**Objectives:** CNUM-NH aims at providing a common framework to evaluate the transport schemes for two nonhydrostatic models (AROME and Meso-NH) with idealized and real cases, to improve the numerical cores of these two atmospheric models.

**Main results:**

The AROME and Meso-NH models share the same physical parameterizations at kilometer scale. In contrast, their dynamical cores are very different. In the recent years, a special effort has been made to improve the dynamical part of these two models by addressing their relative weaknesses (lack of conservation for AROME, small CFL for Meso-NH) and to prepare adaptation to next generation of hybrid GPU/CPU supercomputer.

The 5th order WENO scheme for wind transport, already coded in Meso-NH, has been parallelized, with an increase of the halo depth (the halo is the overlap area between adjacent sub-domains in the decomposition of the domain). Different stability analyses (Von-Neumann analysis, analysis for orographic flow) have been conducted in order to define the best Runge-Kutta temporal combination, for WENO 3rd and 5th order (respectively WENO3 and WENO5). It is clearly observed that stability increases with the order and mainly with the number of stages of the method (with an order lower or equal than the number of stages). The best efficiency/cost numerical ratio is obtained with the 3rd order and 5 stages method, allowing 1.8 and 2.5 CFL values for WENO5 and WENO3 respectively, while CFL is kept significantly less than 1 for centered schemes (4th order centered scheme associated to leap-frog, noted CEN4TH). A comparison between the different wind transport schemes CEN4TH, WENO3 and WENO5 has been achieved for idealized and real test cases, allowing for a validation of WENO5. Indeed the implicit numerical diffusion is significantly reduced with WENO5 compared to WENO3. Additionally it does not produce spurious oscillations in a non-linear advection of high gradients (1D Burger equation solving), on the contrary to CEN4TH (Lunet et al., 2015).

The gains in performance obtained by GPU have been evaluated for the Meso-NH model by focusing on transport schemes (mainly PPM) which constitute the most challenging part for parallelization as this requires an optimal balance between computations on GPU and GPU/CPU communications with MPI. The programming language OpenACC and PGI compiler were obvious choices as the parallelization is easy, the obtained executable works just as well for CPU as it does for GPU, and the code is bit-reproducible, that is essential to resolve optimization errors. The PGI compiler and the profiling tools (PGPROF) give a lot of information on the performance of parallel codes allowing an iterative optimization. However debugging and reaching good performance require a lot of expertise. Code restructuring is also necessary in order to optimize the data management and the argument passing in the subroutines by increasing the halo size and suppressing automatic arrays (as communication and allocation costs are greater than computation costs on GPU). Following this methodology, good performance has been obtained on PPM transport scheme for a beta-version of Meso-NH: a factor of 10 is obtained between a GPU card (TITAN) compared to a CPU core (Ivy Bridge) for reducing computation time. However communication time between GPU via MPI needs to be improved as only a factor of 2 is obtained when comparing 4 GPU cards to 4*8 cores CPU. These tests and results point the way to follow for the next generation of hybrid supercomputer.

The challenge for AROME is to better represent the small-scale phenomena, in particular for strongly convergent/divergent flows for which the conservation issues play an important part. This is especially crucial that the future development towards hectometer scales will give greater importance to small-scale phenomena and therefore to the divergent modes. For that, a modified Semi-Lagrangian (SL) scheme, COMAD (Malardel and Ricard, 2015) has been evaluated. It allows weighting the values of prognostic variables as a function of the dilation/contraction due to the wind along the Lagrangian trajectories. This modification takes place in...
interpolation steps by changing standard linear and cubic weights. Thus the conservation property of the scheme is significantly improved for idealized and real cases of deep convection. An evaluation based on subjective analysis but also on objective diagnostics (classic and fuzzy scores, precipitation distribution) has been achieved over several periods (summer and winter). In particular the precipitation bias is reduced during summer and the outflows under convective cells are less strong. During this project, several idealized cases (supercell, warm bubbles...) have been implemented for the AROME model.

Future of the project:
- Integration of the COMAD scheme in the new operational version of AROME (April 2015)
- Maintaining the set of test cases and adding new idealized cases
- To achieve the best use of the performance of GPU cluster, a lot still remains to be done to optimize communications between GPU (that will be facilitated by the new protocol NVLINC proposed by NVdia).
- The WENO5 scheme will be integrated in the next version of Meso-NH planned for the end of 2015 (the code is open-source since April 2014).

Main publications