Choosing an adequate FEM grid for global mantle convection modelling

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Abstract

Global numerical models of mantle convection are typically run on a grid which represents a hollow sphere. In the context of using the Finite Element method, there are many ways to discretise a hollow sphere by means of cuboids in a regular fashion (adaptive mesh refinement is here not considered). I will here focus on the following two: the cubed sphere [1], which is a quasi-uniform mapping of a cube to a sphere (considering both equidistant and equiangular projections), and the 12-block grid used for instance in CITCOM [2]. By means of simple experiments, I will show that at comparable resolutions (and all other things being equal), the 12-block grid is surprisingly vastly superior to the cubed-sphere grid, when used in combination with trilinear velocity - constant pressure elements, while being more difficult to build/ implement.

Methodology

The Finite Element code ELEFANT was used in this work. It is based on trilinear-constant pressure (Q1P0) elements and solves the mass, momentum and energy equations. The inner Stokes solve is carried out by means of a CG solver or with the direct solver MUMPS, and the outer solve is a Preconditioned Conjugate Solver (PCG) [3]. Note that the penalty method is also available [5].
In all simulations, the fluid is assumed to be incompressible (density=3300kg/m^3), of constant viscosity (10^{22} Pa.s). Thermal effects are neglected. No-slip boundary conditions are prescribed on all boundaries.

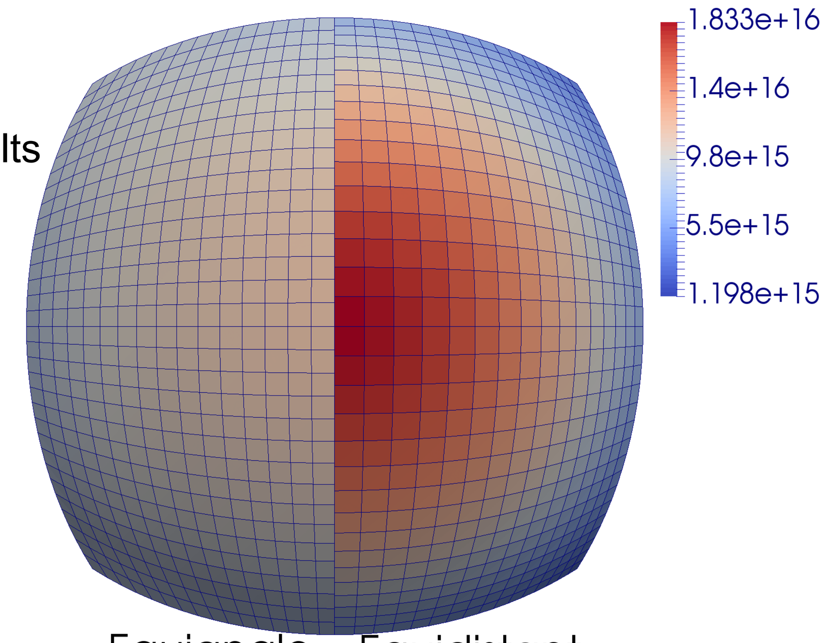
www.cedricthieulot.net/elefant.html

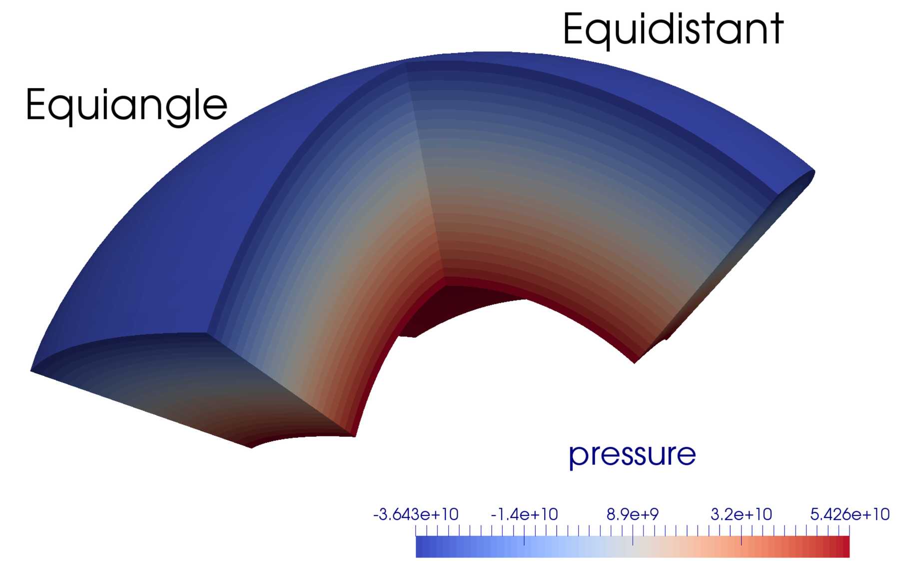
References

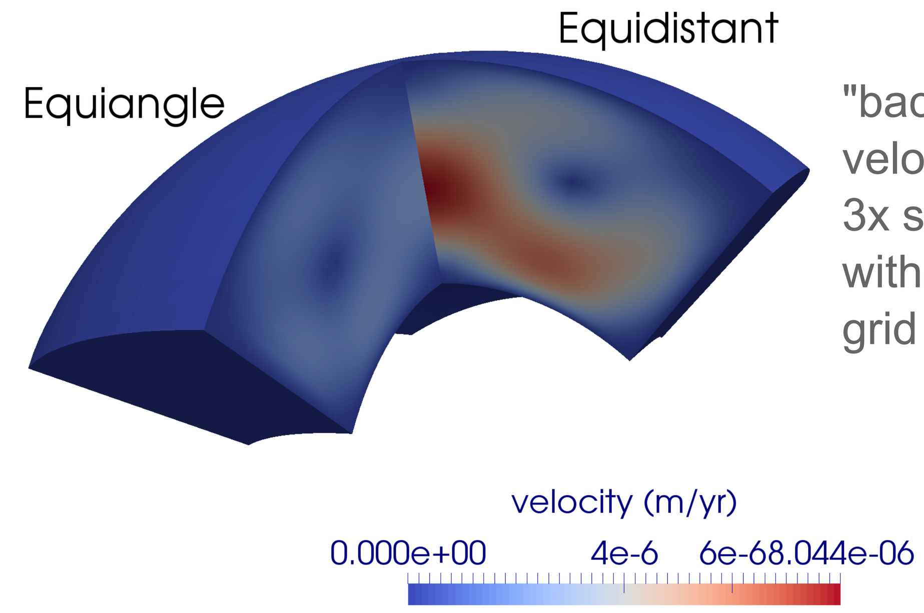
[1] C. Ronchi, R. Iacono, and P. S. Paolucci, The "Cubed Sphere": A New Method for the Solution of Par- tial Differential Equations in Spherical Geometry, Journal of Computational Physics, 124, p93–114 (1996).
[2] S. Zhong and M.T. Zuber and L.N. Moresi and M. Gurnis, Role of temperature-dependent viscosity and surface plates in spherical shell models of mantle convection, Journal of Geophysical Research, 105 (B5), p 11,063-11,082 (2000).
[3] D. Braess, Finite Elements, Cambridge (2007)
[4] Sadourny, Conservative FD approximations of the primitive equations on quasi-uniform spherical grids, Monthly Weather Review, 100(2), 1972.
[5] Thieulot, FANTOM: Two- and three-dimensional numerical modelling of creeping flows for the solution of geological problems, PEPI 188, 2011.

Conical Section Geometry: equi-distant vs. equi-angle

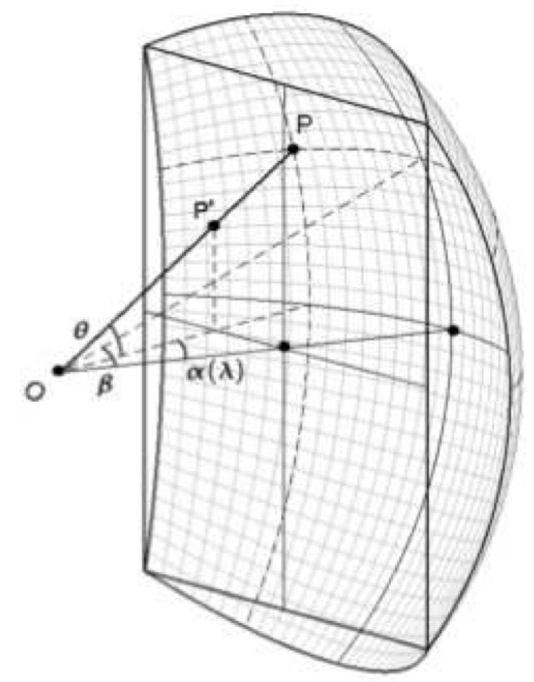
32x32x24
=24,576 elts



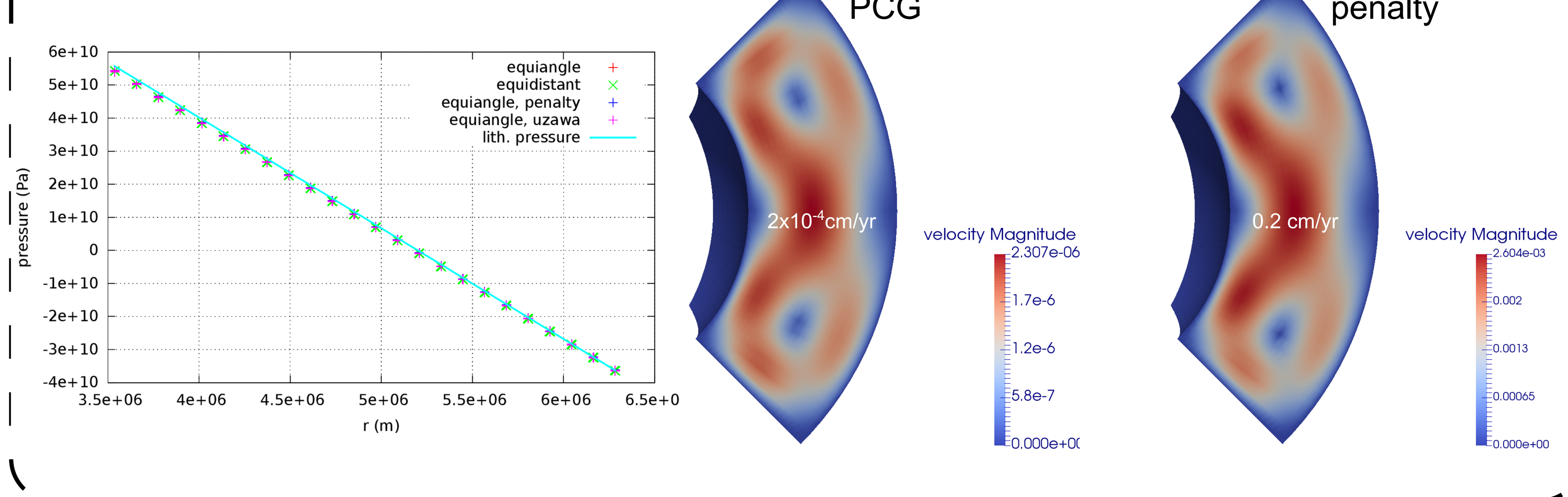




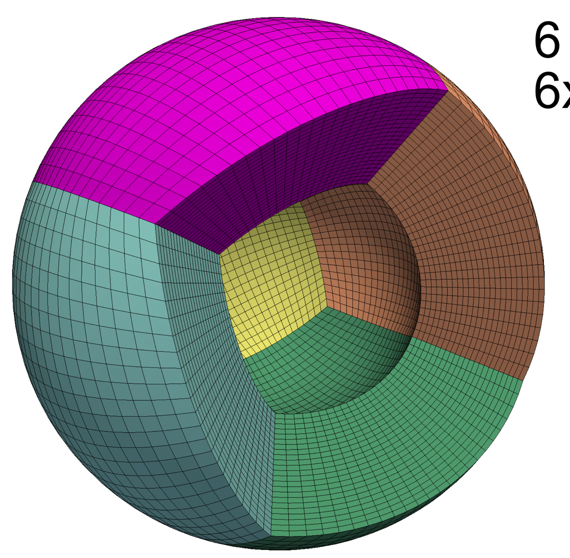
"background" velocity 3x smaller with equidistant grid



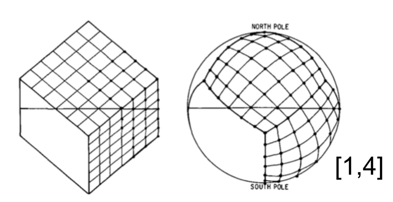
Influence of outer solve algorithm

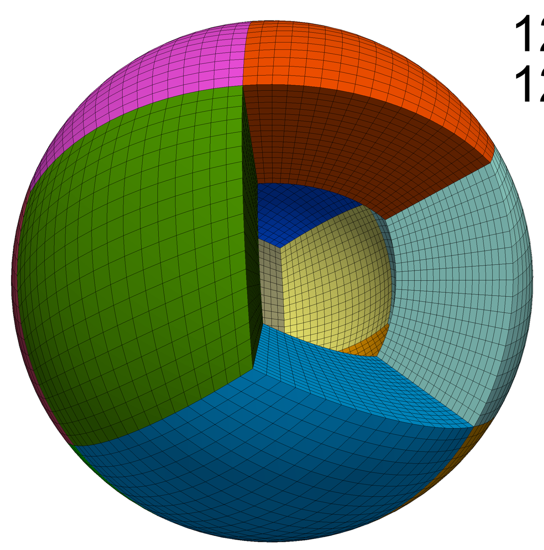


Spherical Geometry



6 blocks
6x23^3=73,002 elts





12 blocks
12x18^3=69,984 elts