Geoscientific
Model Development
Discussions

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

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We thank the referee #3 for your helpful comments. Our reply is given below.

1. General evaluation: The authors present the mathematical description for an orthogonal curvilinear terrain-following coordinate, claiming that this type of coordinate will improve the numerical accuracy of advection and the pressure-gradient term compared to models with a conventional non-orthogonal terrain-following coordinate. Unfortunately, only passive advection tests are presented in the main part of the paper, leaving the question behind if a model code that actually solves the 3D prognostic atmospheric equations in the orthogonal coordinate system (OS) already exists.

Response:

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Thanks for the referee's comments. The title of the revised manuscript may be changed into "An orthogonal curvilinear terrain-following coordinate and its preliminary tests using 2-D idealized advection experiments".

2. Given the results that are available up to now, the mathematical description of the OS (sections 2 and 3) is much too detailed. Moroever, parts of these sections are quite difficult to understand because there is no clear separation in nomenclature between a coordinate system and a coordinate. Section 4, presenting the results of the passive advection tests, suffers from comparing apples with oranges (see comment #4 below), and the conclusions again mention improvements in the computation of the pressure-gradient term that have nowhere in the paper been demonstrated.

Response:

Thanks for the referee's comments.

First, we will revise the description of the design of the OS coordinate, and put the details into the supplementary materials of the revised manuscript.

Second, we will check and revise the description of a coordinate and a coordinate system to make the paper more clear.

Third, we will implement new experiments (see the response in No. 6) in the revised manuscript to investigate the distinct effect of "the orthogonal grids" created by the OS coordinate.

Finally, we will only focus on the advection errors in the revised manuscript; and for the PGF errors, we will only mention it in the discussion, and the description will be "the PGF errors might be reduced in the OS coordinate, which will be tested carefully in the other study".

3. Some specific remarks follow. 1. (Fig. 4) The strong convergence of the vertical coordinate lines at mountain peaks not only imposes a severe limitation on numerical stability when really solving the atmospheric equations (CFL criterion) but also leads

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me to the question what will happen in real mountainous orography with steep mountain ridges and deep narrow valleys. Will the valleys be reasonably resolved with the OS approach, or will nearly all vertical coordinate lines cluster around the mountain crests? If the latter is the case, the OS approach will be useless for practical purposes, because the main goal of high resolution NWP (or modelling in general) in mountainous regions is usually to forecast the atmospheric conditions in the valleys as accurately as possible.

Response:

We appreciate the referee for pointing out this.

First, the "vertical coordinate lines" (see blue lines in Fig. 4, on P5847 of the original manuscript) cluster around the mountain crest do affect the numerical stability; however, the extent of this cluster is "adjustable", via the rotation parameter b, and then the horizontal resolution in the valley is also adjustable. For example, in the grids of OsBr1, OsBr2, and OsBr3 (Fig. 10, on P5853 of the original manuscript), the minimum of the horizontal resolutions are 0.5 m, 0.6 m, and 0.9 m respectively, due to the different definition of b in each experiment.

Second, in the revised manuscript, we will reproduce the idealized advection experiments of Schär el al. (2002), in which the terrain is wavelike (Fig. 1). Since that wavelike terrain is with the ridges and valleys, the effects of the OS coordinate tackling the steep ridges and valleys will be investigated. Furthermore, we will plot the grids of the OS coordinate based on the wavelike terrain and submit them as the supplementary data of the revised manuscript according to the editor's suggestion.

Schär, C., Leuenberger, D., Fuhrer, O., Lüthi, D., and Girard, C.: A new terrain-following vertical coordinate formulation for atmospheric prediction models, Mon. Weather Rev., 130, 2459-2480, 2002.

4. 2. (End of section 3.1) As already mentioned by another reviewer, the projections

of the gravitational acceleration on the horizontal directions constitute in fact a second component of the horizontal pressure-gradient terms. Thus, it is by no means clear a priori that the OS reduces the related discretization errors. By the way, the authors should also distinguish clearly between scalars and vector components. Their transformation behaviour is essentially different.

Response:

As our response in No. 1, we will not emphasize the reduction of the PGF errors by the OS coordinate in the revised manuscript. And also we will check and fix the usage of the scalars and the vector components in the revised manuscript.

5. 3. (section 4.1) A Leapfrog-centred difference scheme, which nowadays no one would ever use for advecting positive definite tracers, tends to exaggerate the numerical artifacts induced by small-scale orographic structures in the coordinate surfaces.

Response:

Thanks for the referee's comment, and we will add some descriptions of the other possible discritization methods of the advection equation in the revised manuscript.

6. 4. (section 4.1; Figs. 8–16) For a meaningful comparison between the CS and OS coordinates, the authors need to consider pairs of experiments with equal shapes of the coordinate surfaces. So far, only Cs and OsBr1 are comparable, showing just a tiny improvement by a few per cent when changing from CS to OS, which is not very convincing.

Response:

Thanks for the referee's suggestion. In the revised manuscript, we will add new experiments by comparing the OsBr2 or OsBr3 with their corresponding hybrid σ coordinate which have similar vertical levels as those in the OsBr2 or OsBr3 to investigate the distinct effect of the orthogonal grids created by the OS coordinate.

7. The fact that smoother coordinate surfaces improve the numerical accuracy of advection is not a specific property of the OS coordinate – this is valid for the CS coordinate as well, as has been demonstrated extensively for the SLEVE coordinate and similar approaches.

Response:

Yes, the smoother vertical coordinate surfaces are not the specific property of the OS coordinate. For the first step of the OS coordinate, we aimed to make the vertical layers of the OS coordinate just behavior like a hybrid σ coordinate. Since we give three principles for the b, people can design their own b to smooth the vertical layers as they need. Moreover, we are going to design some new formulations of b to make the vertical layers of the OS coordinate to be smoothed like the SLEVE (Schär, et al. 2002) or STF (Klemp, 2011), which will be proposed in other study.

Actually, the specific properties of the OS coordinate are the "one-term PGF" and the "orthogonal and terrain-following vertical grids", meanwhile its vertical layers can be smoothed easily via the rotation parameter b. And, we will not emphasize the "one-term PGF" in the revised manuscript, since we didn't implement an experiment to investigate its effect.

8. I also have to note that the extremely strong squeezing of the coordinate surfaces appearing in OsBr3 would very likely lead to numerical instabilities in a full model solving the prognostic atmospheric equations. Thus, the good behaviour of this coordinate type in the advection tests is at best of academic interest.

Response:

Thanks for your comment. Any hybrid σ coordinate or similar methods will induce the squeezing of the σ coordinate surfaces, include our Os coordinate, which affect the numerical stabilities. However, as our response in No. 3, both the horizontal and vertical coordinate surfaces in the OS coordinate are adjustable, via the rotation parameter b.

and in a numerical model we can choose a proper b of the OS coordinate to obtain the proper coordinate surfaces therefore satisfying the numerical stabilities.
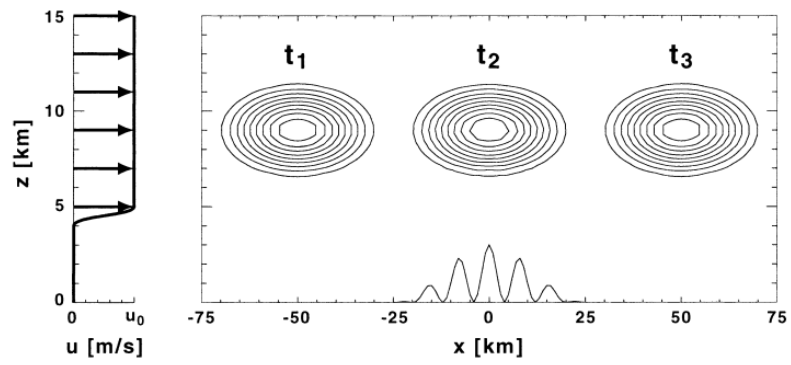
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FIG. 4. Vertical cross section of the idealized two-dimensional advection test. The topography is located entirely within a stagnant pool of air, while there is a uniform horizontal velocity aloft. The analytical solution of the advected anomaly is shown at three instances.

Fig. 1. The 2-D advection experiment implemented by Schär et al. (2002)