Development of Super High Resolution Global and Regional Climate Models

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The purpose of this five-year project is to develop a global climate model with a horizontal resolution of 20 km realistically simulating typhoons (tropical cyclones) and the Baiu front, and cloud resolving regional models with a horizontal resolution of a few km simulating heavy rainfalls and heavy snowfalls. These models are utilized to investigate the effects of global warming on these phenomena through time-slice numerical experiments. The project consists of two subprojects: "Development of a global climate model with a horizontal resolution of 20 km" and "Development of non hydrostatic models (NHMs) with horizontal resolutions of several km" (hereafter referred to as subproject 1 and subproject 2, respectively).

As for the subproject 1, the computational efficiency was further enhanced by about ten times than that attained last year by optimizing the model to the Earth Simulator, improving the quasi-conservative semi-Lagrangian scheme and introducing a two-time level integration to the semi-Lagrangian scheme. Improvements of physical processes and adjustments of parameters in the parameterizations led to a better performance in simulating the Baiu front and tropical cyclones. Multi-year time integrations at TL959L60 (horizontal grid sizes of about 20 km with 60 layers) and 20 years integrations at T213L40 (horizontal grid sizes of about 60 km with 40 levels) were performed successfully, which demonstrated that stable long-term integrations are possible by the global model on the Earth Simulator.

As for the subproject 2, the cloud-resolving NHMs for the Earth Simulator were further optimized. To make long-term simulations of the NHMs, the spectral boundary coupling method was included and the physical processes were also improved. The 70-day simulations were performed in the East Asia areas (horizontal resolution 5 km, grid number 800*600*48) in June and July of 2003. The simulated precipitation closely agreed with the observed one in June. However, it decreased by two thirds at the end of July. In order to solve such problems, surface flux and boundary layer schemes were improved, and reasonable results were obtained.

Thus, both subprojects have proceeded on schedule in FY2003 and we are ready for the time-slice global warming experiments for the Fourth Assessment Report of the IPCC.

Keywords: global warming, climate model, high resolution, tropical cyclones, Baiu front, cloud-resolving non-hydrostatic models (NHMs), heavy rainfall, heavy snowfall, 70-day simulation, spectral boundary coupling method

1. Subproject 1: Development of a global climate model with a horizontal resolution of 20 km

1.1. Improvements of computational efficiency

We use automatic parallelization by the compiler in each node (8 CPUs per node), and MPI parallelization between the nodes on the Earth Simulator. In the dynamical processes, we use a quasi-conservative semi-Lagrangian scheme for time integration to reduce the total number of time steps. This year we further enhanced the computational efficiency by about 4.5 times than that attained last year by stabilizing the semi-Lagrangian scheme to allow a longer time step, and by optimizing the MPI communication and the Legendre transformation. An introduction of the two-time level integration to the semi-Lagrangian scheme increased the efficiency by two times. Table 1 shows the efficiency of the present global model on the Earth Simulator. The TL959 version attained 35% of the peak performance of the Earth Simulator.

1.2. Improvements of physical parameterization

We improved physical processes and adjusted parameters in the parameterizations to improve the performance in simulating the Baiu front and tropical cyclones as well as large scale fields. We modified the convection scheme to

Table 1 Efficiency of the global model on the Earth Simulator

Horizontal resolution	TL959 (~20 km)	TL959 (~20 km)	T213 (~60 km)
Grid points	1920 × 960 × 60	1920 × 960 × 60	640 × 320 × 40
Time step	6 min.	3 min.	15 min.
Time integration	2-time level	3-time level	3-time level
Number of nodes	30	60	8
Execution time for one-month integration	240 min.	230 min.	20 min.

reduce the cold bias in the lower tropical troposphere, cloud ice falling scheme and the cloud water and large scale condensation scheme to reduce the time step dependency of precipitation. We introduced the prognostic cloud water content scheme and the stratocumulus scheme to improve the moisture process in the atmosphere. We tuned several parameters to reduce the positive bias in global mean precipitation with increasing resolutions, and to realistically simulate the frequency and intensity of tropical cyclones.

1.3. Multi-year integration

Time integrations of several years at TL959L60 (20 km-mesh) and 20 years at T213L40 (270 km-mesh) have been performed successfully, which demonstrates that stable long-term integrations are possible. Figure 1 shows the horizontal distribution of monthly-mean precipitation simulated by the model at TL959L60 using climatological SST data as the boundary condition. The results agree well with the observations in terms of spatial patterns. Yet, compared with the results of T42L40 (270 km-mesh) and T213L40, a systematic tendency is still found that the global average of precipitation increases with finer resolution. A similar tendency is reported for the NCAR CCM3 atmospheric model (Duffy et al., 2003).

Many efforts are underway to more realistically simulate the tropical cyclones by tuning/improving the convection schemes. The simulated tropical cyclones have many features of those observed: a large-scale organization of cumulus convections at the development stage, an eye wall structure and the spiral bands at the mature stage and so on. Figure 2 shows that the number of the generated tropical cyclones is about 80 per year, almost comparable to the observed one, and that the locations of the developed tropical cyclones are generally consistent with the observation.

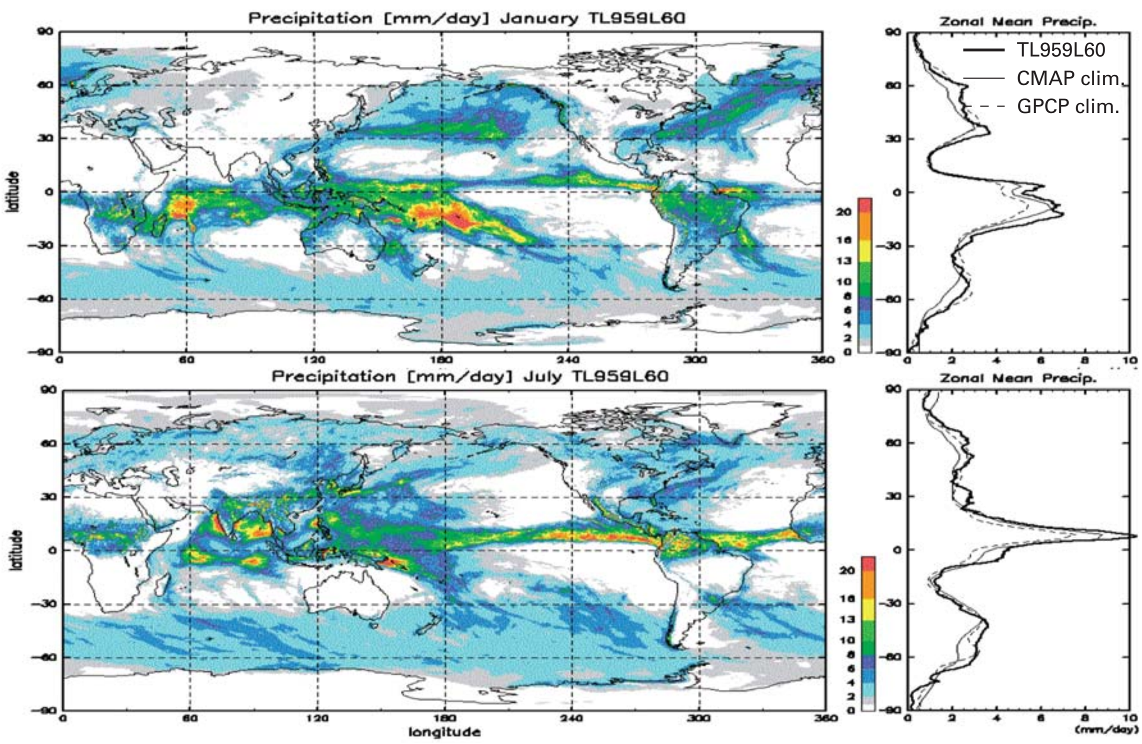

Fig. 1 The horizontal distribution of monthly-mean precipitation of January (top) and July (bottom) obtained from an integration at TL959L60 using climatological SST data as the boundary condition. The zonal mean precipitation of the model (thick solid line) and the climatological estimates of CMAP (thin solid line) / GPCP (thin dashed line) are plotted on the right panels. Units are mm/day.

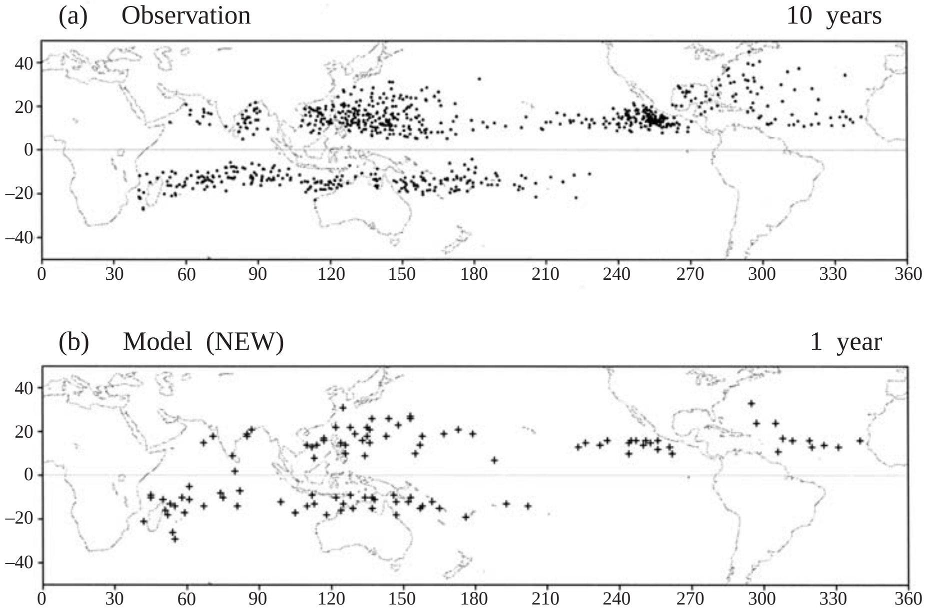

Fig. 2 (a) The location of origins of tropical cyclones by the observational data for 10 years (1979–1988). The points where cyclones grow up to have their wind speeds (sea surface) more than 17 m/s (34 kt) are plotted. (b) Those obtained from the simulation at TL959L60 using climatological SST data. The points where cyclones satisfy the criteria used by Sugi et al. (2002) are plotted.

2. Subproject 2: Development of non hydrostatic models (NHMs) with horizontal resolutions of several km

2.1. Optimization of the NHMs for the Earth Simulator, and improvements of physical processes

2.1.1. Optimization of the NHMs

We optimized the source codes for auto-parallelization and improved to get the high efficiency of the NHMs, similarly to the FY2002. By these efforts, the present NHMs were faster by three times than the old NHMs. The NHMs were improved to predict the correct area-averaged pressures by using the density perturbations instead of the potential temperature perturbations for the buoyancy calculation. The vertical resolutions were also changed from 38 to 48 to get fine structures in the lower layer.

2.1.2. Improvements of dynamical and physical processes of the NHMs

In order to couple the regional NHM with the global model, it is needed to reduce the horizontal phase differences between both models. We adopted the spectral boundary coupling method (SBC), which combines the large-scale modes from the global model and the small-scale modes from the regional model using the wave number decomposition (separation wave number; Kb). This method was applied to horizontal wind and temperature fields above the 5km and the inverse Kb was selected to be about 1000km. Figure 3 shows the precipitation patterns of (left) SBC case, (center) no SBC case, and (right) observation at 09 JST on 31 May 2003. A good agreement between observation and SBC case was seen, while not in no SBC case.

2.2. 70-day long-term simulations using the NHMs

The 70-day simulations were made using the improved NHMs. The region is 4000 km × 3000 km in the horizontal directions (horizontal resolution 5 km) and 48 layer in a vertical direction. The initial and lateral boundary data were supplied from the regional data assimilation cycle in Japan Meteorological Agency. The initial time was 09 JST on 21

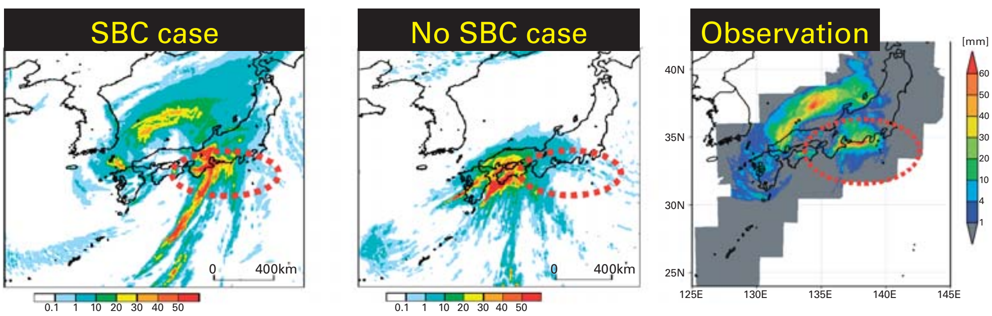

Fig. 3 Distributions of 1-hourly precipitation of (left) SBC case, (center) no SBC case and (right) observation at 09 JST on 31 May 2003.

May 2003. Figure 4 shows the distributions of (left) observed precipitation and (right) simulated precipitation (cone shapes) and surface pressures (solid lines) at 09 JST on 18 June 2003. The simulated typhoon is located on the western side of Okinawa Islands and the simulated Baiu frontal zone is found in an east-west direction from the southern China, East China Sea to Tokai areas. Compared with the observation, a good agreement was obtained for the precipitation pattern.

When the temporal variations of observed and simulated precipitation were examined over the Japan Islands (Fig. 5), good agreements were obtained in the early stage. However, the simulated precipitation decreased with time, getting 2/3 of observed one at the end of July. By examining the decreases of precipitation in detail, an excess moisture was found in the lower layer over the continent, while a lower potential temperature and a lower moisture were seen over the Pacific Ocean and East China Sea, resulting in the decrease of total precipitation.

There had been problems in the surface flux and boundary layer schemes of the NHMs such as insufficient temperature rise in the daytime, a moister air near the surface compared with the observations, and an insufficient turbulent mixing in the lower layer. Therefore, we improved the surface flux and boundary layer schemes so that we got reasonable results such as a sufficient temperature rise in the daytime and a less moist air near the surface.

References

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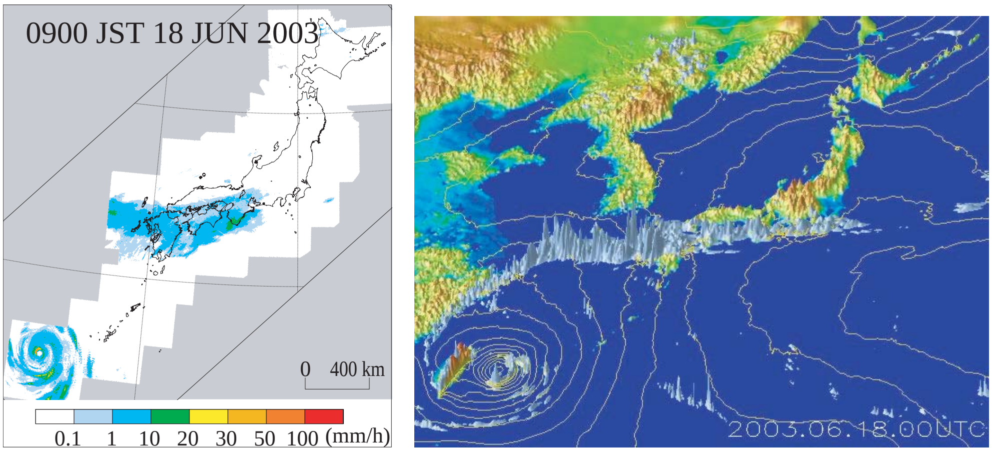

Fig. 4 Distributions of (left) observed precipitation and (right) simulated precipitation (cone shapes) and surface pressures (solid lines) at 09 JST on 18 June 2003.

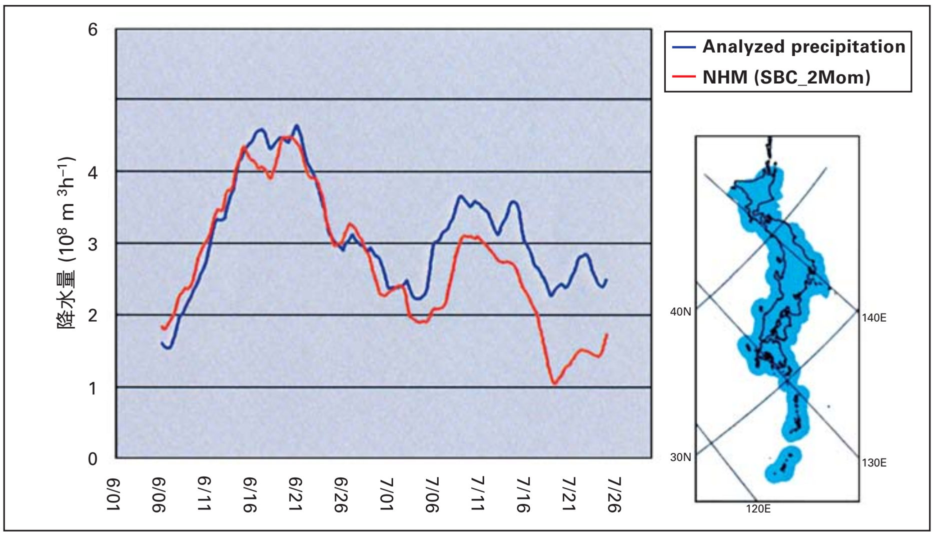

Fig. 5 (Left) temporal variations of observed (blue) and simulated (red) precipitation during June and July 2003 over the Japan Islands. (Right) regions where the comparison was applied.