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

Project Representative

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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 diamond NICAM, whose simulation domain consists of one diamond (two triangles in an icosahedron for the whole globe). In this fiscal year, we introduced a new lateral boundary scheme into the diamond NICAM. 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 plain-coordinate NICAM is also developed which can be used for the case of cyclic boundary conditions. In this fiscal year, the model is used for the whole simulation of the Tropical Warm Pool International Cloud Experiment (TWP-ICE). The model well simulates precipitation change responding to the environmental state.

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 an 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). The developing process and the results of the some 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 some 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 a regional model based on the global cloud-resolving model, NICAM, had developed and used 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). We modified the original NICAM to enable the limited area simulation with minimum modification of source code. Non-hydrostatic equations system version of the diamond NICAM has developed in FY2011.

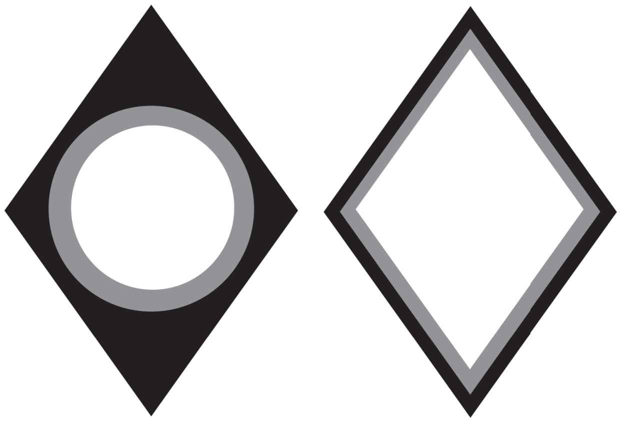

Fig. 1 Concept of the nudging schemes introduced in the regional NICAM. Left panel shows the nudging scheme in which the nudging coefficient depends on the distance from a certain point. Right panel shows the new lateral boundary scheme. Black indicates the areas where prognostic variables are replaced by the reanalysis data. Gray indicates the areas where the nudging coefficient varies by location. White indicates nudging-free areas.

In this fiscal year, we introduced a new lateral boundary scheme into the regional NICAM. Although we developed a nudging scheme, we calculate the strength of nudging by the distance from a certain point on the globe in the scheme. The left panel in Fig. 1 shows the concept of the scheme. In the new nudging scheme, shown in the right panel in Fig. 1, the strength of nudging is calculated not by the distance from a certain point in the domain but by the distance from the lateral boundary. The main concept of the scheme is almost same as Marbaix et al. (2003) [4], which uses grid number from the lateral boundary in the calculation. Because the grid distance in the regional NICAM is not exactly equal in horizontal space, we use the distance from the lateral boundary instead of grid number from the lateral boundary. By this modification, we can use the global cloud-resolving model, NICAM, like as general limited area models such as MRI-NHM, WRF, etc. Figure 2 shows simulated OLR (outgoing long-wave radiation) using the regional NICAM with the new lateral boundary scheme after 36-hour integration. Right panel shows TBB observed by MTSAT at the same time. The simulated OLR shows good agreement with the observation. The temporal progress of the convections, such as location of triggering, developing, and decaying is also well simulated during the integration.

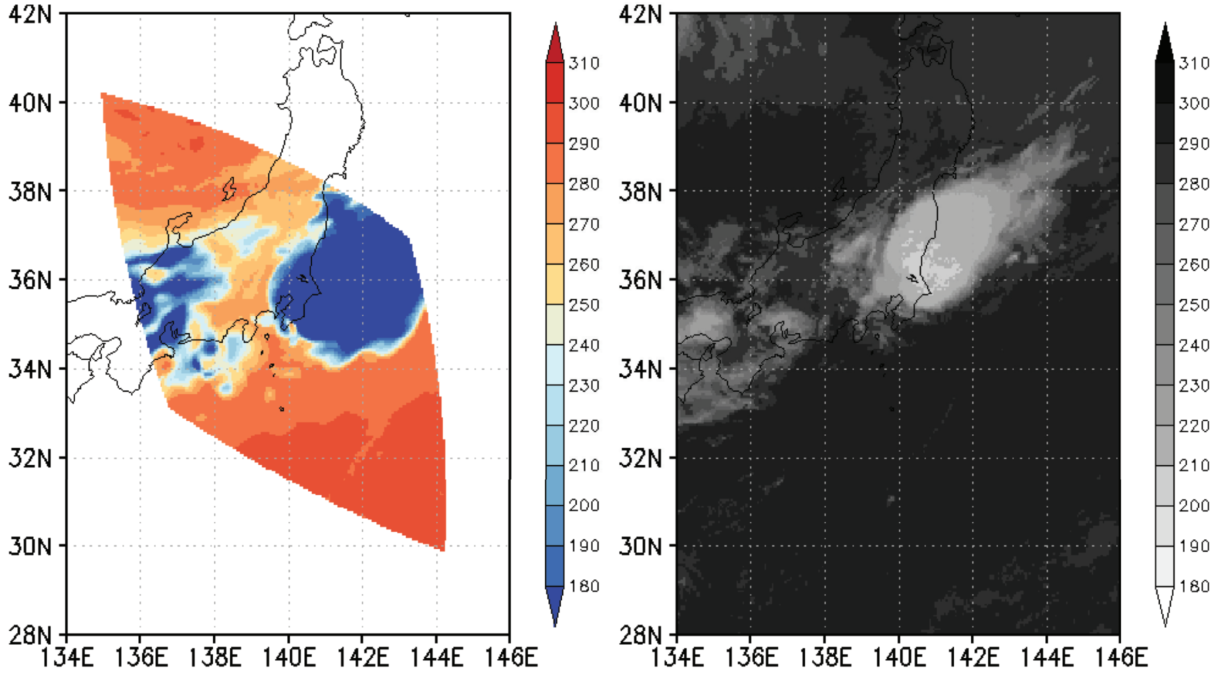

Fig. 2 Simulated OLR (W m^{-2}) at 00UTC 26 July 2010 with the regional NICAM after 36-hour integration (Left panel). Right panel shows TBB (K) observed by MTSAT at the same time.

3. Numerical experiments of deep convective systems using plain-coordinate NICAM

We develop 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 developing in the tropics 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[5]), 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. Please refer to Fridlind et al. (2012)[6] for the details of the setting of the simulation.

Figure 3 compares observed and modeled domain-mean surface precipitation. The targeted period (18 Jan 2006-2 Feb 2006) corresponds to monsoon season over northern Australia. For observation, precipitation stronger than 1 mm/hr occurs intermittently by 25 Jan 2006, which indicates an active phase of the monsoon. Because of transition to a break period, in contrast, precipitation abruptly decays after the day. The model well predicts precipitation that changes responding to the environmental state although it tends to predict its magnitude overly. Figure 4 shows dependence of frequency of occurrence

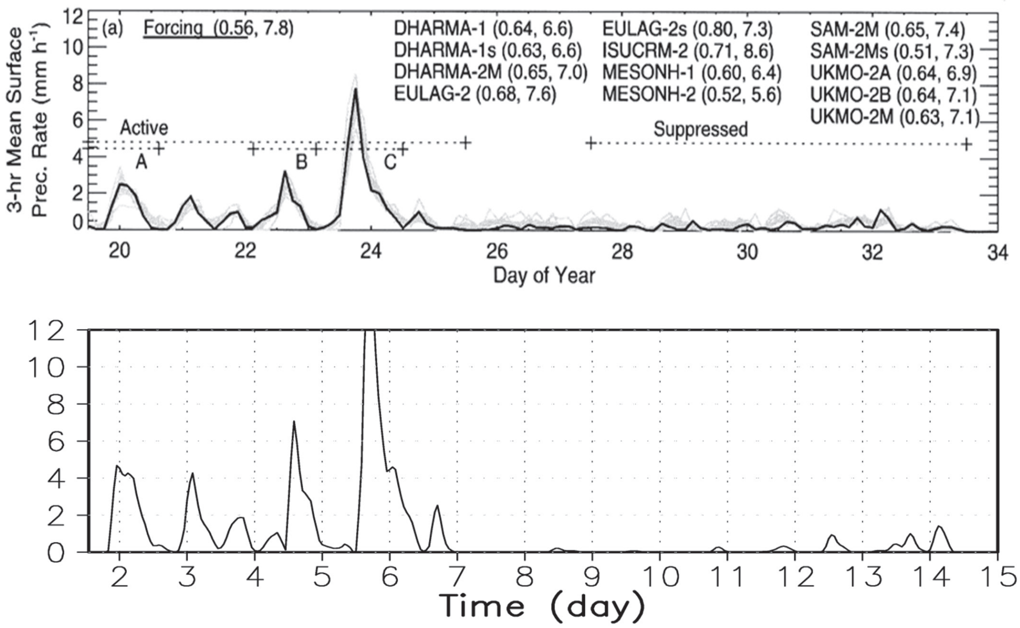

Fig. 3 Comparison between observed (top) and modeled (bottom) surface precipitation from 00UTC 18 Jan 2006 to 00UTC 2 Feb 2006 (mm hr^{-1}). Observation data obtained by ground radar are after Fridlind et al. (2012).

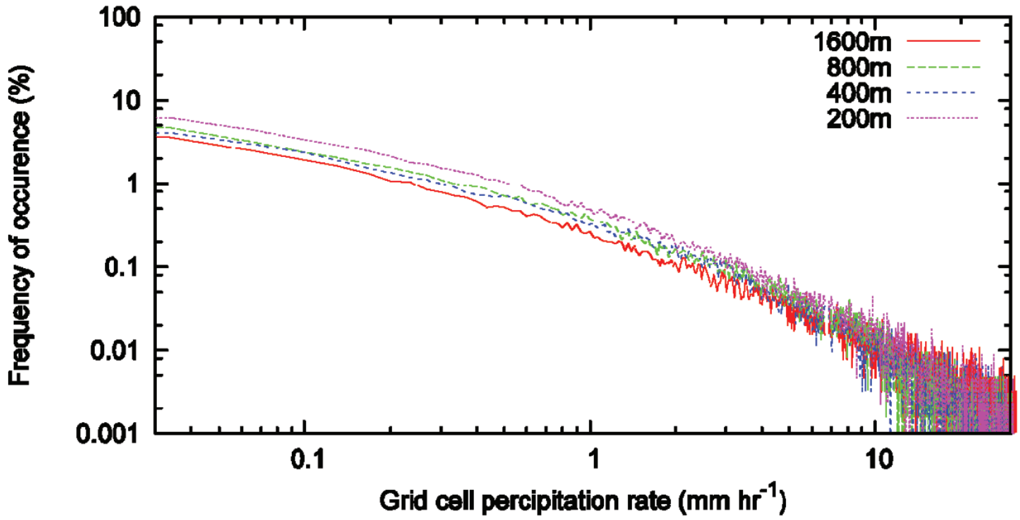

Fig. 4 Frequency distribution of surface precipitation intensity simulated in 1600-m, 800-m, 400-m, and 200-m mesh models.

of surface precipitation intensity on horizontal resolution. The result clearly shows that frequency of week and moderate surface precipitation (< 10 mm/hr) increase with the grid size becomes smaller, and the contribution of precipitation stronger than 10 mm/hr decreases.

References

[1] Satoh, M., T. Matsuno, H. Tomita, H. Miura, T. Nasuno, and S. Iga, "Nonhydrostatic icosahedral atmospheric model (NICAM) for global cloud resolving simulations," Journal of Computational Physics, 227, 3486-3514, DOI: 10.1016/jjcp.2007.02.006, 2008.

[2] Tomita, H., "A stretched icosahedral grid by a new grid transformation," J. Meteor. Soc. Japan, 86A, 107-119, 2008.

[3] Satoh, M., T. Inoue, and H. Miura, "Evaluations of cloud properties of global and local cloud system resolving models using CALIIPSO/CloudSat simulators," J. Geophys. Res., 115, D00H14, DOI:10.1029/2009JD012247.

[4] Marbaix, P., H. Gallée, O. Brasseur, and J.-P. van Ypersele, "Lateral Boundary Conditions in Regional Climate Models: A Detailed Study of the Relaxation Procedure," Mon. Wea. Rev., 131, 461–479, 2003.

[5] May, P. T., J. H. Mother, G. Vaughan, C. Jakob, G. M. McFarquhar, K. N. Bower, and G. G. Mace, "The tropical warm pool international cloud experiment," Bulletin of the American Meteorological Society, 89, 629-645, 2008.

[6] Fridlind, A. M., A. S. Ackerman, J.-P. Chaboureau, J. Fan, W. W. Grabowski, A. A. Hill, T. R. Jones, M. M. Khaiyer, G. Liu, P. Minnis, H. Morrison, L. Nguyen, S. Park, J. C. Petch, J.P. Pinty, C. Schumacher, B. J. Shipway, A. C. Varble, X. Wu, S. Xie, and M. Zhang, "A comparison of TWP-ICE observational data with cloud-resolving model results," Journal of Geophysical Research-Atmospheres, 117, D05204, DOI: 10.1029/2011JD016595, 2012.

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（その２）

プロジェクト責任者
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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改良を進めた。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。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進め、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