RF-061 Development of the flexible nesting (FlexNest) system for climate studies and its application to the regional-scale climate change projection under the global warming（Abstract of the Final Report）

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1. Introduction

In the forthcoming IPCC fourth assessment report (AR4), advanced scientific outcomes have been obtained for regional climate change due to global warming, including changes in mesoscale weather events such as tropical cyclones and extreme precipitation. It is noted that Japanese research community that intensively run the high-resolution global climate model (GCM) using the Earth Simulator has significantly contributed to them. Nevertheless, fundamental questions regarding uncertainty in climate projection are not solved yet since the ‘high resolution’ GCM resolves meteorological phenomena on the order of hundred kilometers at most, which still requires parameterization to unresolved, sub-grid scale motions including individual clouds.

A possible approach to downscale the projected future climate change is to nest fin-meshed regional atmospheric models into GCMs. This has been implemented in weather forecast, but in climate simulations in which multi-scale interaction is much more important the nesting should be implemented in an interactive manner, i.e., two-way nesting. A newer approach has recently been proposed by several research groups in US, called multi-scale modeling framework (MMF), which embeds a number of two-dimensional cloud resolving model (CRM, resolution of a few kilometers) at all the grids of the GCM, working as ‘parameterization’. This MMF directly resolves individual cloud systems instead of increasing the resolution of GCMs and therefore has a large potential for climate change studies. Unfortunately, an attempt to develop own MMF is not found so far in the Japanese community, which will be one of urgent issues toward AR5.

2. Purpose of this study

Referring to the domestic situation as described above, the present study aims at developing a MMF-based climate model that can be applied to the global warming simulation. While the method of the MMF basically follows that proposed by the US groups, we develop our own idea that overcomes a weakness of the present MMF, which cannot simulate extratropical mesoscale systems including squall line and orographic phenomena. Namely, we first define the 3D CRM domain at one GCM grid (Fig. 1a). By incorporating the so-called double-parallelization, multiple CRMs can be combined and integrated as if a single CRM covers a complicated domain (Fig. 1b). This is an extension of the conventional nesting, but with more flexible manner of the domain setting. When each CRM is shrunk, the CRM is able to have higher horizontal resolution with the same computational cost (Fig. 1c). Consequently more CRMs can be embedded into the GCM grids, which will become closer to the MMF proposed in US. As such, our proposing system has advantage of both nesting and MMF, therefore we call it flexible nesting (FlexNest) hereinafter. The FlexNest would have a potential to be applied to a variety of climate studies, so that the development of this system is the primary subject of the present study. There are also related issues such as the relevance of two-way nesting in climate studies and improving the representation of clouds in GCMs. These are therefore examined in subprojects as well.

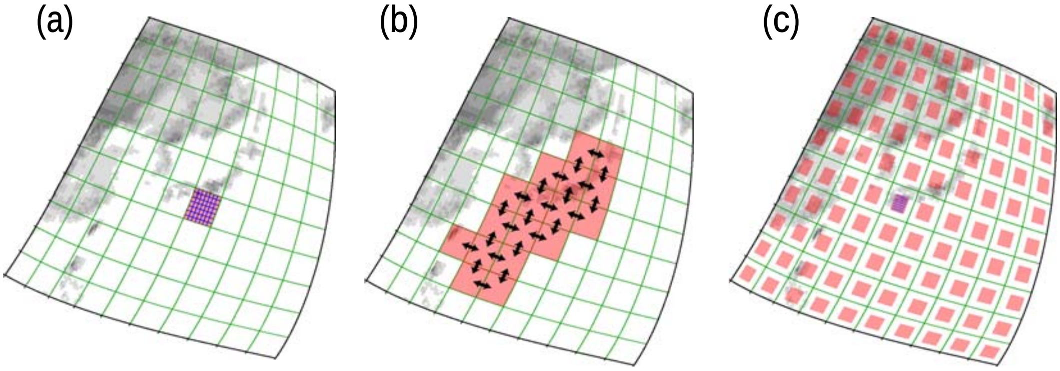

Figure 1. Schematic of the flexible nesting. Mesh indicates the GCM grid while shading represents the CRM domain embedded: (a) one CRM plugged in one GCM grid, (b) multiple CRMs embedded and coupled with each other, and (c) CRMs are embedded into all the GCM grids but each of them cover a small area of the respective GCM grid.

3. Results during FY2007

Based on the results obtained in FY2006, we have completed most of the tasks initially planned. The results of FY2007 are summarized for each of the subprojects below.

(1) Development of FlexNest

This subproject is responsible to the core part of the present study, namely, development of the FlexNest. For constructing the system, we use two numerical models each of which we have been participated in the modeling works: a GCM jointly developed at CCSR, Univ. of Tokyo, National Institute for Environmental Studies (NIES) and

Frontier Research Center for Global Change (FRCGC), called CCSR/NIES/FRCGC GCM, and a CRM which has been developed at Nagoya University, abbreviated as CReSS. During FY2006, we determined the basic framework for coupling and extended CReSS to the global spherical coordinate. Fully parallel code has also been developed using MPI. The preliminary version of the FlexNest was implemented as in the original US style; CRMs embedded in GCM's grids are independent of each other assuming a cyclic boundary condition. This system is useful for investigating the tropical disturbances, but cannot be applied to middle latitudes where complicated topography exists. Therefore, we developed a complete version of the FlexNest in FY2007 as schematically shown in Fig. 1. The nested system that follows Fig. 1b was then applied to the summer atmospheric circulation over East Asia, with attention on the Baiu front. It turns out that the two-way interaction between the GCM and CRM has a significant impact on the large-scale circulation since the precipitation field that is realistically simulated in the CRM modulates the diabatic heating for the large scale circulation. The frequency occurrence of intense rainfall was also shown to be more realistic in the FlexNest than in the conventional GCM. These results advocate that the FlexNest is useful not only for qualifying the meteorological fields under warmed climate but also for elaborating roles of multi-scale interaction in forming mean climate as well as the natural climate variability.

(2) Analysis of cloud fields in a long term CRM simulation

It is widely recognized that the major cause of uncertainty in climate models comes from the cloud feedback. In most of GCMs, clouds (excluding cumulus) are calculated by assuming a sub-grid scale distribution in temperature and total water (sum of moisture and cloud condensates). Cloud fraction can be obtained by integrating the saturated portion in a grid, however, it is not known what physically determine the probability distribution function (PDF) of such sub-grid scale quantities. In this subproject, we run a stand alone CRM for more than one year and then analyze the sub-grid scale (which implies the GCM's grid scale) features of cloud and related variables. In FY2006-2007, we have integrated CReSS with varying horizontal resolution from 1 km to 5 km over the Japan area and over the equatorial Indian Ocean. Then basic statistics of the sub-grid scale (corresponding to 250 by 250 km GCM grids) PDF were calculated for total water field. The PDF was found to be close to the normal distribution when it is averaged over time, but varies considerably in time and also in space. Specifically, PDF shape was systematically different over oceans and lands but less depends on altitude and latitude. In FY2007, these results were validated in comparison with in-situ data over the equatorial Indian Ocean and a relationship between the convective lifecycles and the PDF moments was discussed in detail, which can be applied to validate cloud parameterization for the GCM that is under development in sub-project (3).

(3) Improvement of cloud parameterization in GCM

Regardless of the way to model the multi-scale phenomena either the pMMF or the nesting, the region of subject is influenced by larger scale fields. Therefore not only higher resolution but also more reliable simulation cannot be performed unless the GCM itself has higher reality. In this subproject we focus on to improve the cloud scheme in the CCSR/NIES/FRCGC GCM called MIROC. In FY2006, we analyzed the global warming experiments in detail and compared to the results obtained from another state of the art GCM developed at Hadley Centre, UK. We proposed a useful method of analysis referred to as the cloud water budgets, which enable us to clarify possible sources of difference in climate change scenarios. It turned out that the response of mixed-phase cloud to increasing GHGs is one of the key ingredients in simulating difference climate changes in different GCMs.

Provided the results in FY2006, we started developing a new cloud parameterization that follows prognostic equations of PDF for the sub-grid scale temperature and total water fields. The mathematical design of the scheme has been developed and it is tentatively implemented in the atmospheric component of MIROC. In FY2007, the new scheme was completed and verified with a cloud-resolving simulation. Since this PDF-based cloud parameterization is not the best way to represent ice-phase cloud, we also introduced a prognostic ice cloud parameterization. When MIROC uses these new schemes, the model does show improvements in climatological features not only for clouds but also for other fields. These schemes are not used with FlexNest, but co-usage of them would certainly provide a powerful approach for the forthcoming global warming simulation and research.

(4) Developing and testing two-way nested system

For comparing with the FlexNest, this subproject attempted to develop a two-way nesting system based on the CCSR/NIES/FRCGC GCM coupled to a non-hydrostatic model (NHM) developed at the Japan Meteorological Agency. The basic framework has been developed in FY2006, so that several experiments were performed in FY2007 in order to understand the numerical stability dependent upon the model grids and the possible impact of the two-way interaction between the GCM and CRM. It is found that in the conventional nesting framework the nest ratio should at most be 1:5, which means that the CRM grid cannot be finer than 40km for T42 GCM. Yet, with this nest ratio, the two-way nesting was shown to be influential in simulating the large-scale climate such as the summer monsoon and precipitation over the tropical western Pacific. The impact of the subgrid-scale feedback onto the grid-scale was mainly due to mesoscale circulation forced by fine topography.

4. Discussion

We have set up subprojects for both the model development and its application in the present study although they might be too dense during the short period of the 2yr-project.

While the first version of the FlexNest was successfully completed, time slice experiments for the last half of 20th and 21st centuries using the FlexNest, which has been planned to obtain small-scale feature of the global warming projection, have not done because of the following two reasons. The first is the FlexNest must be validated for various uses in climate simulation before the actual application to the global warming study. Without confidence to the model performance, the heavy computation for future projection might be waste of resources. Furthermore, through subproject (3) we recognized the fast change in situation around IPCC. Namely, we will soon need to start computation toward AR5. Thus, the application of the FlexNest should be done with the next version of the global climate model that is to be used for AR5; the cloud parameterization developed in this project is actually implemented in the Japanese community model MIROC.

Successful development of the FlexNest is a large outcome for the forthcoming global warming research. The important respect is the continuity of the work in other running projects. In this regard, our project was successful as well; the subprojects (1)-(3) are involved in the Kakushin project by MEXT while the subproject (4) continues in the Global Environmental Research Fund S-5 that has started in FY2007.

Major Publications

None