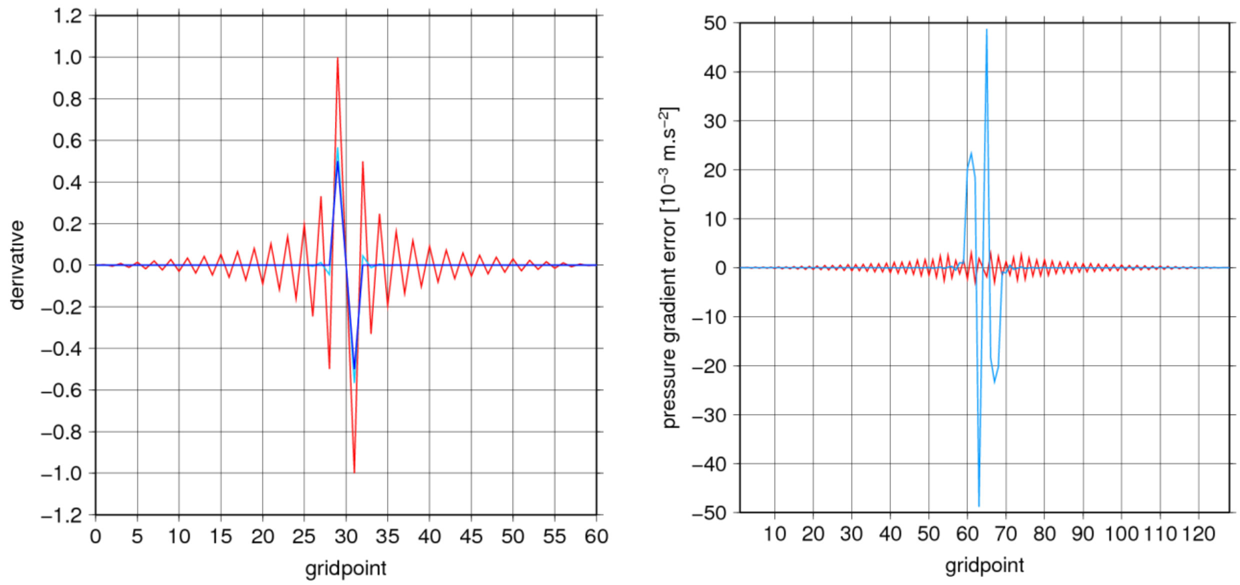

Figure 1 – Left panel: *Horizontal derivative of triangular mountain 8 points wide as computed by spectral method (red), spectral method smoothed by cosine filter (cyan) and central differences (blue);* Right panel: *Error of the pressure gradient force computed from orography derivatives of the left panel (the cyan and blue lines are overlapping). It is evident that the high order consistent spectral approximation even affected by small scale Gibbs waves still offers the best performance for the model numerics.*

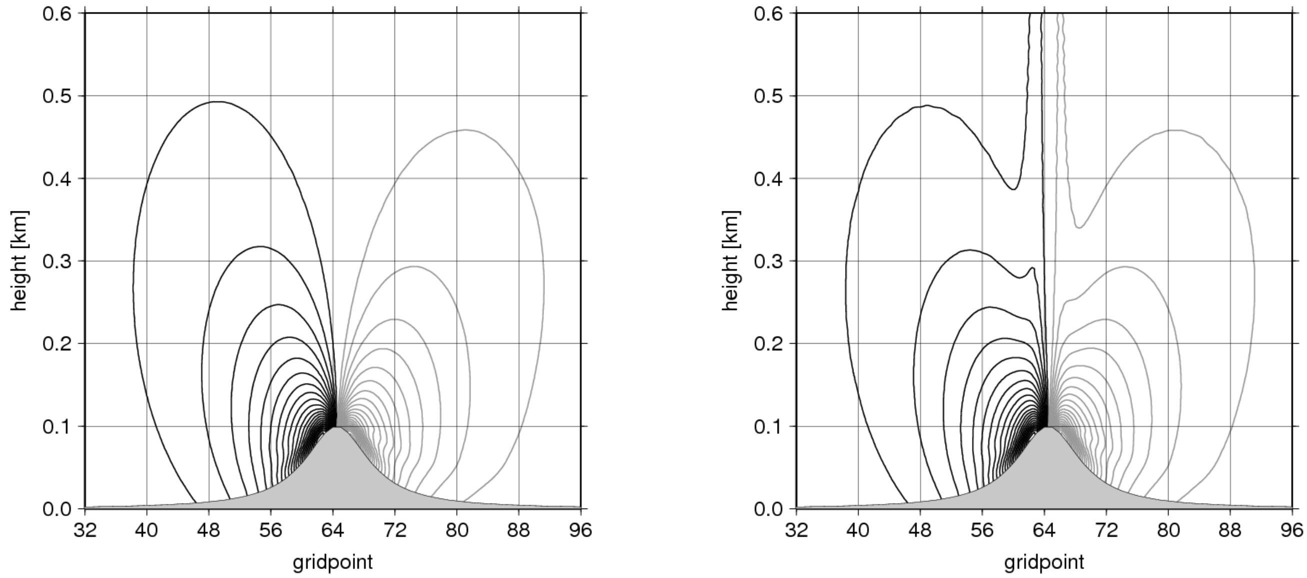

Figure 2 – *Vertical velocity as computed for the potential flow regime (a highly NH case delivering in ideal case symmetric situation on both sides) as obtained with spectral derivatives (left) and centered differences (right).*

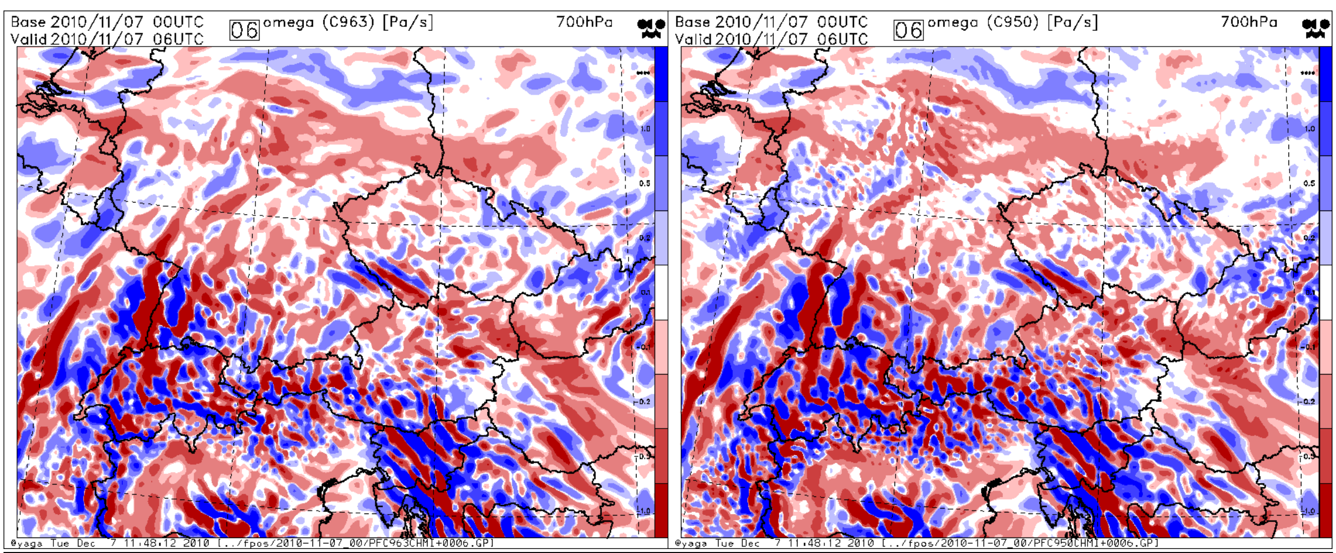

Figure 3 – *Vertical velocity field at 700 hPa with the new horizontal diffusion tuning suppressing the linear spectral diffusion bellow 100 hPa (left) and the original situation with the linear spectral diffusion complementing the SLHD scheme (right). Note specially the small scale noise nicely visible above central Germany.*

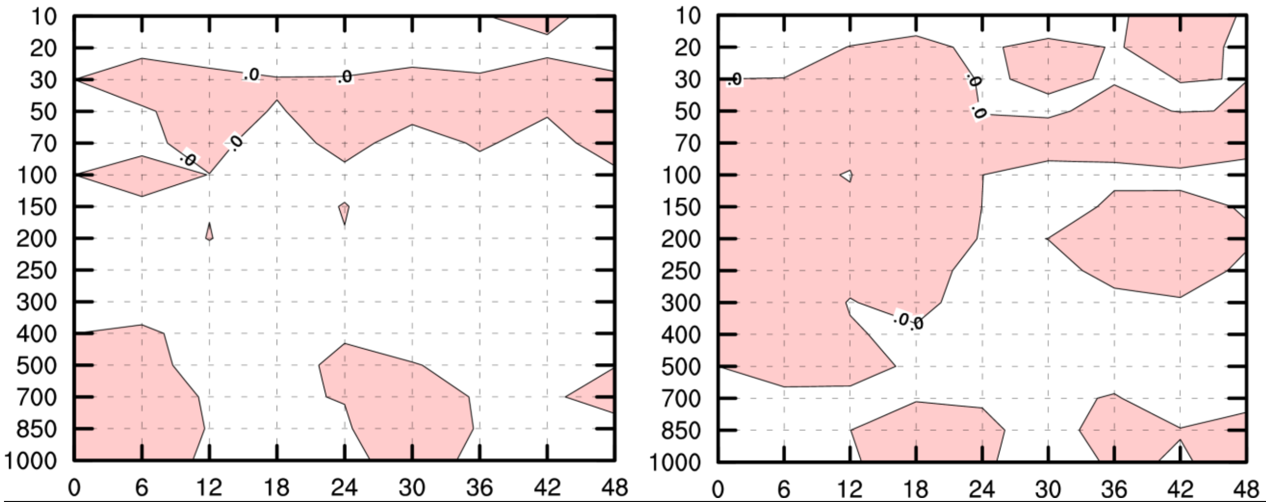

Figure 4 - *Differences of root mean square error (rmse) for geopotential of 1 month simulations by hydrostatic and NH dynamics with ALADIN/CE operational model from January 2009 with 9km/L43 (left) and September 2010 with 4.7 km/L87 (right). The white areas denote altitudes and ranges where the simpler hydrostatic dynamics offers better performance, red areas indicates where the NH has potential to outperform hydrostatic dynamics. (Note than in both cases the contour interval is 0.4 gpm. The fact that only 0 isoline is drawn illustrates extremely weak signal from comparison of the two dynamics.)*

Project related publications:

P. Smolíková – Implementation of the fully compressible flux conservative thermodynamic equation, 2008, LACE report

M. Kolonko - Development of VFE scheme, 2008, LACE report

J. Vivoda – VFE integral operator, December 2009, LACE report

J. Mašek – Discretization of horizontal pressure gradient force, November 2009, LACE report

R. Brožková – Projection of Heat on Temperature and Pressure in Fully Compressible Case, May 2010, LACE report

F. Váňa – Alternative approaches for moisture convergence computation in Aladin, October 2010, LACE report

F. Váňa, P. Bénard, J.-F. Geleyn, A. Simon and Y. Seity – Semi-Lagrangian advection scheme with controlled damping: An alternative to nonlinear horizontal diffusion in a numerical weather prediction model., Q. J. R. Meteorol. Soc., **134**, pp 523-537 (2008)

P. Bénard, J. Vivoda, J. Mašek, P. Smolíková, K. Yessad, Ch. Smith, R. Brožková and J.-F. Geleyn – Dynamical kernel of the Aladin-NH spectral limited-area model: Revisited formulation and sensitivity experiments., Q. J. R. Meteorol. Soc., **136**, pp 155-169 (2010)

Project team

I. Bašták-Ďurán (Sk), R. Brožková (Cz), J. Mašek (Sk, Cz), P. Smolíková (Cz), J. Vivoda (Sk), F. Váňa (Cz) + M. Kolonko (Pl)

Summary of resources/means in person/month

2008:

2008	Planned in 2008	Executed
LACE funding	3	1.5
Total	6	4.5

2009:

2009	Planned in 2008	Executed
LACE funding	4	3
Total	10.5	7

2010:

2010	Planned in 2009	Executed
LACE funding	3	2
Total	11	9

2008-2010:

2008-2010	Planned in 2008	Executed
LACE funding	6.5	6.5
Total	21	20.5