GMDD-2020-150 Short Reply to Reviewer#1

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The authors are very grateful to this Reviewer for their valuable comments. We will carefully improve the manuscript, add more details and experiments, and rewrite some parts. This will take some time. But as GMDD has this unique interactive discussion, I would like to first address some issues raised by this Reviewer for some clarification.

1. The model description in Section 2 is lacking.

– For example, it is unclear exactly what numerics are being applied. Finite volume, I assume? What is the vertical discretization? How close are the numerics to the Model for Prediction Across Scales (MPAS)?

Reply: We apologize for all the incompleteness. We will add more details regarding the numerical operators. In short, GRIST is formulated on an unstructured Voronoi-Delaunay mesh based on the staggering finite-volume method. This choice is made to achieve a balance of solution accuracy, efficiency, implementation and runtime cost. As a new global model group that focuses on weather-climate modeling, GRIST used some well-established techniques available in the icosahedral-/Voronoi-mesh modeling community, based on publicly available papers and documents. These details can be clearly found in the previous model description paper (Zhang et al. 2019; Zhang et al. 2020), and we will concisely summarize them in the revision. MPAS pioneered some key numerical features, and GRIST used some of them. However, some detailed formulations are clearly different. GRIST has its own unique aspects as the numerical operators are implemented under a different solution strategy and a different general environment (i.e., governing equations, vertical coordinates, physics-dynamics coupling workflow, and infrastructure). The comparison of numerics and its behaviors may be more meaningful in some isolated and highly idealized tests (e.g., passive 2D/3D advection and shallow water waves) that specifically examine the numerical operators.

2. On several comments about the diffusion option.

Reply: We will add more details regarding the diffusion operators. In the initial submission, the VR configuration only alters the mesh file, the timestep, and some tuning of the Smagorinsky coefficient (one for the whole mesh). There is no additional horizontal or vertical filters, except those implicitly generated by the numerics (e.g., the upwind flux operator). In the code (ParGRIST-A20-0705), there is a 4th-order computational hyperdiffusion for the horizontal wind field, but not activated for those tests. Also note that the cyclone tests activate Smagorinsky for tracer transport, which is actually *fairly unnecessary* (shape-preserving filter is enough for tracer, while the impact of activating this is rather small). This option was preserved for the supercell tests with constant-coefficient 2nd-order diffusion, and can be switched to a Smagorinsky-style diffusion in other tests. Due to the evolutionary nature of model development, the running script does not turn it off because of regression and sanity check.

The Smagorinsky diffusion, though stronger than hyperdiffusion, does not really generate *that diffusive* solutions because of its flow dependent nature (i.e., its diffusion strength is acceptable). This nature makes it selective in terms of where and how much to damp (see e.g, Fig. 9 in Gassmann 2013, QJRMS). In contrast, the artificial computational diffusion or 2D divergence damping is always active. The weakly diffusive evidence can be clearly observed in the JW baroclinic wave solution at G8 resolution (with Smagorinsky activated), which produces very sharp gradient and filament structures for the vorticity field. The Smagorinsky diffusion is indeed stronger if fully activated, and the side effect probably lies in a slightly higher stability restriction.

The original Smagorinsky formulation works well for the tests in the initial submission, as the mesh transition is at most X4. In some recent VR modeling tests with full-physics, the original formulation (using a global mean constant length scale) is found to be unstable for the more highly-deformed mesh (~6 km-~30km-~120 km). We are testing some modifications to the original Smagorinsky: reducing the Smagorinsky coefficient, and/or using a variable length scale. Meanwhile, only using 4th-order hyperdiffusion (requires some code changes from ParGRIST-A20-0705) for horizontal winds or using ZERO explicit diffusion can produce reasonable solutions. Results from these three configurations look similar (Fig. 1). In full physics modeling, the physics is stronger than simple physics, so we are also going to check whether using ZERO explicit diffusion will work well for the full-physics situations. In the pure dynamical core (baroclinic wave) or simple physics (tropical cyclone) tests, using explicit Smagorinsky diffusion will in general, make the solutions look better. Also note that explicit diffusion is often used as a cleaner for dynamics (with or without physical meanings), but the discrete numerical operators may introduce additional problems, especially for the highly deformed meshes.

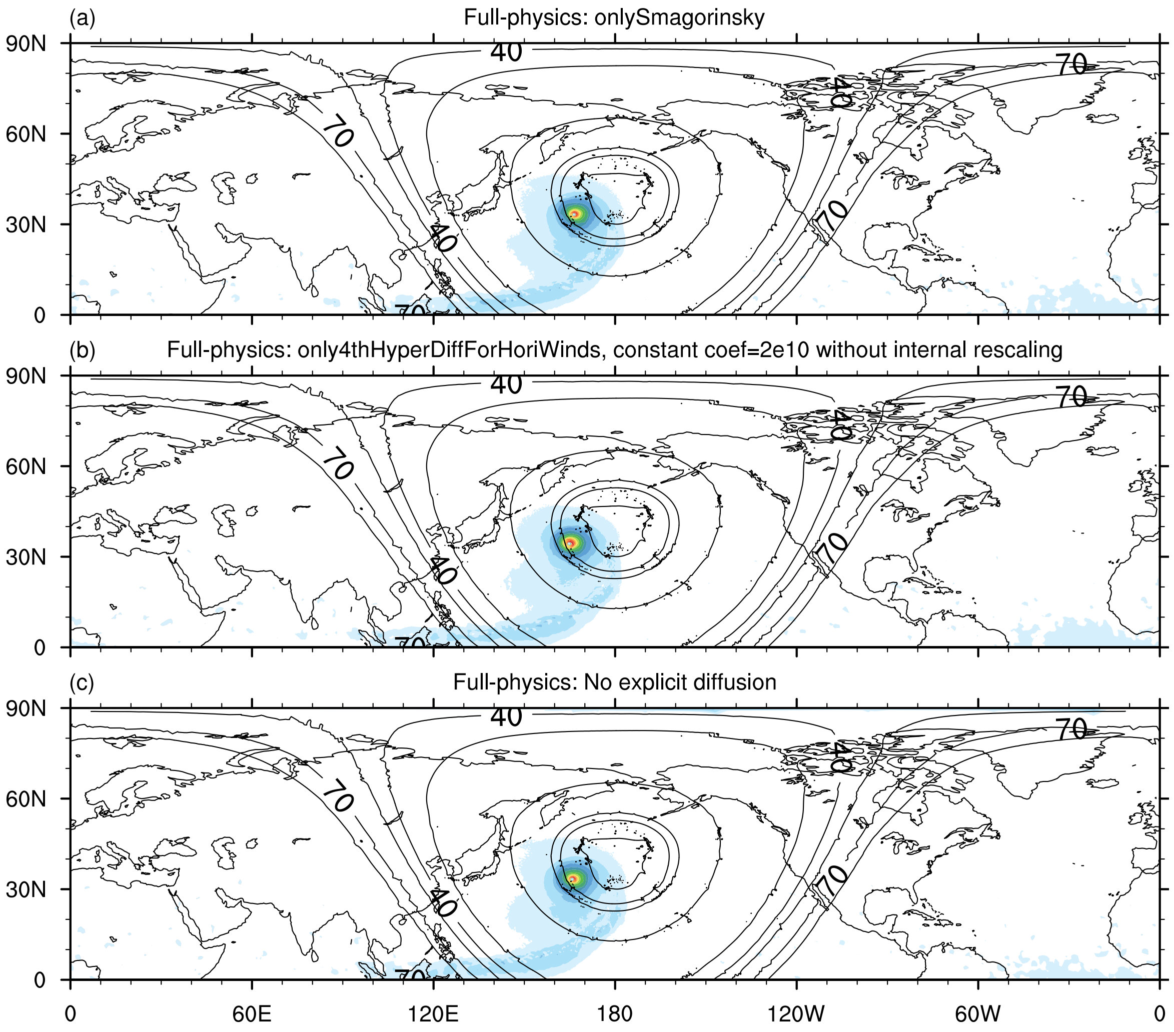

Fig. 1 GRIST-NDC with full physics in the same tropical cyclone test, using a mesh ranges from ~6 km-~30 km-~120 km (approximately estimated); (a) only-Smagorinsky for winds and potential temperature with a variable length scale and a small coefficient $c_s^2 = 0.0025$; (b) only 4th-order hyperdiffusion for the horizontal wind field with a constant coefficient; (c) no explicit diffusion. Day 10 results are shown as in the initial manuscript.

3. **Appealing aspects of V-R modeling are the computational savings when solving a regional problem. Do the authors have scaling numbers that could provide a more objective quantification of this? Should they expect the simulations to scale linearly with the number of degrees of freedom in the mesh? Is there additional overhead associated with refinement that causes this scaling to be sub-linear?**

Reply: We will check this issue. Dr. Z. Liu actually has a separate manuscript specifically focusing on the computational performance, including the VR mesh. So in this work, we will restrict ourselves to the physical performance (but we will also mention this point). For QU and VR grids with the same degree of freedom, their respective parallel efficiency will be similar, as the domain decomposition uses the same philosophy that does not distinguish between VR and QU meshes.

Moreover, we would like to point out that a VR model is definitely more cheaper than its fine-resolution QU counterpart. This advantage has clear implications, and is especially valuable for model development. Via VR, we may economically test and examine full-physics configured GRIST at convection-permitting (CP) resolution in a *global* environment, to check whether the configuration is suitable. A global ~5 km QU icosahedron-based mesh has 23592962 primal cells. It is apparently crazy and inefficient to test and run global CP modeling at such high-resolution in our daily model development and debugging efforts. The computational resource is a key limitation. With the VR approach, one may achieve regional ~5 km with a grid number like 368642. Given the same theoretical time step and vertical levels, this implies a ~64X savings for one model variable. Moreover, the VR approach provides a more challenging environment in terms of scale variation, and the multiscale behavior of model physics can be well examined. A properly formulated VR model thus gives a valuable guidance for the fine-resolution QU model.

In short, the added value of a VR model not only lies in its application end. For model developers, it is an economical tool for developing and evaluating scale-aware physics, and an important intermediate step before establishing global CP modeling.

4. I am not sure what this sentence means in the code and data availability section: 'GRIST is available at https://github.com/grist-dev, in private repositories. A way is provided for the editor and reviewers to access the code, which does not compromise their anonymity (to our best effort).' I would double-check that this all conforms to GMD's policies.

Reply: GRIST is open to the general public, while needs authorization. This is a requirement in the current model development projects. Both the GitHub repo and the Zenodo link currently require authorization for access. In the initial submission, a GitHub account is provided for public access, but this way is not recommended any more. An accessible Zenodo shared link is generated, and I have asked the handling Editor to send it to all the reviewers if possible. The Zenodo link does not compromise the anonymity of access, which is required by GMD's policy. In the revision, the latest version will be uploaded as a reference. Some statements in the code and data section will be modified accordingly.