Building resolving large-eddy simulations (LES) with EULAG model.

Andrzej A. Wyszogrodzki *
Piotr K. Smolarkiewicz

National Center for Atmospheric Research
P.O. Box 3000, Boulder, CO 80307-3000, USA
* Corresponding author: andii@ucar.edu

EULAG (Eulerian/semi-Lagrangian fluid solver) is an established multi-scale, multi-physics computational model for simulating thermo-fluid flows across a wide range of scales and physical scenarios; see Prusa et al (2008) for a recent review. It is noteworthy for its non-oscillatory integration algorithms, robust elliptic solver, and generalized coordinate formulation enabling grid adaptivity technology. The analytic formulation of EULAG assumes the nonhydrostatic anelastic equations of motion, with options available for compressible/incompressible Boussinesq, incompressible Euler/Navier-Stokes, and fully compressible equations for high-speed flows. The advanced and unique numerical technology of EULAG allows maintaining high accuracy while being adaptable to a broad range of fluid dynamics applications. EULAG has a proven record as a research tool in fields of a turbulence, urban flows, gravity wave dynamics, and flows past complex/moving boundaries, micrometeorology, cloud dynamics, global atmospheric flows, and basic fluid dynamics of incompressible fluids. The model is fully parallelized using message-passing, and it scales well on the variety of platforms including the NCAR Blue Gene/L system where it demonstrated near teraflop performance (Prusa et al. 2008).

Fig 1. EULAG LES of a contaminant dispersion and flow past downtown of the Oklahoma City.

A complex problem of modeling flows around multiple buildings requires accounting for aerodynamic features as channeling, enhanced vertical mixing, downwash and street level flow. In order to investigate small scale transport and dispersion (T&D) within intricate urban structures, we are resolving buildings explicitly using the immersed boundary (IMB) approach. In this method fictitious body forces in the equations of motion are introduced to represent the internal boundaries (Peskin 1977, Mittal and Iaccarino 2005), effectively imposing no-slip boundary conditions at the building walls. The particular technique employed in EULAG adapts the feedback forcing of Goldstein et al. (1993), with implicit time discretization admitting rapid attenuation of the flow to stagnation within the building structure in O(δt) time comparable to the time step δt of the model. For the full description of the method see Smolarkiewicz et al. (2007).
The EULAG-IMB model has been applied to numerous problems under different stratification regimes, including the idealistic flows around the simple cubed obstacles (Wyszogrodzki et al. 2006a, 2006b) and such complex structures as the Pentagon building. For the latter case the model generated flow was compared with wind tunnel measurements (Smolarkiewicz et al. 2007) and equivalent results generated with boundary fitted mappings. These comparisons show that IMB technique is an efficient and accurate tool, less stringent to the computational stability requirements than the equivalent continuous grid transformations. Furthermore the IMB method provides relative simplicity in circumventing the imposition of an explicit internal-boundary condition for elliptic problems in incompressible fluid models. This makes IBM an attractive tool for a range of computational studies. In order to investigate realistic T&D processes within the urban areas EULAG was coupled to the mesoscale weather prediction WRF model. In this approach the WRF model collects the information from land use characteristics, surface emission sources, high-resolution data assimilation system, and fine-scale atmospheric analysis. This information is then used to generate realistic large scale atmospheric conditions to provide initial and boundary conditions for EULAG. The WRF-EULAG coupling was validated against the data from Oklahoma City Joint Urban 2003 experiment (Wyszogrodzki et al. 2009). For illustration, Fig. 1 shows an instantaneous boundary layer flow and contaminant dispersion over the downtown of Oklahoma City from EULAG generated LES computed at NCAR’s IBM-BG/L system.

Computer time was provided by NSF MRI Grants CNS-0421498, CNS-0420873, and CNS-0420985; NSF sponsorship of the National Center for Atmospheric Research and the University of Colorado; and a grant from the IBM Shared University Research (SUR) program.


