NEWSLETTER ABOUT NON-HYDROSTATIC DYNAMICAL CORE IN ARPEGE/IFS/AROME: SUMMER 2014.

Karim YESSAD, Pierre BENARD, Ludovic AUGER, Yann SEITY, Nils WEDI, et al.

August 7, 2014

- We provide news about NH dynamical core in ARPEGE/IFS and AROME since July 2013;
- Contributions for next releases of this NewsLetter are welcome;
- The distribution is essentially internal (not institutional);
- Consequently, the tune is free (positive and negative statements are welcome, respecting a good balance).

1 Finite difference vertical discretisation (FD).

1.1 LAM model AROME.

Extensive validations have been done at METEO-FRANCE with AROME1.3 (1.3 km) and AROME0.5 (0.5 km) and two important results were found, to ensure numerical stability:

- About the treatment of term NHX, option ND4SYS=2 is more stable than ND4SYS=1 at these horizontal resolutions. This is consistent with results obtained for coarser horizontal resolutions at ECMWF.
- The horizontal diffusion which must be applied to pressure departure variable must be significant and must have the same order of magnitude as the one applied to temperature and vorticity.

The planned future version of AROME1.3, which must become operational early 2015, takes account of this modification.

Additionally, we found that the only "robust" configuration (for both global and LAM models) is to use LGWADV (gw as prognostic variable in grid-point calculations) with one iteration of ICI scheme (NSITER=1). We use LPC_CHEAP=T. The future version of AROME1.3 will use that. Runs done with LGWADV=T and no ICI scheme are not stable.

The future version of AROME1.3 will use a timestep of 45 s, but numerical stability is still ensured for a timestep of 60 s.

About AROME0.5 on a domain covering the Alps, experiments done show good stability with a timestep of 30s. Extensive simulation on summer cases must be still done.

Testings have started on versions of AROME with mesh-size of 250 m, 100 m and 50 m. The domain tested covers Grenoble and south of Chartreuse mountains, to study behaviour above steep slopes.

- We suceeded to run AROME 250 m with SITRA=70 K (SITRA is the second reference temperature in the linear system).
- We suceeded to run AROME 100 m with SITRA=50 K (unstable for SITRA=60 K and SITRA=70 K).
- AROME 50 m is unstable with SITRA=50 K, SITRA=60 K and SITRA=70 K.

Instability occurs only in NH runs; when switching to hydrostatic dynamical core runs are stable.

1.2 More details about the parallel suite AROME1.3 at METEO-FRANCE.

AROME1.3 is expected to become operational early 2015, on a domain close to the current operational AROME2.5 (slightly enlarged to the North).

The tested AROME1.3 configuration has the following features:

- Timestep: 45 s.
- 90 levels.
- Bottom level at 5 m.
- Upper level at 1000 Pa.
- Coupling frequency: 1h.
- LGWADV with one iteration of ICI scheme (PC_CHEAP).
- ND4SYS2 and RDAMPPD=20.
- Cycle cy40_op1.
- Horizontal domain (1440x1536 points):Lambert projection centered at (2 E,46.7 N).

This model has been evaluated in spin-up mode, on case studies (Xynthia storm for instance) and also on longer periods:

- Daily experimental runs on a small domain since June 2012.
- 48 most active convective situations from summer 2012.
- January 2013 (containing both anticyclonic situations and heavy-snow events).
- July 2013 (containing severe convection with hailstorms).

Results: A cell tracking algorithm has been applied on simulated and observed radar reflectivities from summer 2012 convective cases. It shows that AROME-1.3km cells are more realistic than AROME-2.5km ones, in terms of size, intensity and life-time. Indeed, AROME-2.5km had e tendency to produce too large and too active convective cells, with an over-estimation of their life-time. AROME-1.3km significantly reduces these defaults. In terms of scores, AROME-1.3km configuration improves rainfall scores, especially in summer, but also 10 m winds and simulated satellite radiances.

1.3 Testings done at ECMWF

ECMWF is happy with the progress made using the Fast Legendre Transforms (FLTs) (Wedi et al, 2013), as this allows to reduce the cost of the Legendre transforms at higher (>=T2047) resolutions. An effort has been made by Meteo-France (Ryad EL KHATIB) to harmonize the reduced Gaussian grid computation between MF and ECMWF. George Mozdzynski has since made a new version that is substiantially more efficient, especiacially at very high resolutions, and as a result we were able to compute a T15999 (1.3km) reduced Gaussian grid. But no model runs have been done with this so far.

ECMWF has worked extensivly on the software to create/derive the underlying climatological surface fields that are needed to perform global simulations at NH resolutions. With 40r3 ECWF will introduce revised fields for orography and land-sea mask, surface albedos and subgrid-orographic parameters.

ECMWF is in the process of testing a horizontal resolution upgrade for next year. There are several possibilities, one of which is to move away from the linear grid: a) due to aliassing that is becoming more difficult to control at higher resolutions and b) the cost of communicating and computing the Legendre transforms (even wit FLT). Especially at high core counts, the so called cubic grid (with at least 4N+1 gridpoints to N waves) is substantially more efficient in this respect. While moving to higher resolution for surface features, physics, and moist quantities, the resolution used in the SI scheme is relatively coarser (truncated, but only to 3-4dx). It would also maintain the validity of the hydrostatic equation set for longer. E.g. a T1999 cubic grid could be run with the T3999 (5km) gridpoint fields, providing a significant advantage in terms of CPU time compared to the linear grid configuration. Moreover, the time-step can be chosen larger (within limits). Various configurations are tested at the moment, for example a T1279 and a T1599 cubic grid.

Sylvie Malardel had found two reasons for the instability of the NH without the ICI scheme at ECMWF, a highly-oscillatory NH pressure departure and steep orography. No satisfactory solution (without deterioating results) had been found. The existing NH has not been developed further during 2014. But with the possibility to run one of the ICI iterations at lower resolution (end of 2014 as part of Oops developments), it will be tested, how this could improve the stability at reduced cost.

Michail Diamantakis has found a weak instability (and a fix in 40r3) in the SL trajectory calculations that was previously circumvented by a fix of Mariano Hortal (but that had detrimental impacts on the stratospheric scores). This had been disabled by mistake, leading to occasional major rejections of satellite information, especially in the stratosphere when sudden stratospheric warmings occur. Unfortunately, the fix has little impact on the NH stability.

Other ECMWF developments are detailed below in part 3.

2 Finite elements vertical discretisation (VFE).

ALADIN partners Jozef Vivoda and Petra Smoliková provided significant developments during autumn 2013. These developments were merged on the top of CY40 and entered cycle 40T1. New features could be sum-up as follows:

- The finite-element basis is redefined.
- Some upper and lower boundary conditions are now taken into account in the vertical integrals too.
- More flexibility has been introduced in the definition of η used in the VFE operators, with a new option.
- Alternate discretisations have been introduced for some terms containing vertical derivatives.
- A bug (present at least since 2007) has been fixed in the linear system, in order to make it valid in the case where the "constraint C2" is not matched.

With these developments we are able to run stable VFE-NH simulations for the following configurations:

- LGWADV=T with one iteration of ICI scheme.
- Horizontal mesh-size >= 2.5 km.
- LAM model and ARPEGE global model.

Unfortunately, instability is still present in AROME1.3 and AROME0.5, in cases where FD is stable.

Jozef Vivoda and Petra Smoliková are still working on VFE-NH to improve stability, but they did not get new results in 2014.

3 Testing alternative dynamical cores.

3.1 Mid-term and long-term prospectives at Meteo-France

There is now a brainstorming in Meteo-France about specifications of the dynamical cores which could be used after 2025. Some questions have been raised:

- High scalability on machines which might reach millions of processors with distributed memory.
- What type of vertical coordinate above steep slopes? Is there actually an issue? It is not guaranteed that terrain-following vertical coordinates could still be used with slopes above 70%.
- Spectral representation could be abandoned for horizontal discretisation. Alternative grid-point discretisations must be examined.
- To sum-up, a lot of "possibles" exist, one must find the ones which will improve NWP and this is not an easy task.

3.2 Research done at ECMWF

ECMWF has been pro-active in this respect by attempting to answer some of the questions raised above or to build the necessary infrastructure to be able to answer these questions in the future. Based on the widely accepted very small impact of using NH systems with grid-meshes >= 5 km, the official deadline for an operational NH model at ECMWF may be delayed to the date when the grid-mesh will go well below 5 km.

It is very clear from the prospectus of emerging energy-efficient computing architectures, that IFS needs to accommodate flexibility in the equations solved, flexibility in the solvers used, flexibility on the meshes and grids used, and flexibility on the communication patterns. With this in mind, ECMWF has or is in the process of starting two important projects:

- In 2013 the ERC Advanced grant PanthaRhei project started with Piotr Smolarkiewicz as the principal investigator and hosted by ECMWF.
- In 2014 the PolyMitos project will be initiated, which is part of the scalability programme, to lay the foundations for a more scalable IFS future.

Two main developments have been undertaken in 2014 with resources from PantaRhei and the CRESTA project:

- The development of a parallel data structure that facilitates the generation of a compact stencil, unstructured mesh. One special case of this new parallel mesh generator allows to arrange the mesh around the reduced Gaussian gridpoints, which in return allows the spectral transforms as before.

- Based on this so called Atlas library (which will form also a building block in ECMWF's future product generation), Piotr has implemented a basic, non-hydrostatic, flexible-mesh solver.

In the longer term, nothing should prevent us to try higher-order schemes, other meshes, other solvers, etc. These developments are outside IFS at the moment, but an attempt will be made next year to introduce the data structure and transport scheme into the chemical IFS (C-IFS) for tracers if funding is available.

In the intermediate future (next 10 years) ECMWF can either continue to use the hydrostatic dynamical core, or use the NH-IFS with a cost reduced ICI scheme. But the latter option suffers from issues with steep orography (Christian's investigations confirm that the hydrostatic is always robust but the NH is not), and the communication cost issue does not go away with a SLSI solution procedure and its viability depends on the competitiveness of SLSI compared to emerging other models.

It is expected that the new scalable infrastructure will provide substantial research opportunities, either to combine with or to outperform the SLSI scheme.

In terms of exchange of ideas, Christian Kühnlein and Piotr Smolarkiewicz went to Toulouse on 5 March 2014 to present their work. Fabrice Voitus is visiting ECMWF for a two week period at the end of July.

Some effort has also been spent on the equations that may be used in the future. Piotr has developed a framework that allows to solve either anelastic, pseudo-incompressible, or the fully compressible equations. Christian has added to this now the unified hydrostatic-anelastic system (Arakawa and Konor, 2009). All these should eventually be able to operate with the flexible mesh solver. The extension of the hydrostatic IFS system, with the eta-coordinate, to a unified system has proven more difficult and so far elusive. Work on this is progressing but it seems to emerge now that the solution of the quasi-anelastic (and in fact any flavour of anelastic) equations appears numerically less efficient for NWP-type applications and less stable in the unified case than the fully compressible equations. This has been found in the context of the EULAG model. While the unified equations are theoretically attractive, because they analytically filter vertically propagating acoustic waves by neglecting non-hydrostatic pressure perturbations in the mass continuity equation, numerically it poses other restrictions. The aim to retain the robust hydrostatic solution procedure while (iteratively) calculating the NH update has thus proven illusive so far.

Christian is also working on an analysis of different vertical coordinate choices and their behaviour in the presence of real (steep) orography. This highlighted problems with the existing NH-IFS.

In collaboration with the Oxford university a single precision version of IFS has been produced that has been quite successful in reproducing the double precision version. The main advantages are the halving of the communication messages and the memory required on a processor to run the model. This is work in progress but highlights the importance to review where accuracy and precision is really necessary in NWP.