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Geoscientific Model Development Discussions

Interactive comment on "A mimetic, semi-implicit, forward-in-time, finite volume shallow water model: comparison of hexagonal–icosahedral and cubed sphere grids" *by* J. Thuburn et al.

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The paper summarizes recently developed numerical methods for cubed-sphere and hexagonal-icosahedral grids suitable for the shallow water equations.

While I agree that the method presented is well suited for the shallow water equations, I doubt that it will stay so unproblematic with regard to full 3-dimensional climate model simulations. My concerns are twofold:

1) The advection method for PV is very attractive seen from the perspective of the shallow water equations because it leads to well controlled enstrophy dissipation. For a full model, however, it is essential that $\mathbf{v}\cdot\nabla\mathbf{v} = (\nabla\times\mathbf{v})/\varrho\times\varrho\mathbf{v}+\nabla K$ holds numerically, at

least to an acceptable degree. A violation of this equality may lead to the Hollingsworth instability. If the advection scheme for PV changes something in the first term on the right for the better to the PV-equation, but not in the kinetic energy gradient term, it is likely that some problems may occur in three-dimensional simulations. Unfortunately this problem does not yet occur in the framework of the shallow water equations, but only in baroclinic zones of the full atmosphere.

2) In the shallow water equations, diffusion is not really needed and with some upwinding and dissipation of enstrophy (but see the first comment) the model is stable enough. However, in three-dimensional simulations a Smagorinsky-type diffusion of momentum with a turbulent momentum flux tensor τ is eventually required. For climate simulations, the dissipated kinetic energy should not be thrown away, as it is usually the case in state-of-the-art models. Rather, this energy has to be fed into the internal energy (temperature equation). Some scientists working with climate models would like to have this feature. Then the kinetic energy changes via $\varrho\partial_t K = ... - \mathbf{v}\cdot\nabla\tau$ and the internal energy gains the dissipated energy $\varrho\partial_t E_{int} = ... - \tau\cdot\cdot\nabla\mathbf{v}$. It has to be proven that this dissipation is indeed a heating to the internal energy. In short, the numerical discretization of τ with the associated strain and shear deformations on the hexagonal and cubed-sphere grid is thus required together with the dissipative heating rate. I personally struggled a lot with this term on the hexagonal C-grid and found it only working reliably if the shear deformation was defined on pairs of triangles (rhombi) and the strain deformation was defined on hexagons. For me, this is a another strong support of my thesis that the dual grid entities are hexagons and rhombi rather than hexagons and triangles (as it is also supported in the manuscript). The shallow water framework could be a nice playing ground to test and develop this Smagorinsky-diffusion term (as said: for the SWEs themselves this is not a must) and it would help the manuscript when seeing the developments from the perspective of an intended 3-dimensional model.

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