# Development of Super High-Resolution Atmospheric and Oceanic General Circulation Models on Quasi-Uniform Grids

Group Representative

Yukio Tanaka Frontier Research System for Global Change

Authors

Masaki Satoh [*1, 2] ・ Hirofumi Tomita [*1] ・ Tomoe Nasuno [*1] ・ Shin-Ichi Iga [*1]
Koji Goto [*3] ・ Yukio Tanaka [*1] ・ Motohiko Tsugawa [*1]
Masahide Sakasita [*1] ・ Masaru Kogi [*1]

*1 Frontier Research System for Global Change

*2 Saitama Institute of Technology

*3 NEC Corporation

New atmospheric and oceanic general circulation models are being developed at Frontier Research System for Global Change. These models are based on quasi-uniform grid, i.e., icosahedral or cubic grids, and are aimed to be run with super-high resolution with a few kilometers on the globe. The atmospheric part of the model is based on the nonhydrostatic equations and is called NICAM (Nonhydrostatic ICosahedral Atmospheric Model). It is aimed to be used as a global cloud resolving model using the Earth Simulator. We have run the dynamical core of NICAM with 3.5 km-horizontal grid interval using half of the ES. Physical processes are also being implemented and some preliminary tests including moist processes have been conducted. Thanks to improvement of computer performance, we are now at a position to run a global cloud resolving calculation. The oceanic part of the model is developed using a quasi-uniform cubic grid. It is aimed to be used as global eddy resolving ocean model on the ES. This year we have completed to develop a three dimensional dynamical core, which is based on the shallow water model developed last year. Eddy resolving simulations in the Southern Ocean are also carried out to study the physics of mesoscale eddies.

**Keywords**: Icosahedral grid, nonhydrostatic model, global cloud resolving model, cubic grid, global eddy resolving model

## 1. Overview

The aim of this project is to develop super-high resolution atmospheric and oceanic generation circulation models. We intend to run these models with a few-kilometer grid interval in the horizontal directions using the Earth Simulator. With such a high-resolution simulation, we aim to explicitly calculate cloud motions for the atmospheric part, and to resolve mesoscale eddies for the oceanic part. To achieve this goal, we are developing new models based on quasi-uniform grids, which are suitable for the Earth Simulator.

## 2. Atmospheric model: Nonhydrostatic ICosahedral Atmospheric Model (NICAM)

Up to the last year, we have developed the dynamical core of the new atmospheric model. This model is based on nonhydrostatic equations and the icosahedral grid (Fig. 1) [1, 2]. We call it Nonhydrostatic ICosahedral Atmospheric Model (NICAM). The main objectives of FY2003 are to run a

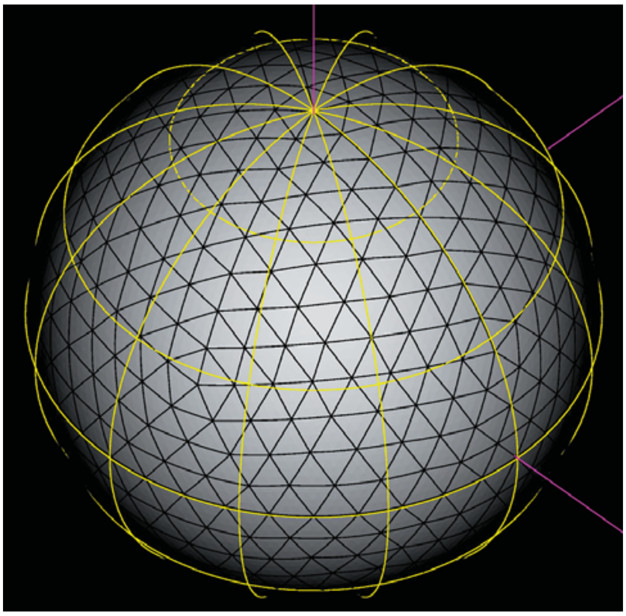

Fig. 1 Icosahedral grid

3.5 km-grid global simulation using the dynamical core of NICAM on the Earth Simulator and tune up the computational performance of NICAM, and to implement various physical processes and make preparation for global cloud resolving calculations.

We have done a dynamical core experiment of life cycle of extratropical cyclones proposed by Polvani et al. [3]. This is a deterministic experiment for about 10-days integration and is suitable for a high resolution simulation. We performed this experiment using different grid intervals: 120, 60, 30, 14, 7, and 3.5 km. Figure 2 shows the results from the 3.5 km-grid simulation: the global distribution of temperature near the surface at day 10. The surface temperature distribution shows very sharp fronts associated with cyclones. Fine structure of the cyclones is more evident as the grid interval becomes smaller. We also found that the maximum speed of vertical velocity becomes stronger as the resolution becomes finer, though the nonhydorstatic effect is not appreciable (not shown here).

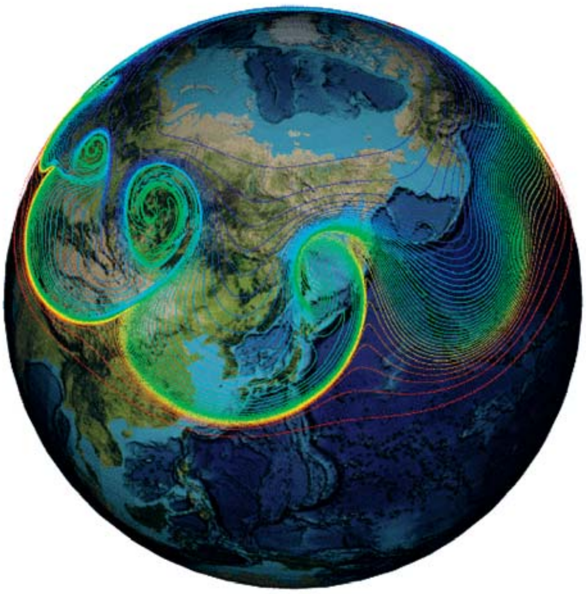

Fig. 2 Global distribution of temperature near the surface obtained from 3.5 km-mesh model for the life cycle experiment of extratropical cyclones at day 10.

The computational performance on the Earth Simulator for the different resolution runs of the life cycle experiments is displayed in Table 1. The scalability is very good and the sustained performance is about half of the peak. The poorer performance of the low-resolution run (120 km) is misleading since the file Input/Output-time becomes more dominant in this resolution. At the finest resolution, 3.5 km-grid interval, it takes about 1.5 hours for one-day simulation. This value is further reduced to 1.1 hours by elaborate tuning of the codes. From this, it is expected that globally cloud resolving calculation with 3.5 km grid interval and full physical processes will take about 2 or 3 hours for one-day.

The second objective of the atmospheric modeling is implementation of physical processes: cloud physics, radiation, and boundary layer turbulence schemes are investigated. To evaluate properties of various physical processes, we need to test them using a cloud-resolving simulation, i.e., a few kilometers resolution. Since NICAM is a global model, we devised the following two methods: a stretched grid model and a small planet model. We also use a Cartesian coordinate model which has the same numerical scheme as NICAM and is separately developed. By concentrating grid mesh in a particular region, we run a squall line experiment, which is proposed as an intercomparison experiment [4] and has been further investigated in terms of resolution [5]. We investigate dependency on physical schemes, particularly on cloud microphysics, and also study cloud-radiation interaction. We tested cloud microphysical schemes from the Kessler-type simple warm rain bulk scheme to 5 categories cold rain scheme including cloud water, cloud ice, rain, snow, and graupel [6]. The results are almost comparable to the previous studies.

Another experiment is a statistical run including moist processes: direct calculations of radiative-convective equilibrium on a uniform sea surface temperature. This experiment is a first step to evaluate climate sensitivity of the global model. Traditionally, this kind of experiment is performed by using a Cartesian coordinate regional cloud resolving model with periodic domain. We set the boundary condition of

Table 1

| Grid level (interval) | Δt[s] | Number of nodes (CPU) | Elapse time [h:m:s] | FLOPS | Sustained performance |
|---|---|---|---|---|---|
| Gl-6 (120km) | 900 | 5 (40CPU) | 00:00:19 | 90G | 28% |
| Gl-7 (60km) | 450 | 20 (160CPU) | 00:00:32 | 410G | 32% |
| Gl-8 (30km) | 200 | 80 (640CPU) | 00:00:68 | 1720G | 33% |
| Gl-9 (14km) | 100 | 80 (640CPU) | 00:06:30 | 2260G | 44% |
| Gl-10 (7km) | 50 | 80 (640CPU) | 00:46:50 | 2450G | 48% |
| Gl-11 (3.5km) | 25 | 320 (2560CPU) | 01:34:10 | 9750G | 48% |

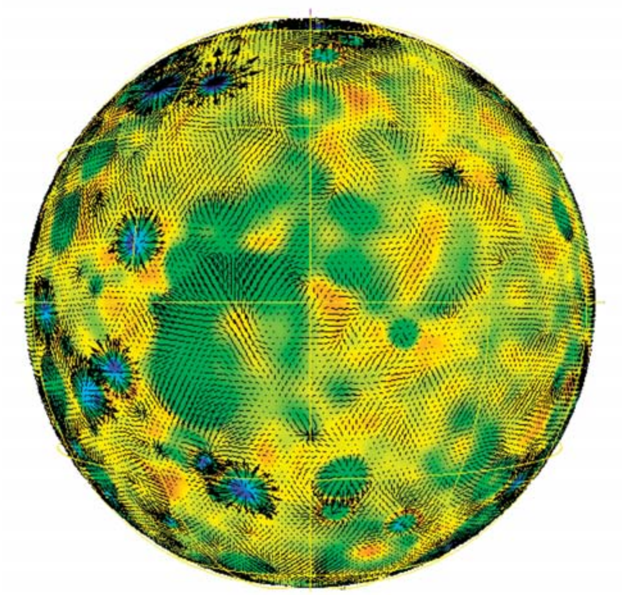

Fig. 3 Snapshot of the distribution of temperature near the surface and horizontal velocities for the radiative-convective equilibrium experiment on the small planet R=400 km.

Fig. 4 quasi-uniform cubic grid.

NICAM to be uniform and reduce its radius to 400 km: that is, a small planet and everywhere tropics [7]. The grid interval is 3.5 km. Figure 3 shows a snapshot of the temperature at the lowest level, which indicates positions of cold pools. The surface area of the planet is $4\pi R^2 = (1168\ km)^2$, which is sufficiently large to discuss statistical properties of clouds in tropics. Although integration time is as long as 5 days, mean temperature is about 265 K, and precipitable water is about 40 $kg/m^2$, which are relatively smaller than those of typical values in the tropics. This difference might come from the fact that the configuration of the everywhere-tropics planet does not take account of the mean large-scale ascent associated with the Hadley and Walker circulations. We are now in a position to run a global cloud resolving experiment on the real size of the Earth, in which cloud-scale motions and large-scale circulations co-exits.

## 3. Ocean model

Last year, we have developed the shallow water model using a quasi-uniform cubic grid (Fig. 4) [8]. This year we have extended it to a three dimensional dynamical core. A split-explicit method is used for the time integration scheme. The barotropic equations are solved using the forward-backward time integration scheme and the baroclinic ones are solved using Leapfrog scheme. Arakawa-B gird method is employed for horizontal spatial descritization to represent the geostrophic adjustment process precisely. For the vertical coordinate, $\sigma$-z hybrid coordinate is used. Figure 5 shows the surface velocity at the Drake Passage calculated using the developed three dimensional dynamical core. The grid size used in this calculation is about 50 km.

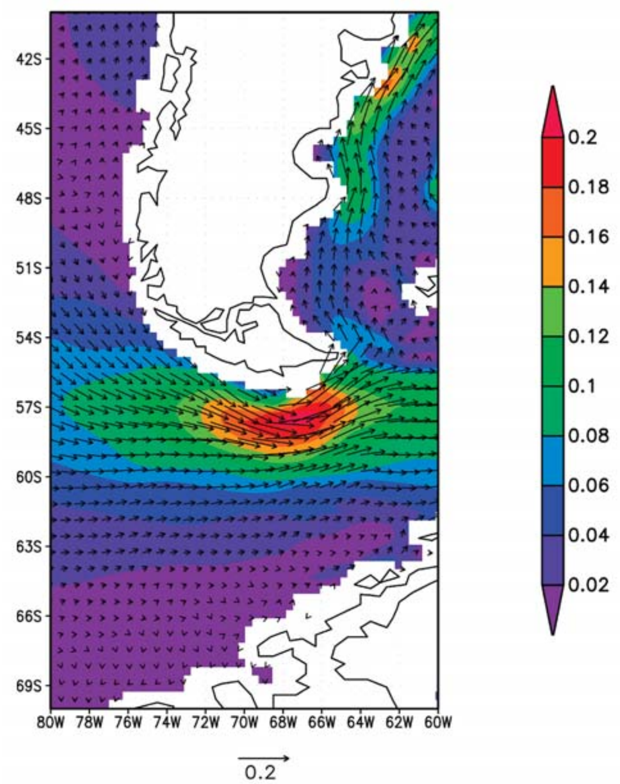


Fig. 5 The calculated velocity field (m/sec) at the Drake Passage.

The eddy resolving simulations in the Southern Ocean is carried out. The model used for this study is the Center for Climate System Research (CCSR) Ocean Component model (COCO) [9]. The purpose of this study is to investigate horizontal grid size sensitivity to the dynamics of mesoscale eddies. The grid size, which is defined at latitude 54 south, is changed from 37 to 9.3 km. Figure 6 shows the root mean square of the sea surface height variations for different grid sizes. This result shows that the less than 19 km grid size is required to resolve mesoscale eddies explicitly.

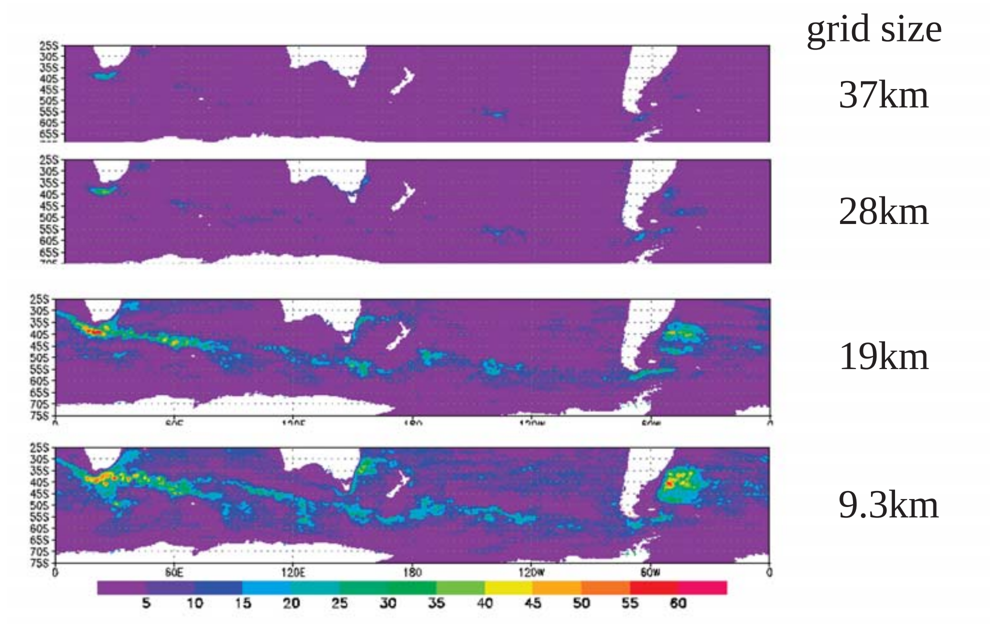


Fig. 6 Sea surface height anomary variability (cm) calculated using from 9.3 to 37 km grid size. The time integration is carried out for 12 years and the last one year variability is shown.

### 4. Summary and the future plan

For the atomospheric model, we have developed the dynamical core of the nonhydrostatic icosahedral atmospheric model, and implemented various physical schemes. Definitely, the plan of the next year is to run a global cloud resolving experiment. First, we need to perform an aqua planet experiment, which is a suitable set to study statistical properties of cloud motions. Then, we will run more realistic case with land-sea distribution (e.g., AMIP experiments). We will further study impact of doubling $CO_2$ and effects of aerosols using a global cloud resolving model. For the ocean model, the dynamical core has been developed. The plan of the next year is to evalutate the physical and computational performance of the developed dynamical core. We also continue to carry out the study of the dynamics of the mesoscale eddies.

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