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Geoscientific Model Development Discussions
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Interactive Comment

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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We thank Dr Ullrich for his positive comments on the manuscript.

1. *Scalability.* Yes indeed, all serious model development efforts are concerned about scalability! Something of the order of 1000 columns per processor are the sort of numbers we hear talked about before models start to run out of scalability (whether or not they require elliptic solves). We are encouraged by the results of Müller and Scheichl (2014) for geometric multigrid, particularly as the elliptic problem that arises from implicit time stepping has an inherent length scale $c_s\Delta t$ (c_s is the sound speed),

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so that, unlike the Poisson problem solved by Heikes et al. (2013), we only need ~ 3 levels of coarsening, thus avoiding the need to gather the coarsened domains onto a smaller number of processors.

2. *Stability.* In short, we don't have a simple answer to this question. Conversely, one could ask why is the scheme stable at all. Although a Crank-Nicolson treatment of linear fast waves is unconditionally stable, and the advection scheme in 1D is stable for Courant numbers up to 1, it is not immediately obvious that the two, combined in the way we have done, should be stable – that is why we did the normal mode stability analysis. We should emphasize that for advective Courant numbers between 0.75 and 1 the instability growth rate is extremely small. Moreover, in 2D on irregular grids there are no analytical guarantees about the stability limit of the advection scheme on its own, but practical experience suggests it is very close to 1. (If a flux limiter were used then stability of the advection scheme could be guaranteed for advective Courant numbers up to 1).

3. *Advection and grid imprinting.* We agree that the cosine bell test is not the most challenging for advection schemes. However, the test suggested by the referee is actually just a consistency check for the way we have formulated our advection scheme (sections 5.7 and 5.8). A tracer initialized on the primal grid to be the same as ϕ remains the same as ϕ thereafter. Initializing a tracer on the dual grid by averaging the primal grid ϕ using equation (28) and then advecting it gives the same result as advecting the primal grid ϕ (or the ϕ-like tracer) and then averaging the result to the dual grid using (28). Figures 1-3 confirm this for the barotropic instability test. Since reviewer 1 also raised a point about tracer advection and preservation of constant mixing ratio, we will add some references to the importance of mass-tracer consistency in section 5.

Around the time we submitted the paper we were concerned that accuracy of the advection scheme, linked to grid imprinting errors, was the primary cause of the errors

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seen in in the barotropic instability test case. In particular, the parallelogram approximation of the swept areas might be inaccurate in strongly sheared flow, as suggested by Ullrich et al. (2013). We therefore extended the advection scheme to use more general quadrilateral swept areas (but still with straight edges). It made no difference to the results! Further investigation (switching off the initial height perturbation and looking at the step 1 errors) revealed that the primary source of errors was the perp operator, which gives the mass fluxes used to advect potential vorticity. Thus the errors do take on a grid imprinting pattern, but are coming not from the advection scheme itself but from the mass fluxes input to the advection scheme. These tests were actually done with a finite element model that uses the same advection scheme but has a consistent perp operator; even so, grid imprinting in the perp operator appears to be the factor limiting accuracy in the bartropic instability test. For the finite volume model discussed in the paper, with its inconsistent perp operator, it would be surprising if this did not remain true.

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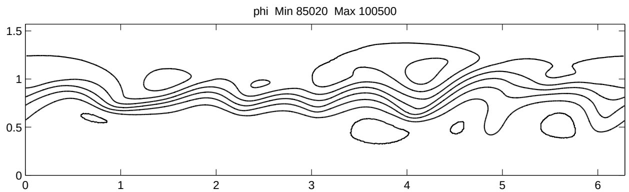

Fig. 1. Geopotential field (day 6) from the barotropic instability test case.

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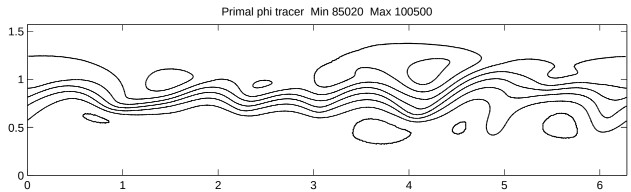

Fig. 2. Primal grid tracer (day 6) initialized to equal the geopotential.

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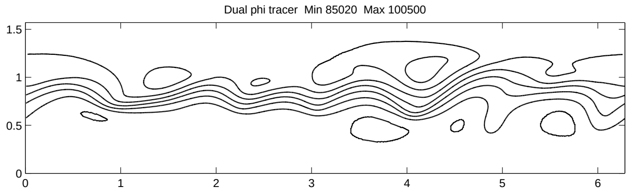

Fig. 3. Dual grid tracer (day 6) initialized from the geopotential using (28).

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