Review of
A deep-atmosphere extension in a nonhydrostatic dynamical core: formulation and idealized tests

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1 Summary

The authors present a recent development regarding the extension of the Grid-Model dynamical CORE (GMCORE) towards the capability of simulating deep atmospheres. The result is a numerical model discretizing the deep-atmospheric equations on a regular latitude-longitude-based grid together with a dry-density-based vertical coordinate system. The authors also pay special attention to the inclusion of the non-traditional component of the Coriolis term. After outlining the algorithm, one standard test case, i. e., the baroclinic wave experiment, and one non-standard test case of a tropical cyclone in shallow- and deep-atmosphere approximation is presented.

To the best of my knowledge, this is the only modeling approach combining the aforementioned features, in particular a global, deep-atmospheric model on a regular lat-lon grid, and insofar it poses a relevant contribution. The presentation of important ingredients of the algorithm, however, lacks in details and the model validation would benefit from adding standard benchmarks.

I recommend the paper for publication after addressing the issues listed below that may further strengthen the impact of this paper.

2 Major issues

- The introduction lacks in addressing relevant literature. Below is a list of suggestions:

  1. Add the publication of Becker and Vadas (2020, `https://doi.org/10.1029/2020JA028034`) as it comprises several similarities to the present study and poses a substantial achievement in the field of upper-atmosphere modeling.
  2. The paper puts some focus on the non-traditional component of the Coriolis force that is usually neglected. Adding the publication of Chew et al. (2022, `https://doi.org/doi:10.1017/jfm.2023.474`) would help to sharpen the discussion on the relevance of this term.

- Section 2 would greatly benefit from adding more detail to the discretization strategy. In particular, please add

  1. a description of the vertical grid, i. e., the effective spatial distribution of vertical levels and the vertical extent of the physical domain;
  2. a comment on whether a sponge layer at the model top is necessary to stabilize the numerics;
  3. a comment on the treatment of orography and the geoid deformation from the perfect sphere;
  4. a motivational comment on why you chose the discretization based on a regular lat-lon grid. Since the majority of the community agreed on circumventing the pole-problem by taking more advanced gridding strategies into account, a motivation would be suitable as to why the grid type presented here is relevant. Please address advantages and potential pitfalls;
  5. details on the horizontal discretization strategy;
  6. more details on the time-stepping strategy, e. g., at the example of one prototypical equation.

- In section 3, generally more information is needed on the test cases that is specific to the presented model. For all presented test cases, if not already included, please add information on

  – the vertical resolution,
  – the vertical extent of the simulation
  – the horizontal resolution
  – HPC configuration (number of nodes and cores, walltime)

- Please address the question on how the model compares to established models. If feasible, add a comparison.

- For the sake of assessing the usability of the model, for at least one of the presented test cases, please add

  – a convergence study demonstrating the consistency and stability of the model;
  – a performance benchmark indicating the scalability of the model.
  – a comment on the typically achieved CFL numbers for you test cases.

- Since you are achieving the horizontal resolution necessary to explicitly resolve substantial parts of the gravity wave spectrum, a test case showcasing the representation of gravity waves would be appropriate.

Please also address the following localized issues:

l. 156-7 The statement "This staggering optimally represents inertia-gravity wave dispersion characteristics and suppresses computational mode" should be justified with a reference. Also give a reference to the advection scheme SWIFT.

Fig. 3 The asymmetry of the storm can affect the ability of "naïve" methods to identify the storm center. Therefore, please give details on how the storm center is computed.

sec. 3.2.1 You traced-back the observed drift of the deep-atmosphere simulation compared to the shallow approximation to the structural differences without further contextualization of the underlying mechanisms. There is a substantial amount of literature in the context of TC asymmetries and their effect on the storm track evolution. I recommend consulting to the work of Polvani, Reasor, Montgomery, Nolan, Schecter, Paeschke, and Doerffel. Please add a short discussion.

3 Minor issues

l. 27 You refer to Borchert et al. (2019) as a reference to the ICON model development. While it is the reference publication for the upper-atmosphere extension of ICON (UA-ICON), the reader may be benefit from a reference to the technical description of the base model ICON, presented by Zängl et al. (2015).

l. 51 The plural noun "researches" is unusal. It could be replaced by studies.

eqs. (1-7) Here you use the governing equations using the Lamb transformation as presented in Gassmann and Herzog (2008, `https://doi.org/10.1002/qj.297`). This reference should be given.

l. 84 The term "horizontal operator" is unprecise. You might use "horizontal differential operator".

l. 115 You use the term "local edge modification" without introducing its meaning. Since (I assume) it is specific to your discretization approach, a brief explanation would be appropriate. Refer also to the major comment regarding the presentation of the discretization.

l. 124 For the description of the vertical coordinate, you use the terms $\rho r^2 \frac{\partial r}{\partial s}$ and $\rho a^2 \frac{\partial r}{\partial s}$ without introducing the meaning of s. Please add this context or adjust the symbol.

l. 133 The use of ∂ as a differential is rather unusual. It should be replaced by d.

Eq. (20) Please introduce the variable γ.

l. 200 The choice of w as a symbol for the weights is unfortunate as it may lead to confusion with the vertical velocity. Please replace the symbol.

eq. (23) In the context of this equation, substantial information is missing to interpret its meaning. What is the purpose of W_j, i. e., in where exactly in the discretization is it being used?

Fig. 3 Are the blue dots representing the time series of the relative positions. Please indicate the trend by color-coding or labels.

l. 151 It seems that there is too large of a whitespace between "and" and "discretization".

l. 154 There should be a whitespace after the end of the sentence ending with "the planetary surface a.".

Author contributions This paragraph systematically uses the wrong tense (simple present instead of simple perfect) in all the sentences. Also (l. 403), the word "based" might be replaced by "basic".

4 Recommendation

I recommend the paper for publication with major revisions.

5 Reproducibility and Data/Code Availability

Code and configuration files are archived on Zenodo which is in accordance with the targeted journal.

End of review.