Acta Geophysica
vol. 59, no. 6, Dec. 2011, pp. 1073-1075
DOI: 10.2478/s11600-011-0057-6

Modeling Atmospheric Circulations with Sound-Proof Equations

PREFACE TO THE TOPICAL ISSUE

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With the rapid progress of high-performance computing, numerical models for simulating general atmospheric circulation can already achieve spatial resolutions fine enough to undermine the validity of the hydrostatic primitive equations that form the theoretical foundation of traditional numerical weather prediction and climate studies. While the capability to capture nonhydrostatic effects opens new avenues for all-scale simulation of atmospheric circulations, it also puts new demands on the mathematical/physical theories and numerical methods comprising weather and climate codes. At the highest level, the choice of the governing equations is being debated. Although compressible dynamics are universally valid across the range of scales from micro turbulence to planetary circulations, they admit computationally troublesome, rapidly propagating acoustic modes of, arguably, relatively little physical significance due to their low energy compared to other modes of motion. On the other hand, the majority of research in low Mach number flows under gravity, such as planetary atmospheres and oceans, has historically relied on reduced sound-proof equations that retain thermal aspects of compressibility but are free of acoustic modes. In particular, the last decade saw numerous developments consequential to the advancement of nonhydrostatic soundproof models for weather and climate, notwithstanding the admittedly universal validity of fully compressible equations for all-scale simulation of atmospheric circulations.

The papers collected in the present volume of *Acta Geophysica* address the capability of sound-proof equations to model all-scale atmospheric circulations. Technical topics covered in this special issue range from theoretical numerical analysis, model design, and massively-parallel programming to simulation of cloud processes, regional weather and global atmospheric circulations.

The opening article by Vater *et al.* highlights computational difficulties imposed by fully compressible equations and discusses how to remedy them with a novel, scale-selective large-time-step integration method. The following paper by Smolarkiewicz and Szmelter documents a new unstructured-mesh soundproof model and provides comparative analysis of the anelastic and pseudo-incompressible equation sets to assess the validity of soundproof equations for deep stratospheric gravity waves. The next two papers, by Prusa and Gutowski, and Abiodun *et al.*, address multi-scale aspects of nonhydrostatic climate simulations using the anelastic research model EULAG. The first study examines fine scale gravity waves generated by baroclinic flows in idealized climate simulations. The second study employs EULAG as the dynamical core for the Community Atmospheric Model, producing an anelastic AGCM known as CEU, to evaluate the capability of the coupled model to simulate realistic regional climate over West Africa. The following two contributions, by Wyszogrodzki *et al.* and Grabowski *et al.* address the physics of convective clouds, studied by means of large-eddy simulation (LES) with advanced microphysics schemes. The first of the two papers examines the impact of microphysics models on local properties of shallow non-precipitating convection, whereas the second paper relates LES of precipitating convection to field observations with two contrasting aerosol backgrounds.

The subsequent three papers summarize a focused effort to adopt EULAG as the dynamical core of a new generation operational model for numerical weather prediction. In the first of these three papers, Ziemianski *et al.* investigate the impact of increasing horizontal resolution – towards grid interval values characteristic of mesoscale studies – on the fidelity of regional-scale simulations of semi-realistic Alpine weather. The following two papers (Rosa *et al.* and Kurowski *et al.*) complement the first study with a series of idealized benchmark simulations evaluating nonhydrostatic flow response to a variety of forcings. The presented sound-proof results for density currents, convective bubbles, inertia-gravity waves, supercells and thunderstorm dynamics are related to equivalent results for fully-compressible models reported in the literature.

Finally, the closing article by Piotrowski *et al.* is devoted to high-performance computing with soundproof models. The authors present a new massive parallelization scheme based on three-dimensional domain-decomposition, and assess its efficacy compared to standard two-dimensional decomposition in two diverse applications of small scale turbulence and planetary climate.

Acknowledgements. The editors express thanks to the authors for preparing their contributions and to the reviewers for their thorough evaluations of the papers.

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Received 13 September 2011