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Impact of Local Grid Refinements of Spherical Centroidal Voronoi Tessellations for Global Atmospheric Models

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Abstract. In order to study the local refinement issue of the horizontal resolution for a global model with Spherical Centroidal Voronoi Tessellations (SCVTs), the SCVTs are set to 10242 cells and 40962 cells respectively using the density function. The ratio between the grid resolutions in the high and low resolution regions (hereafter RHL) is set to 1:2, 1:3 and 1:4 for 10242 cells and 40962 cells, and the width of the grid transition zone (for simplicity, WTZ) is set to 18° and 9° to investigate their impacts on the model simulation. The ideal test cases, i.e. the cosine bell and global steady-state nonlinear zonal geostrophic flow, are carried out with the above settings. Simulation results show that the larger the RHL is, the larger the resulting error is. It is obvious that the 1:4 ratio gives rise to much larger errors than the 1:2 or 1:3 ratio; the errors resulting from the WTZ is much smaller than that from the RHL. No significant wave distortion or reflected waves are found when the fluctuation passes through the refinement region, and the error is significantly small in the refinement region. Therefore, when designing a local refinement scheme in the global model with SCVT, the RHL should be less than 1:4, i.e., the error is acceptable when the RHL is 1:2 or 1:3.

AMS subject classifications: 86-08, 65C20

Key words: Spherical Centroidal Voronoi Tessellation, local refinement, numerical experiments, width of the transition zone, ratio between high resolution and low resolution.

1 Introduction

Accurate simulations of global weather and climate require much finer model resolutions. In order to improve the performance of global atmospheric numerical models,

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many model developers attempt to refine the model resolution to the greatest extent. However, a finer resolution implies a substantial increase in computational costs. A halving of the horizontal mesh spacing implies an increase in computational cost of about a factor of eight: a factor of four is due to doubling the degrees of freedom in both horizontal directions, and a factor of two is attributed to halving the time step. The computational load associated with increases in global horizontal resolution everywhere quickly exhausts available computational resources. For instance, conducting a global atmospheric simulation with a horizontal resolution of several kilometers is impracticable at present and a daunting computational burden for many institutes. However, if the resolution is only locally refined, obviously the computational resources can be saved. To achieve this goal, multi-resolution (local refinement) schemes will be required [1, 2].

The hierarchical nesting scheme is widely used in limited area structured grid numerical atmospheric models, such as the well-known Weather Research Forecast (WRF) model [3]. WRF supports horizontal nesting that allows the resolution to be fined over a region of interest by introducing an additional grid (or grids) into the simulation. Nested grid simulations can be realized using either 1-way nesting or 2-way nesting. The ratio between the grid resolutions in the low- and high-resolution regions (for clarity, RHL) is generally set to 1:3. However, the local refinement scheme generates reflective waves inside the finer grid boundary, which are not inherent waves of the atmosphere and thus influence the forecast results. At present, many model developers are beginning to pay close attention to local refinement scheme of the global icosahedral mesh model [4, 5]. However, questions remain unanswered how to design the local refinement scheme and what is the appropriate value for the RHL and how wide the transition region between the coarse grid and the fine one should be for the purpose to reduce the simulation errors to minimum.

In this study, we aim to address the above questions. The paper is organized as follows. Section 2 describes the local refinement scheme of the global SCVT model. The ideal numerical experiments and results are presented in Section 3. RHL and the width of the grid transition zone (hereafter WTZ), and shape-preserving issues are discussed in Section 4. Conclusions are summarized in Section 5.

2 Local refinement scheme of the global SCVT model

The local refinement scheme should be designed according to the weather process considered, for instance, the larger the surface wind speed of typhoon is, the finer the resolution should be, and vice versa. When a frontal system is simulated, the resolution over the region of large temperature gradient should be refined. In the present study, two ideal test cases, i.e. Cosine bell and global stable state nonlinear zonal geostrophic flow [9] are chosen because they have analytical solutions. Thus the grid density function corresponding