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Interactive comment on “Development and evaluation of a hydrostatic dynamical core using the spectral element/discontinuous Galerkin methods” *by* S.-J. Choi and F. X. Giraldo

Anonymous Referee #2

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The authors present two versions of a 3D dynamical core based on two different horizontal discretizations: spectral-element (continuous Galerkin) and discontinuous Garlerkin; referred to as SE and DG, respectively. Similar 3D dynamical cores based on SE and DG already exist in the literature, however, the models presented here differ in terms of transformations (Cartesian used here), polynomial order, flux computations (for DG), vertical discretization and possibly with respect to other aspects (see detailed comments below). Whether these differences are important or not in terms of model efficiency and/or accuracy is unclear to the reviewer. The CG and DG models are compared against each other using two idealized wave test cases and simulations using Held-Suarez forcing. The manuscript provides a "clean comparison" between CG and

DG horizontal discretizations in their model setup. The author's repeatedly point out that a main novelty of the manuscript is that this is the first time (to their knowledge) that results from a Held-Suarez run using a DG dynamical core is published.

Having CG and DG in the same framework provides a nice tool to compare these two numerical methods. How much novelty there is in the CG and DG formulations is unclear to the reviewer. So a clear statement of that would be useful. The testing of the model could be significantly improved by following existing protocols for idealized testing that facilitates model intercomparison (see detailed comments below). The reviewer is curious about how the model performs when it can be directly compared with other hydrostatic dynamical cores.

The reviewer recommends major revisions. In terms of algorithmic novelty the manuscript seems to lack some substance (unless the authors can justify that their choices lead to increased accuracy/efficiency compared to already published SE and DG dynamical cores), the testing could be significantly improved as alluded to above, and important details for reproducibility such as time-step size used in the experiments is missing. The reviewer appreciates that this manuscript could serve as a documentation for the dynamical core development at KIAPS and therefore does not need to have significant algorithmic novelty; the GMD journal was created to, among other things, serve that purpose. However, if that is the case the model testing should be much more rigorous as that would be that main novelty of the manuscript; there are several standard test case setups (with specifications for resolution etc.; lead by C. Jablonowski) that would make it a lot easier to compare the SE/DG dynamical core directly with existing state-of-the-art models. This would be of interest to the community and the author's may also gain valuable insight into their models performance.

Detailed major comments (in order of appearance) are listed below. A list of minor comments is not provided in this review. For points marked "(optional)" the reviewer will leave it up to the Editor to decide if the point is beyond the scope of this manuscript.

- Section 3: Taylor (2011) showed that CAM-SE has mimetic properties resulting in mass-conservation to machine precision and conservation of total energy to time-truncation errors. Does the SE and DG models presented in this manuscript have mimetic properties? This is considered important for dynamical cores intended for climate modeling.

- Section 3: What explicit diffusion (if any) is applied to the SE and DG models? If any, please specify numeric values for diffusion strength applied for the different configurations/resolutions.

- Section 3: What exactly is the computational cost difference between the SE and DG models presented here?

- Section 3: The cost of tracer transport in modern climate models appears to dominate the cost of the dynamical core (at least for hydrostatic models). And for practical applications it is highly desirable (some would say required) that the transport is shape-preserving. Do the authors have practical limiters that work with high order (12th-order) polynomials? Some discussion on this would be highly appreciated.

- Section 4: please provide information about what time-steps are used for the different configurations as well as values for all tunable parameters such as viscosity coefficients (if applicable), sponge-layer strength and depth (if applicable), etc. What are the stability limits for the Held-Suarez test case for the different configurations?

- Section 4: Some discussion on why the author's choose 8'th degree polynomials for some simulations and degree 5 for other simulations is needed. Preferably the authors should use the same order basis functions for all simulations unless they intend to discuss how the solutions vary as a function of polynomial order. In any case, they must be consistent across test cases.

- Section 4: Related to the previous point: how was the order of polynomial chosen?

- Section 4: This comment is a technicality but yet important for non-DG/CG readers.

Please specify the average grid spacing at the Equator for easy comparison with other grids so that readers not so familiar with SE/DG methods can get a sense of resolution immediately. Please use that measure of resolution on the Figures.

- Tracer transport: (optional) it would be interesting to see results from 2D tracer advection comparing CG and DG, for example, by using the Lauritzen et al. (2012, 2014) test case suite. The author's have a unique framework to compare CG and DG and these test cases would isolate horizontal transport errors; and the authors could easily compare the accuracy of their methods with many state-of-the-art schemes.

- steady-state test case (section 5.2; Figure 4 and 5): For easy comparison with other models please follow the protocol in Lauritzen et al. (2010); that is, show PS at day 9 at 1 and 2 degree resolutions so that the reader can compare with column 1 of Figures 7-10 for other state-of-the-art dynamical cores. Similarly for Figure 4: please show 1 and 2 degree resolution results and show up to day 30 instead of day 20 (again so that the reader can compare with column 1 of Figures 11 and 12 in Lauritzen et al., 2010).

- baroclinic wave test case (Section 5.3, Figures 7,8 and 9): same comments as for the steady-state test case: please show results for 1 and 2 degree resolutions. In addition: while Figure 9 is informative with respect to wave intensity a more global measure of accuracy would be to follow Jablonowski and Williamson (2006) and produce Figures equivalent to Figures 21-24 in Lauritzen et al. (2010).

- Held-Suarez test: (optional) It has recently been shown that the NCAR SE model (CAM-SE) conserves axial angular momentum very well in Held-Suarez setup (Lauritzen et al., 2014b); it would be useful to confirm that the SE-DG models models presented here have the same property.

- Held-Suarez: what is the upper-level boundary condition? Do the authors have a sponge layer near the model top. If yes, please provide details. Similarly with the vertical finite differencing; what is done near the top and bottom of the domain?

- Held-Suarez (Figure 10): plotting z instead of p as a vertical coordinate can make it easier to detect differences (it is the reviewers experience that differences can be found in the Equatorial region around 10-70 hPa between models which is very hard to see with p as a vertical coordinate). Perhaps difference plots could be shown as well. Where is the model top located? Do the plots show all levels or are the top levels cut off?

- Held-Suarez: The authors should discuss existing SE Held-Suarez simulations from the literature, e.g., Fournier et al. (2004).

- The authors use high-order finite-differences in the vertical. These could significant reduce PGF errors; therefore it would be very interesting to see how the model performs with a mountain and a steady-state atmosphere at rest (basically following the research of J. Klemp and the MPAS group at NCAR). Again, for easy comparison with other dynamical cores the reviewer suggests to use test 2-0-1 in the DCMIP test case suite (see page 29):

`https://earthsystemcog.org/site_media/docs/DCMIP-TestCaseDocument_v1`

Since this test case suite has not been published in a peer-reviewed journal, the reviewer will let it be up to the editor to decide if adding this test can be required.

References

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