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A Flexible Atmospheric Modeling Framework for the CESM

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Abstract

Key words: Nonhydrostatic global modeling, unified system, Z-grid, icosahedral grid, super-parameterization

We have created two global dynamical cores based on the unified system of equations and Z-grid staggering on an icosahedral grid, which are collectively called UZIM (Unified Z-grid Icosahedral Model).

The z-coordinate version (UZIM-height) can be run in hydrostatic and nonhydrostatic modes. The sigma-coordinate version (UZIM-sigma) runs in only hydrostatic mode.

The super-parameterization has been included as a physics option in both models. The UZIM versions with the super-parameterization are called SUZI. With SUZI-height, we have completed aquaplanet runs. With SUZI-sigma, we are making aquaplanet runs and realistic climate simulations.

SUZI-sigma includes realistic topography and a SiB3 model to parameterize the land-surface processes.

Intellectual Property

The intellectual property produced by our project includes equation systems, computer software, and model output, as well as publications. There are no patents. Our work has been carried out with the intention of sharing all of our results with the scientific community at large.

Summary of Results

Construction of dynamical cores and tests

In this project, we have completed or made very good progress towards the completion of different versions of icosahedral (global) dynamical cores.

Planar dynamical core development and tests

We completed the construction of a planar dynamical core that can utilize nonhydrostatic unified systems of equations, and performed variety of simulations with it. A paper discussing the development details and presenting results of the unified version was published (Konor, 2014) this year.

Icosahedral dynamical core development

We have developed the height vertical coordinate version of the Unified Z-grid Icosahedral Model, which we call UZIM-height. A paper describing the grid optimization and discussing performance of the finite-difference Laplacian, Jacobian and divergence operators used in UZIM-height has been published (Heikes et al., 2013). This dynamical core has been successfully tested with five of the test cases suggested by the Dynamical Cores Model Intercomparison Project (DCMIP). The results are posted at UZIM page of DCMIP webpage (https://www.earthsystemcog.org/projects/dcmip-2012/uzim). We have continued the tests through the nonhydrostatic gravity wave simulation (test case 3.1). Fig. 1 shows the results in the format required by DCMIP. Our simulation results compare well to those obtained with the ENDGAME model of the UKMO. We are currently preparing a paper describing UZIM-height and presenting results from various test cases. Only remaining challenge in completing the model development and the paper is that the 3D elliptic solver needs to be generalized to the cases, in which the horizontal grid distance is much longer than the vertical grid distance. We have a lead from Dr. Piotr Smolarkiewicz and pursuing his suggestion. We are expecting to finish the 3D elliptic solver, implement it to the model and perform test simulations within two months.

We have made progress in the construction of the sigma coordinate version of the same model (UZIM-sigma). The sigma coordinate version allows surface topography, and it is constructed on a Charney-Phillips vertical grid. The quasi-hydrostatic version of the model has been constructed and successfully tested (see Fig. 2). The vertical coordinate of the model can be traditional sigma or hybrid sigma-pressure. We are working on the construction of the nonhydrostatic version. We have also constructed a hybrid isentropic-sigma version of UZIM, which we call UZIM-isen.

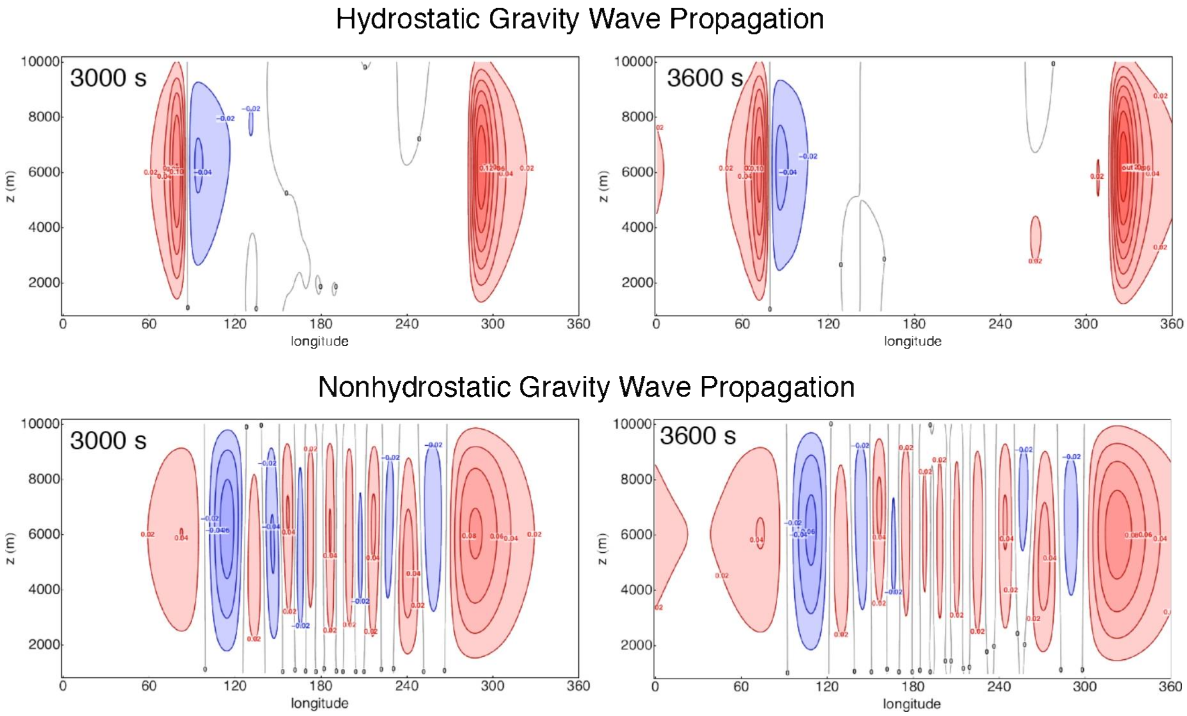

Fig. 1. Simulation of gravity wave propagation with the hydrostatic (upper panel) and the nonhydrostatic (lower panel) versions of UZIM-height. The setup for this simulation (test case 3.1) is described in DCMIP website.

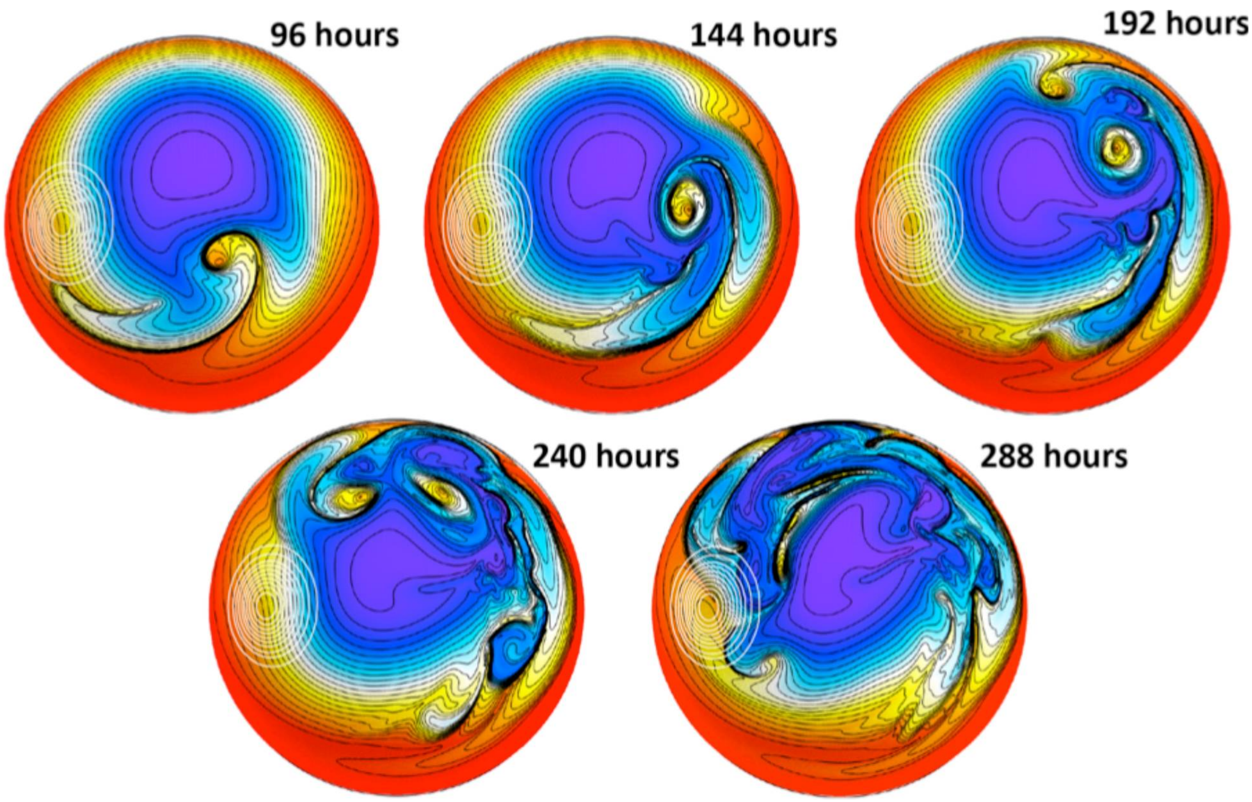

Fig. 2. Simulation of extratropical cyclogenesis modified by a 2-km-high mountain that is roughly modeled after the Rockies with the quasi-hydrostatic version of UZIM-sigma. The colors denote surface potential temperature. The mountain is indicated by the white circular contours on the right side of each panel. Note that UZIM-sigma uses a Charney-Phillips vertical grid.

Aquaplanet simulations with super-parameterized UZIM-height

The UZIM-height dynamical core has been coupled with a super-parameterized physics. We call this model SUZI. The term super-parameterization is used to describe the physics of a climate model, in which the traditional convection parameterization is replaced by 2D cloud resolving models (CRMs) as depicted in Fig. 3. Figure 4 presents a comparison between SUZI and SP-CAM aqua-planet simulations. In the SUZI simulation, there are almost always westerly and easterly at the west and east sides of precipitation maxima, respectively, which is expected, while the convective systems move westward in a reasonable speed. In the SP-CAM simulation, such a correlation is weak and often broken and the convective systems move rather fast.

The sigma coordinate version of SUZI (SUZI-sigma) has also been constructed. Currently, we are in the spin up stage of an aquaplanet simulation with SUZI-sigma. Ultimately, SUZI-sigma and/or SUZI-isen (SUZI based on the hybrid isentropic and sigma coordinate version) will be evolving to GCMs.

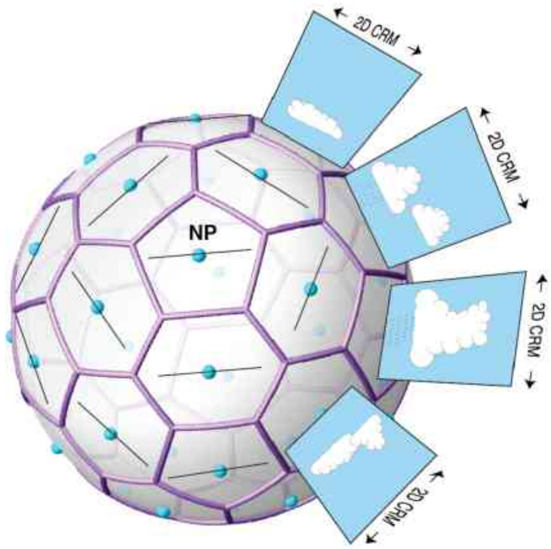

Fig. 3. A schematic depiction of the inclusion of CRMs in SUZI.

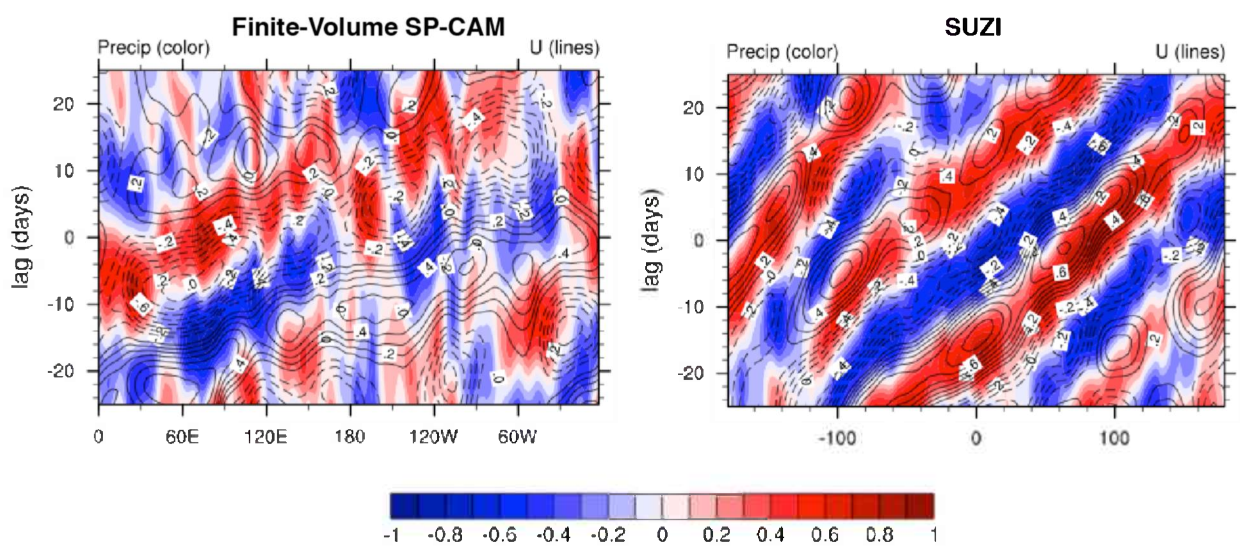

Fig. 4. Lagged correlations of precipitation (color) and zonal wind (contour) along Equator from aqua-planet runs of FV SP-CAM (left panel) and SUZI (right panel).

Publications/Presentations

Journal Papers:

1. Heikes, R. P., D. A. Randall, and C. S. Konor, 2013: Optimized Icosahedral Grids: Performance of Finite-Difference Operators and Multigrid Solver, *Mon. Wea. Rev.*, Vol. **141**, No. 12. 4450-4469.

2. Konor, C.S., 2013:Design of a Dynamical CoreBased on the Nonhydrostatic "UnifiedSystem" of Equations, *Mon.Wea.Rev.*,Vol.**142**, No.1, 364-385.

Presentations:

1-Konor, C. S., 2011: Design of a Dynamical Core Based on the Nonhydrostatic Unified System of Equations. WCRP OSC Climate Research in Service to Society, October 24 – 28, 2011, Denver, Colorado.

2- Konor, C. S., 2012: Design of a Dynamical Core Based on the Nonhydrostatic Unified System of Equations, PDE's on the Sphere, Isaac Newton Institute for Mathematical Sciences, 24-28 September, 2012, Cambridge, UK

3- Konor, C. S., 2012: Modeling Atmospheric Motion with the Nonhydrostatic Unified System of Equations, NOAA's 37th Climate Diagnostics and Prediction Workshop, 22-25 October, 2012, Fort Collins, CO, USA

4- Konor, C. S., 2012: Design of a Dynamical Core Based on the Nonhydrostatic Unified System of Equations, 2012 KIAPS International Symposium on Global NWP System Modeling, 12–14 November 2012, Seoul, Korea

5- Konor, C. S., 2012: Design of a Dynamical Core Based on the Nonhydrostatic Unified System of Equations, Second International Workshop on Nonhydrostatic Numerical Models, 28–30 November 2012, Sendai, Japan

6- Konor, C. S., 2012: Modeling Atmospheric Motion with the Nonhydrostatic Unified System of Equations, Frontiers in Computational Physics, Modeling the Earth System, 16-20 December 2012, Boulder, Colorado, US