Simulation and Verification of Tropical Deep Convective Clouds using Eddy-Permitting Regional Atmospheric Models

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The objective of this project is to develop an eddy-permitting regional atmospheric model, which can simulate turbulent motion with deep moist convection. In order to develop the model efficiently, we adopted a model using similar dynamical and physical frameworks to those of a global cloud-resolving model called NICAM (Nonhydrostatic ICosahedral Atmospheric Model). We develop a regional model called a diamond NICAM, whose simulation domain consists of one diamond (two triangles in an icosahedron), although the original NICAM global domain consists of ten diamond-shaped subdomains (twenty triangles). We modified the original NICAM to enable the limited area simulation with minimum modification of source code. The performance of the model is examined. Although the diamond NICAM can be used for a very small region, the model cannot be used for the case of cyclic boundary conditions because the model is based on a spherical-coordinate. Therefore, another model called a plain-coordinate NICAM is also developed which can be used for the case of cyclic boundary conditions. The model is used for the case called the Tropical Warm Pool International Cloud Experiment (TWP-ICE). The results indicate typical characteristics of deep clouds that develop over a boundary layer to a free atmosphere.

Keywords: LES, regional atmospheric model, deep convection, NICAM, cloud resolving model

1. Introduction

The deep convection in tropics is one of the most important heat sources for the planetary-scale atmospheric circulation. Although the convection system occurs in synchronization with a diurnal cycle, the diurnal cycle, intensity and space distribution of deep convection is not well simulated in most of GCMs. Therefore, it is an important task to understand the dynamical aspects of such deep convective systems in relation with the diurnal cycle and local circulation. The purpose of this project is as follows;

- to develop a eddy-permitting regional atmospheric model, which can simulate turbulent motion with deep moist convection, by the use of a grid resolution on the order of a hundred meters, in order to represent explicitly the cloud-scale processes,
- to perform several Large-Eddy Simulation (LES)s for tropical convection using this model, and to improve the model by comparing the results with observation and performing some sensitivity studies, and
- to investigate the generation and maintenance mechanism of convective systems based on the simulated data, which can be fundamental for improving cumulus parameterization schemes used in larger-scale atmospheric models including GCMs.

For the eddy-permitting regional atmospheric model, we are developing a model based on a global cloud-resolving model called NICAM (Nonhydrostatic ICosahedral Atmospheric Model, Satoh et al., 2008[1]). We develop a regional model called a diamond NICAM, whose simulation domain consists of one diamond (two triangles in an icosahedron), although the original NICAM global domain consists of ten diamonds (twenty triangles). We modified the original NICAM to enable the limited area simulation with minimum modification of source code. The developing process and the results of the test experiments are shown in section 2. Although the diamond NICAM can be used for a very small region, the model cannot be used for the case of cyclic boundary conditions because the model is based on a spherical-coordinate. Therefore, another model called a plain-coordinate NICAM is also developed which can be used for the case of cyclic boundary conditions. The developing process and the test results are shown in section 3.

2. Diamond NICAM for regional climate simulations

This regional atmospheric model is developed for conducting realistic regional climate simulations, targeted onto a certain limited area. Stretched horizontal grid version of regional model based on global cloud-resolving model, NICAM, had developed and applied by Tomita (2008) [2] and Satoh et al. (2010) [3]. In these simulations, inhomogeneity of horizontal grid sizes causes inconsistency of physical parameterizations such as cumulus convection. Simulation domain of the newly developed regional model (hereafter diamond NICAM) consists of one diamond (two triangles in an icosahedron), although the original NICAM global domain consists of ten diamonds (twenty triangles). Non-hydrostatic equations system version of the diamond NICAM has developed in FY2011. We modified the original NICAM to enable the limited area simulation with minimum modification of source code.

Figure 1 shows the simulation domain of a regional climate simulation targeted on Japan. Lateral boundary of the simulation domain (outer side of the grey line circle of Fig. 1) is forced by reanalysis data. We performed some test simulations using the diamond NICAM and the global NICAM of partly high-resolution with stretched horizontal grid using Schmidt transform to compare the results with each other. Figure 2

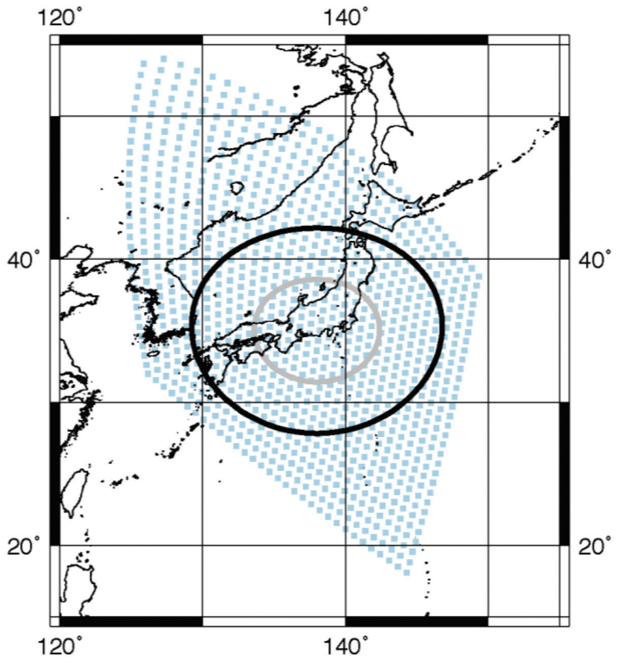

Fig. 1 Simulation domain targeted on Japan. Light blue dots indicates grid points. We applied reanalysis nudging in outer side of grey line circle.

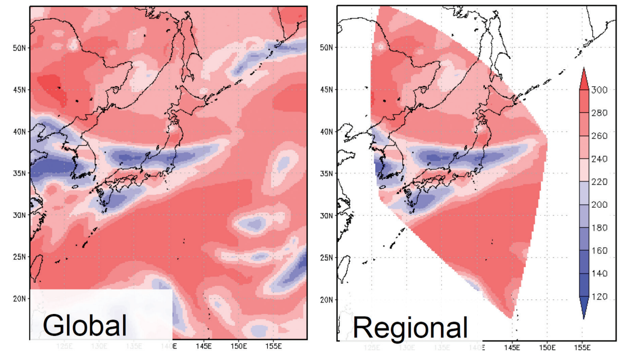

Fig. 2 Outgoing longwave radiation of simulations after two-hour integration. Left panel shows the result by global stretched grid simulation, right panel shows the one by regional simulation.

shows the outgoing long-wave radiation (OLR) of the two models. The result of the diamond NICAM is similar to well-tested stretched grid simulation, and correctly simulates the rain band system over Japan islands.

3. Preliminary experiment of deep convective systems using plain-coordinate NICAM

We developed plain-coordinate NICAM based on former spherical-coordinate NICAM, aiming at conducting much higher resolution simulations with the same physical processes and dynamic core of the spherical model. Herewith, we can directly compare the data using the both models, and improve simulated clouds in the real atmosphere using the spherical model by modifying physical parameterizations including microphysics and turbulent schemes based on high-resolution data in the plain model.

We conducted a high-resolution simulation of deep convective clouds observed during an austral summer season using the plain-coordinate NICAM. The model setting we adopted is the case called the Tropical Warm Pool International Cloud Experiment (TWP-ICE, May et al. 2008[4]), a major field experiment undertaken in the Darwin, Northern Australia, area in January and February 2006. The horizontal and vertical domain sizes are 100 km^2 and 24 km, respectively. The horizontal and vertical grid sizes are 390 m and, in average, 100 m, respectively. We used level 2 of MYNN (Nakanishi and Niino 2004[5]; Noda et al. 2010[6]) for computation of the subgrid-scale turbulence, and NSW6 (Tomita 2008[2]) for process of cloud microphysics, which parameterization schemes are generally being used in cloud-resolving simulations of NICAM.

Figure 3 shows the temporal changes of maxima of vertical velocity and condensates in the computed domain. Intense vertical velocity gradually develops from a 2 km height to higher altitudes after 20 min, and it eventually extends over a 15 km height. The maximum exceeds 60 m/s at around 12 km height by 100 min. The values of condensates become larger from the lower to the higher troposphere. Different from that of vertical velocity, it shows maximum around the 6 km height, which corresponds to the freezing level. Figure 4 shows the contribution of each category of condensates to the total (shown in Fig. 3b). Quantitatively, the contributions of rain water and graupel are dominant below and above the freezing level, respectively, and next are that of cloud water and cloud ice. The value of snow is the smallest in this case.

We are going to extend the simulation period to 1 day to analyze characteristics of statistical behavior of simulated convective clouds, along with a sensitivity study of horizontal resolution.

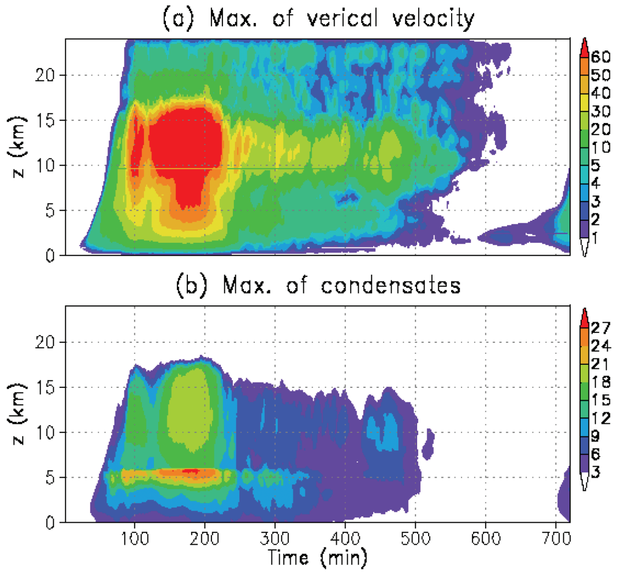

Fig. 3 Temporal changes of simulated deep convective systems. Maxima of (a) vertical velocity (m/s) and (b) condensates (g/kg) in the computed domain are shown.

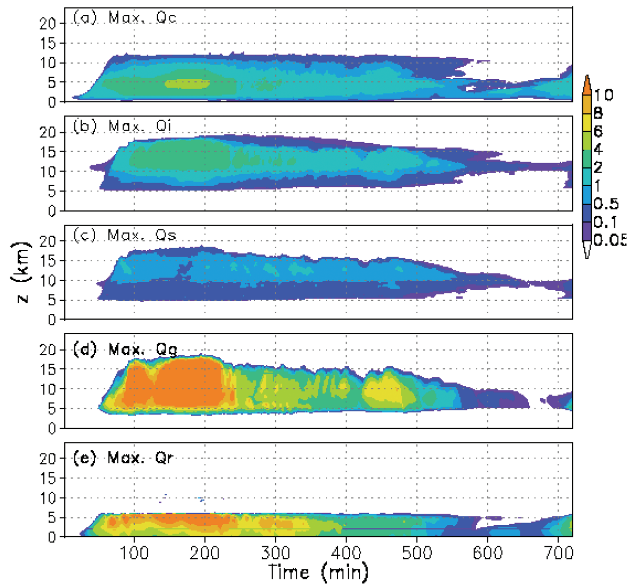

Fig. 4 Vertical distribution of simulated condensates. From left to right, maximum mixing ratios (g/kg) of (a) cloud water, (b) cloud ice, (c) snow, (d) graupel, and (e) rain water.

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渦解像可能な領域大気モデルを用いた深い対流のシミュレーションとその検証

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本プロジェクトは、十分に細かい格子を用い、深い湿潤対流を解像できるモデルの開発を目的としている。効率的な開発のため、全球雲解像モデル（NICAM、Nonhydrostatic ICosahedral Atmospheric Model）と共通の力学／物理フレームワークを用いた２つの NICAM モデルを開発した。領域版 NICAM は全球版 NICAM の一部を用いるもので、境界条件やナッジングの方法のチェックを進めた。全球実験とほぼ同じ結果が得られるようになった。領域版 NICAM は計算領域が狭くてもあくまでも球面上のモデルであり、周期境界条件を適用することはできない。そこで、周期境界条件を適用することができる平面版 NICAM を新たに作成した。予備実験として、通常の積雲対流解像モデルで比較実験が行われているケースのシミュレーション実験を行い、良好な結果を得た。

キーワード : LES, 領域大気モデル, 深い対流, NICAM, 雲解像モデル