A Comparison Study of Computational Performance between a Spectral Transform Model and a Gridpoint Model

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1. Introduction

For more precise weather predictions and climate understandings using atmospheric general circulation models(AGCMs), higher resolution has been required continuously. Because the spectral transform method based on spherical harmonics provides high accuracy to represent the spherical field, it is employed in many of the existing AGCMs. It is pointed out by many literatures, however, that the spectral transform method becomes less efficient computationally than the gridpoint method in high resolution simulations. This is theoretically because the amount of calculation associated with the Legendre transformation increases in the sense of $O(N^3)$, where N stands for the truncation wavenumber.

Recently, quasi-uniform grid systems for global gridpoint models has been used to overcome the pole problem, which occurs in the latitude-longitude gridpoint method. For example, the model using the conformal cubic grid system, CCAM (Conformal Cubic Atmospheric Model) in CSIRO (Commonwealth Scientific & Industrial Research Organization), was established [1,2]. There are several models using the icosahedral grid system; CSU AGCM in Colorado State University for the climate model [3] and GME in Deutscher Wetterdienst for the numerical prediction model [4].

Our research group (the Next Generation Climate Model Research Group in Frontier Research System for Global Change) also has been developing a new global model using the icosahedral grid system [5,6]. In order to resolve the cumulus convection explicitly, our target resolutions are 5 km or less in the horizontal directions and 100 m in the vertical direction. For such a high horizontal resolution, we should reconsider the dynamical framework from the usually used hydrostatic equation to the nonhydrostatic one. Our research group has been developing a new nonhydrostatic scheme, in which the conservations of mass and total energy are completely satisfied [7,8]. We have completed to apply this nonhydrostatic scheme to the icosahedral grid system [9]. This model is called NICAM (Nonhydrostatic ICosahedral Atmospheric Model).

Continuous effort for fast calculation by the spectral transform method has been made from the viewpoints of computational algorithm and tuning. For example, AFES (AGCMs For Earth Simulator) successfully performed a very high-resolution simulation (T1279L96) on the Earth Simulator (ES) [10]. This model is a hydrostatic spectral transform model with full physical processes developed by Earth Simulator Center (ESC). Its code is highly optimized on the ES for high-resolution simulations. Especially, the Legendre transformation that is a bottleneck for speedup is much improved for a vector supercomputer.

Although we may say that the gridpoint method is theoretically advantageous over the spectral transform method in terms of computational efficiency, it is not clear from which resolution it is true. We carried out a performance study for dynamical core of NICAM and AFES in high resolutions. In this paper, comparing the performance of NICAM as a gridpoint model with

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that of AFES as a spectral model, we actually demonstrate that the gridpoint method using a quasi-uniform grid system has computational advantage over the spectral transform method in our target resolutions.

2. Comparison of computational performance

The conditions of measurement are as follows. The number of vertical levels is 32 in both of models. The horizontal resolution increases from T159 to T2559 for AFES and from glevel-7 to glevel-10 for NICAM*, respectively. All of measurements were performed by using 80 nodes of the ES. It should be noted that we extract only the dynamical part from the original AFES for valid comparison between two models.

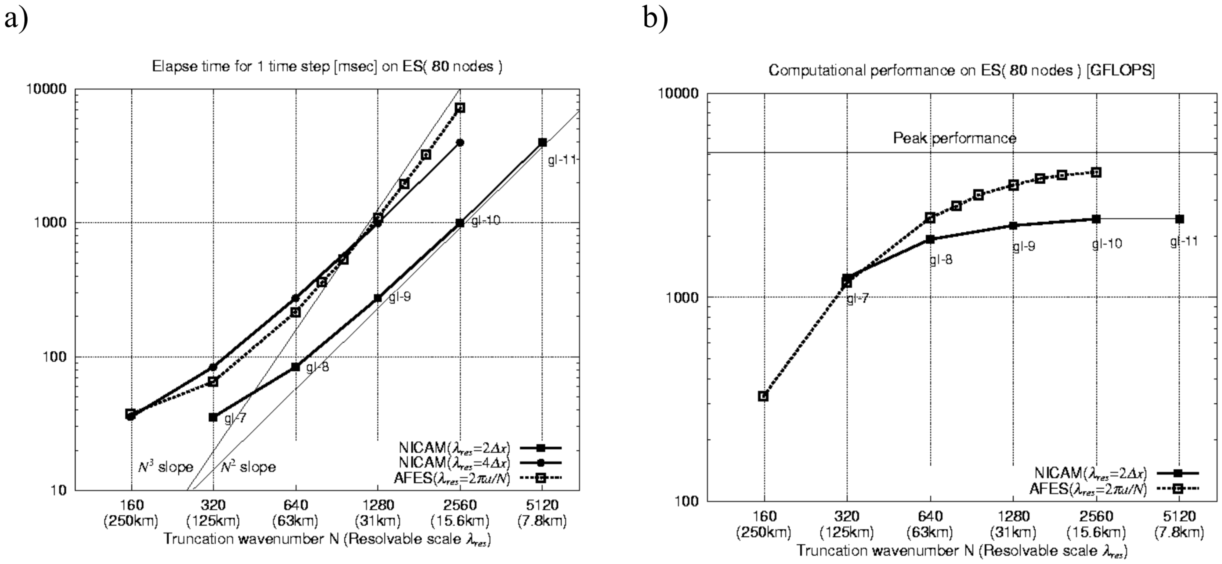

Figure 1. Comparison of computational performance between NICAM and AFES. λ_{res} stands for the resolvable scale on the equator.

The line with black rectangles in Fig.1(a) indicates the elapse times of one time step of NICAM. If we consider that two-grid scale structures are resolvable in NICAM, the resolution of glevel-7 roughly corresponds to that of T320 in the spectral transform model because the mean grid interval for glevel-7 grid system is about 60 km and the truncation wavelength for T320 is about 120 km. The line for NICAM in Fig.1(a) is close to N^2 slope in higher resolutions. The reason of this tendency is that the flops value is almost saturated at glevel-10 as shown in Fig.1(b). The performance at glevel-11 is easily presumed from the tendency from glevel-9 and 10. Assuming that the flops value of glevel-11 is the same as glevel-10, the slope of the elapse time of one time step from glevel-10 to 11 should be on the N^2 line. On the other hand, the line of AFES in Fig.1(a) (the line with white rectangles) is close to N^3 slope in higher resolutions than T1279. This would be partly because the calculation amount of Legendre transformation becomes dominant over the other processes and partly because the flops value becomes saturated as shown in Fig.1(b).

The available time interval without numerical instabilities is also an important factor. By performing 1000 days integration on the condition of Held & Suarez dynamical core experiment[11], we investigated the maximum time intervals Δt_{max} as 50 [s] increment for Δt for T159 (AFES) and for glevel-7 (NICAM), respectively. Table 1(a) and (b) show the results of Δt_{max} at these resolutions (bold letters). We can presume the maximum time intervals in higher resolutions for NICAM, because this model employ a quasi-uniform grid; if the resolution becomes

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* The "glevel" means the grid division level and the subsequent number is the division number from the original icosahedron. The grid interval for glevel-7, 8, 9, and 10 is about 60 km, 30 km, 15km, and 7.5 km, respectively. The detail description is referred to [5].

double, the maximum interval becomes half. For AFES, the criterion for the maximum time interval is not clear but it is empirically known that the maximum time interval is in inverse proportion to the truncation wavenumber. Those guessed values are shown in Table 1. From the maximum time interval and the elapse time of one time step, the elapse times that are consumed for 1-day simulation can be estimated for each of models (the third line of each table).

Table1. The available time intervals and elapse times for 1-day simulation.

(a) AFES					
Resolution	T159	T319	T639	T1279	T2559
Δt_{max} [s]	**400**	200	100	50	25
1 day simulation time[s]	8.02	27.9	184	1880	24900

(b) NICAM					
Resolution	glevel-7	glevel-8	glevel-9	glevel-10	glevel-11
Δt_{max} [s]	**450**	225	113	57	29
1 day simulation time[s]	6.70	32.1	210	1520	12200

3. Discussion

In general, the computational performance depends on the computer architecture, the degree of code optimization, and so on. However, since both AFES and NICAM are aimed to be performed on the Earth Simulator and are well tuned for vectorization and parallelization, it is proper to compare those computational performances on the ES.

One point at issue is the physical validity of short wave in the gridpoint model. Straightforwardly, two-grid scale structures are considered to be resolvable in the gridpoint model. In this sense, it is proper to compare the results of glevel-7 and T319, or glevel-8 and T639, and so on. Actually, we confirmed that there is only a little difference of physical results between glevel-7 and T319 in Held & Suarez dynamical core experiment. On the other hand, one regards a two-grid scale wave as a computational noise in the gridpoint model and argues that scales that have physical meanings are limited to four-grid scales in the gridpoint model. In this case, the line with black rectangles in Fig.1(a) is shifted to the left line with black circles. Based on this consideration, it is proper to compare the glevel-7 and T159, or glevel-8 and T319, and so on.

Even if we employ the latter opinion, Table 1 shows a fact that the gridpoint method using a quasi-uniform grid system has computational advantage over the spectral transform method in the higher resolution than about T1000.

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