ECMWF 2013 Annual Seminar

Recent developments in numerical methods for atmosphere and ocean modeling,

Reading, 2-5 September

Report by

Giovanni Tumolo
Earth System Physics Section
The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy
gtumolo@ictp.it

This ECMWF annual seminar was focused on providing the participants with a general overview on both currently used techniques and emerging new ideas related to numerical methods for modeling the atmosphere and ocean, with special emphasis on recent developments and future trends.

Different solutions to key issues concerning the development of atmospheric and oceanic dynamical cores have been proposed by several research teams. Each proposal emphasized both strengths and weaknesses/limitations and so encouraged the participants to form a comprehensive and critical view.

The main topics that were addressed during this week were high resolution and non-hydrostatic modeling, the related issue of scalability and efficiency of algorithms and codes on massively parallel architectures, how to handle fast modes in a stable way, the problem of spurious modes, the numerics of the coupling between different components in the context of a coupled modeling system and the interface between dynamical cores and physical parametrizations (the former topic, a 'traditional' distinction, was shown to become questionable in the near future as we go towards ultra-high resolution modeling).

Regarding high resolution, paths towards convective resolving modeling were discussed, considering current and future model resolutions, and comparing results obtained at different resolutions by solving hydrostatic or nonhydrostatic equations, with special attention to the interaction between physics and dynamics (thanks to which the process of non-parametrized moist convection exists). The perspective of a global LES has also been shown as a possible future milestone for the exascale computing era, even if several critical points still need to be solved (moist processes inject energy at grid scale thus affecting the energy cascade theory in the inertia subrange, large aspect ratios typical of atmospheric meshes collide with the homogeneous turbulence hypothesis at the basis of LES).

Related with the issue of high resolution modeling, different mesh choices, structured and nonstructured, have been discussed, and different staggering solutions too, including icosahedral meshes, edge-based finite volume discretizations, C-grid centroidal Voronois ones with application to nonhydrostatic modeling, with attention to their performances in terms of variable resolution (and therefore downscaling and upscaling). In general the advantages of unstructured meshes in terms of geometric flexibility and efficiency were clearly recognized, allowing a multiresolution approach, enabling adaptive mesh refinement (AMR) and also giving better bottom representation through their ability to align the mesh with topography.

Flexibility on general grids of continuous Galerkin (CG) and discontinuous Galerkin (DG) methods was also discussed in the framework of a unified CG-DG model, with a fair and comprehensive comparison of these two families of element-based methods in terms of accuracy, efficiency, easiness of adaptive mesh refinement and scalability, their high order being beneficial for scalability too (in addition to their locality i.e. reduced communication stencils) because they exhibit more on-processor work compared with off-processor work. The idea itself of combining CG and DG in the same code taking the best of each technique also appeared promising.

Many challenges set by parallelization and scaling issues at exascale were also considered and analyzed.

Different approaches for handling fast modes have been considered, including the solution of the fully compressible equations with semi-impicit schemes (with discussion of their limits especially at higher resolutions and proposals for new improvements), or with HEVI schemes based on the idea of splitting the horizontal (treated explicitly) and the vertical (implicitly, computationally cheap and with no implications for the parallelization), with focus on RK-IMEX schemes, or the alternative of solving instead filtered equations, derived in a systematic and rigorous way from asymptotic analysis, or from variational principles. The proposed unified framework for the discrete solution of soundproof and compressible atmospheric dynamics equations provided an interesting tool for a fair comparison of these two philosophies and for blending corresponding models.

Related to the time integration of slow modes, the present and the future of the semi-Lagrangian technique for solving the atmospheric transport equation was also discussed, with special emphasis on the problem of the mass conservation (and the possible remedies through fixers, economical but not truly locally conserving, or through inherently conserving formulations, more expensive but more accurate and anyway competitive if multitracers applications are envisaged) and on the problem of its performance on massively parallel architectures (with attention on reworking the semi-Lagrangian advection communications to reduce the communicated halo, on overlapping reduced halo communications with SL interpolations and on using Fortran 2008 coarrays to communicate only halo points that are effectively used).

The issue of spurious modes detection and analysis was also considered, as well as possible ways to avoid them, given for example by the use of compatible finite elements spaces, with additional advantages like high order consistency on arbitrary meshes, absence of orthogonality constraints, flexibilty to differents DoF ratios, and good mimetic properties.

The discussions and different talks gave me the impression that we could envisage future models that blend various equations (e.g. fully compressible vs. filtered ones) and also different numerical methods (e.g. continuous Galerkin vs. discontinuous Galerkin). In this spirit this intensive ECMWF annual seminar has been particularly fruitful, in particular by merging many experts with different approaches to address common problems and by giving participants the possibility to interact in a constructive and friendly environment. I would like to thank again the European Meteorological Society for having supported my participation to this valuable training week.