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Interactive comment on "An orthogonal curvilinear terrain-following coordinate for atmospheric models" *by* Y. Li et al.

Anonymous Referee #2

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Report on: An orthogonal curvilinear terrain-following coordinate for atmospheric models, by Y. Li, B. Wang, and D. Wang

The authors present a formulation for an orthogonal curvilinear terrain-following coordinate that may have some attractive features for use in atmospheric models. They derive the orthogonal coordinate transformation using a "rotation parameter b" in the basis vectors that controls that rate at which the terrain influence is removed from the coordinate surfaces, and demonstrates results for Schar's (2002) advection test case. However, their presentation is superficial and somewhat misleading, and the authors are apparently unaware of previous published work relevant to this research. Therefore, I believe this paper is not suitable for publication in the reviewed literature in its current form.

The authors state that with their orthogonal sigma (OS) coordinate, pressure gradient force (PGF) errors are reduced because "the computational form of PGF in each momentum equation has only one term." However, this statement is misleading; since the velocity components are aligned with the OS coordinate directions (i.e. no longer horizontal and vertical), each momentum equation has an additional gravitational acceleration term that is proportional to the slope of the coordinate surface. This term is essentially the same as the second term that arises in the classic sigma (CS) coordinate (the vertical pressure gradient times the coordinate slope). Thus, PGF errors still arise due to computational imbalances in removing the hydrostatically balanced portion of the PGF to recover the (often small) residual that actually induces accelerations along the coordinate surface. The authors present no evidence, either theoretical or numerical, to support their claim of reduced PGF errors.

The only idealized test case considered by the authors is a simple Schar-type advection test with the pressure-gradient and buoyancy terms removed from the equations. A disturbance is advected over a mountain with a wind that is constant at the level of the disturbance and that decreases to zero at a height above the mountain-top level. Thus, the correct numerical solution should be the same as that obtained with no mountain present. The authors present results for three different rotation parameters (Br1, linear b: Br2, squared b; and Br3, exponential b), and in comparison with the CS coordinate, they conclude that the OC coordinate results are superior, particularly those obtained with the increased "smoothing" in the Br2 and Br3 simulations. The suggestion that these results indicate any inherent benefits of the OC coordinate is highly misleading. The results actually just confirm that a hybrid coordinate formulation (terrain influences removed from the coordinate surfaces faster than linearly with height) is superior to the classic approach (terrain influences removed linearly with height) for this test case. In the authors' OS formulation, the rotation parameter b is not a smoothing parameter in the sense that the influences of small-scale terrain features are selectively removed more rapidly with height than larger scale terrain features. Rather, this parameter regulates how rapidly the overall terrain influences on the coordinate surfaces decrease with height. In this regard, the variable b just adds flexibility to the OS coordinate that allows it to behave similarly to the hybrid variation of the CS coordinate. For this case it's obvious that the more rapidly the coordinate surfaces approach constant height surfaces, the more accurate the results (i.e. the better they agree with the no mountain results). For the Br1 (linear b) simulation, the results are virtually the same as those for the CS coordinate (linear decrease of terrain influence with height). For a fair comparison of the Br2 and Br3 OS simulations, they should be compared with the corresponding hybrid version of the traditional sigma coordinate. To be specific, by defining sigma = z - b(z) * h(x) for the hybrid version of the CS coordinate, setting b(z) = Br1, Br2, or Br3 will produce appropriate comparisons with the OS simulations, and I expect will produce very similar results. It's also important to note that this test case, by itself, is of limited value in assessing the coordinate design; while a strong hybrid character is beneficial for this case, in any realistic flow, rapid removal of the terrain influences with height can cause increased problems with accuracy and stability near the surface, where coordinate surfaces may be highly compressed. These effects are not included in this test case.

The authors make no reference to similar previous work in developing and testing nonhydrostatic models in orthogonal curvilinear coordinates. While there may be other related studies, two come to mind that are particularly relevant:

Sharman, R. D., T. L. Keller, and M. G. Wurtele, 1988: Incompressible and anelastic flow simulations on numerically generated grids. Mon. Wea. Rev., 116, 1124-1136.

In this study, Sharman et al. derive the equations in orthogonal curvilinear coordinates for the 2-D incompressible and an elastic systems and present credible mountain wave solutions for a variety of terrain profiles. In these systems acoustic modes are filtered and numerical integration requires solving an implicit Poisson equation at each time step. Their motivation in considering orthogonal coordinates was that it led to a much simpler form of the Poisson equation since cross terms were eliminated.

Satomura, T.,1989: Compressible flow simulations on numerically generated grids. J. Meteor. Soc. Japan, 67, 473-482.

Satomura developed an orthogonal coordinate formulation for the 2-D compressible equations and demonstrated good agreement with linear theory for hydrostatic and nonhydrostatic mountain-wave simulations. He also obtained better results with the orthogonal coordinate than with the CS coordinate for a case with steep terrain having discontinuities in slope (to be expected, since the orthogonal coordinate removes the singularity in coordinate slope above the surface).

Both of these papers focus on 2-D systems, and emphasize that in three dimensions it is not possible to generate orthogonal coordinates that follow an arbitrary terrain shape. If the authors of the current paper believe their techniques will be suitable for real world applications, this will be an important issue for them to address.

Interactive comment on Geosci. Model Dev. Discuss., 6, 5801, 2013.