Chapter 11

Computational Climate Science Research Team

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11.2 Research Activities

Our research team conducts the pioneering research work to lead the future climate simulation. In order to enhance the reliability of climate model more, we have aimed to construct a new climate model based on the further theoretically physical principles. Conducting such a new model needs tremendously large computer resources. Therefore, it is necessary to design the model to pull out the capability of computers as much as possible. Recent development of supercomputers has a remarkable progress. Hence another numerical technique should be needed under the collaboration of hardware research and software engineering for the effective use on the future HPC, including the K computer and Post K computer.

For the above research purpose and background, our team is cooperating with the computational scientists in other fields and computer scientists. We enhance the research and development for the future climate simulations including effective techniques; we build a next-generation climate model.

The establishment of the above basic and infrastructure research on the K Computer is strongly required, because this research leads to the post K computer or subsequent ones in the future.

We highlight the following studies in this fiscal year.

1. Construction of a new library for climate study:
We have proposed the subject "Estimation of different results by many numerical techniques and their combination" as a synergetic research to MEXT in 2011 through the discussion with the Strategic 5 fields (SPIRE). We develop a new library for numerical simulation. The progress in development of SCALE is reported. NICAM-DC was imported to SCALE as a global dynamical core in this fiscal year. The two landmark papers of the SCALE are reported.

2. Grand challenge run for sub-km horizontal resolution run by global cloud-resolving model:
Another outstanding simulation of global model NICAM on the K computer, with super-high resolution (870m), has been done. We analyze the simulation in cooperation with the SPIRE3. We report the further comprehensive analysis of convection properties in the simulation.

3. Disaster prevention research in establishment of COE project:
Hyogo-Kobe COE establishment project has accepted 5 subjects in 2012. One of subjects is "the computational research of disaster prevention in the Kansai area". In this subject, one of sub-subjects is "Examination of heavy-rainfall event and construction of hazard map", which our team is responsible for. The tuning of physical properties focusing on the climatological precipitations and the preliminary result by direct downscaling are reported.

11.3 Research Results and Achievements

11.3.1 Construction of a new library for climate study

We are working on research and development of a library (named SCALE) for numerical models in fluid dynamical field especially in meteorological field. We examined feasibility of numerical scheme and methods for developing new ones which are suite on massive parallel computers especially the K computer. In order to validate the schemes and test their performance in atmospheric simulations, we have been developing an atmospheric regional model (named SCALE-RM) as a part of the SCALE library. The SCALE library and the SCALE-RM are currently available as open source software at our web site (http://scale.aics.riken.jp/). It is also installed on the K computer and is available for the K computer users as an AICS Software (http://www.aics.riken.jp/en/kcomputer/aics-software.html). In this year, we continued to develop components which are necessary for real atmospheric simulations; a boundary turbulence scheme, an urban canopy model, nesting system, and preprocessing tools. We also have improved the library and the model for better performance in both physical and computational aspects. As a remarkable feature, NICAM-DC (Nonhydrostatic ICosahedral Atmosphere Model Dynamical Core) was equipped to SCALE library as a global dynamical core.

The validation for the physical performance is an important issue as well as code development. In this fiscal year, we tuned the microphysical scheme, focusing on the one-moment bulk method (Tomita et al.2008). Although this scheme was used also in NICAM through the project SPIRE, it depends on the resolution and phenomena we can see. For this purpose, we conducted the series of systematic parameter tuning suitable to Japanese western region using the GSM data as the boundary condition and compared the precipitation with AMeDAS data. Figure 11.1 (a) and (b) shows results of hourly precipitation histogram from two typical parameter sets of the microphysics, which has been used in NICAM experiments (Miyakawa et al. 2014, Miyamoto et al.2013). After several key parameters were swept, we successfully tuned the parameters as shown in Fig.11.1 (c).

In this fiscal year, two landmark paper for SCALE was published. The first paper describes the proof-of-concept like study according to SCALE policy (Sato et al. 2015[16]). The three microphysical schemes, the one-moment bulk, two-moment bulk, and spectral bin schemes were compared by sensitivity experiments in which the other components were fixed in SCALE-RM. Since SCALE is targeting to enable self-model inter-comparison easily, this paper is high significant as a SCALE reference paper. The other paper is about the model description of SCALE-RM dynamical core(Nishizawa et al. 2015[13]). In this paper, we reveals that the influence of the grid aspect ratio of horizontal to vertical grid spacing on turbulence in the planetary boundary layer (PBL) in a large-eddy simulation (LES). This paper gives a deep suggestion to meteorological LES. One key point is how the filter length be configured. It should be based on consideration of the numerical scheme. We also

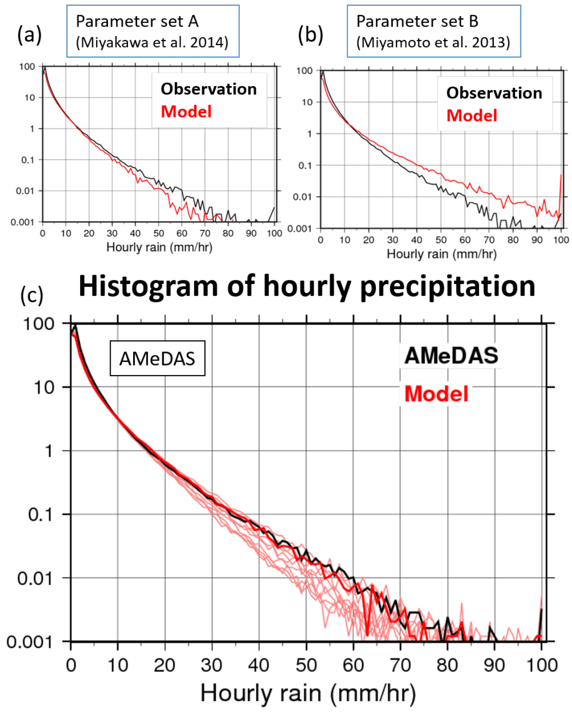

Figure 11.1: Results of microphysics tuning.

confirmed necessity of a corrective factor for the grid aspect ratio into the mixing length. As shown in Fig.11.2, these remedy generates the theoretical slope of the energy spectrum; otherwise, spurious energy piling appears at high wave numbers.

We investigated also the computational performance of SCALE-RM from the viewpoint of strong scale. Figure 11.3 shows the results of the strong scaling experiments for SCALE-LES. The most time-consuming part is the dynamics, and its scaling factor tends to be saturated by decreasing the problem size. This degradation comes from the increasing ratio of the communication time against the computational time. On the other hand, the scaling of physics gives relatively ideal scaling. In addition, the I/O part is not a bottleneck. To obtain the faster calculation, we implemented several choices both for the temporal and spatial difference schemes. As a result, the longer time step can be obtained in a certain configuration that is 4th order Runge-Kutta scheme in time and 3rd order advection scheme in space.

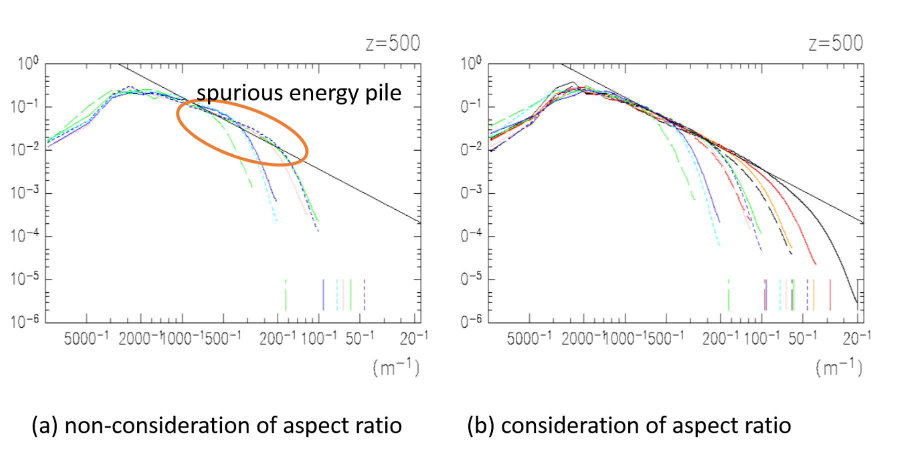

Figure 11.2: The kinetic energy spectrum.

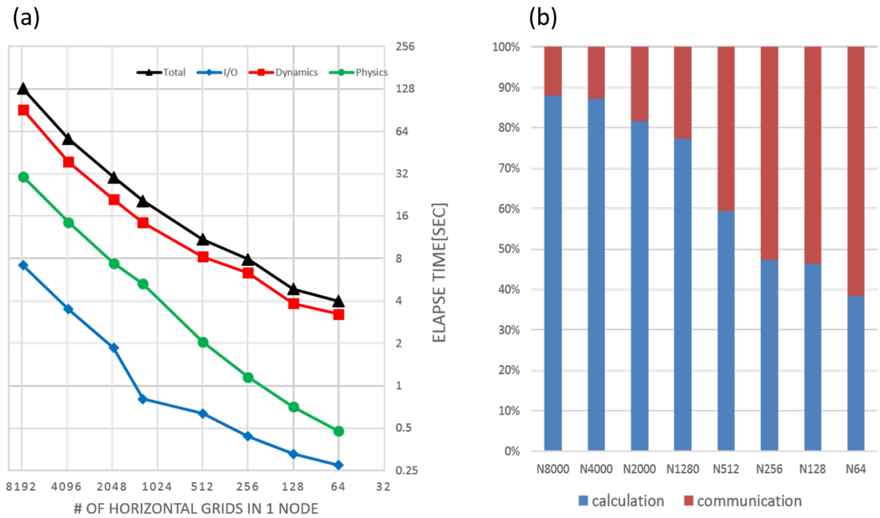

Figure 11.3: (a) Strong scale of SCALE-RM. (b) Ratio of communication to calculation.

11.3.2 Grand challenge run for sub-km horizontal resolution run by global cloud-resolving model

Using the K computer, we have succeeded in conducting the global simulation with the world's highest resolution, 870 m, which is published in the 2013 fiscal year (Miyamoto et al. 2013). In the fiscal year 2015, an additional analyses to reveal the differences in convection properties in various atmospheric disturbances has been done. We focused on the differences in convection under four representative cloudy disturbances: Madden-Julian Oscillation, Tropical Cyclones, Mid-latitudinal Lows, and Fronts (Miyamoto et al. 2015[12]). In this fiscal year, we summarized the knowledge that we have obtained so far, as a review paper (Kajikawa et al. 2016[6]). We conducted further comprehensive analysis of the global-mean state and the characteristics of deep convection, to clarify the difference of the essential change by location and environment. By this paper, this project in our team collaborating with SPIRE was closed once. The subsequent collaboration project leads to the post-K priority project 4.

11.3.3 Hyogo-Kobe COE establish project

In this fiscal year, the boundary conditions inputted to our regional model SCALE-RE was selected. We decided to use the data from the global warming experiments by MRI-AGCM. Figure 11.4 (a) shows the target region. Figure 11.4 (b) shows the histogram of hourly precipitation of downscaling result, compared with AMeDAS in the present climate. The simulation period is from June to September in 10 years. Owing to the successful model tuning described in the previous section, the observation and model result indicate little difference. Figure 11.4 (c) gives comparison between the present and future climates, regarding to the precipitation intensity. The heavy rainfall event increases in the whole Japan area, while the frequency of heavy rainfall is not so changed in the Japanese western area. Figure 11.4 (d) shows an expected maximum rainfall intensity that stochastically occurs once twenty years. This result indicates that extreme rainfall occurs in the Kyushu area, but little change occurs in the Kansai area. However, we should note that this result was obtained from just one scenario and one GCM model output; we have to regard this result as one of possible ensembles. For the more reliable result, we should increase the number of scenario and the integration period.

11.4 Schedule and Future Plan

In the next year, we will continue to further develop, update and maintain the numerical library for the K computer (SCALE library). We also try to enhance the performance of each existing scheme. Especially, validation of cumulus parameterization is necessary. At the same time, we will work on

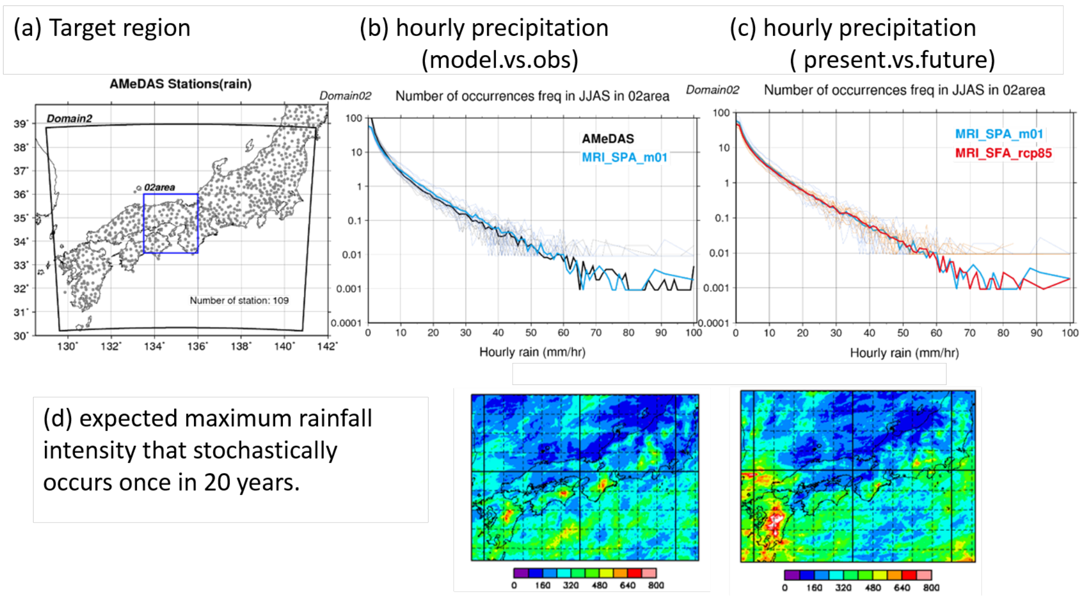

Figure 11.4: The result of the preciptation property in the Japan/Kansai region by the direct downscaling.

the following three projects in the collaboration with other team in AICS and the scientist in other institute.

1. On the Hyogo/Kobe COE establish project, we will continue the long-term climate simulation by using SCALE-RM to examine the heavy rainfall over Kobe city area. Several MRI-AGCM results for the future climate is used for increase of scenarios. We will obtain the geographical distribution of the frequency of heavy rainfall and evaluate it more precisely. For this purpose, the pseudo global warming method will be also employed.

2. We will also contribute to the CREST, Strategic Basic Research Programs "Innovating "Big Data Assimilation" technology for revolutionizing very-short-range severe weather prediction" to develop the main climatological model in SCALE library. In collaboration with the Data Assimilation team in AICS, we developed a prototype of SCALE-LETKF (Local Ensemble Transform Kalman Filter). For this short range forecast, we will pursue both of the computational and physical performance.

3. We join the POST K Science priority project under the collaboration with JAMSTEC. NICAM-LETKF is one of the target applications. Our team will continue to develop and update that application.

11.5 Publications

Journal Articles

[1] D. Goto et al. "Application of a global nonhydrostatic model with a stretched-grid system to regional aerosol simulations around Japan". In: *Geoscientific Model Development* 8 (2015), pp. 235–259.

[2] H H. Kusaka et al. "Assessment of RCM and urban scenarios uncertainties in the climate projections for August in the 2050s in Tokyo". In: *Climatic Change (accepted)* (2016).

[3] S. Iga. "Smooth, seamless, and structured grid generation with flexibility in resolution distribution on a sphere based on conformal mapping and the spring dynamics method". In: *Journal of Computational Physics* 297 (2015), pp. 381–406.

[4] T. Iguchi et al. "Overview of the development of the Aerosol Loading Interface for Cloud microphysics In Simulation (ALICIS)". In: *Progress in Earth and Planetary Science* 2(45) (2015).

[5] Y. Kajikawa et al. "Impact of Tropical Disturbance on the Indian Summer Monsoon Onset Simulated by a Global Cloud-System-Resolving Model". In: *Scientific Online Letters on the Atmosphere* 11 (2015), pp. 80–84.

[6] Y. Kajikawa et al. "Resolution dependence of deep convections in a global simulation from over 10-kilometer to sub-kilometer grid spacing". In: *Progress in Earth and Planetary Science* 3(16) (2016).

[7] C. Kodama et al. "A 20-Year Climatology of a NICAM AMIP-Type Simulation". In: *Journal of the Meteorological Society of Japan* 93 (2015), pp. 393–424.

[8] J. Leinonen et al. "Performance assessment of a triple-frequency spaceborne cloud-precipitation radar concept using a global cloud-resolving model". In: *Atmospheric Measurement Techniques* 8 (2015), pp. 3493–3517.

[9] Y. Liu et al. "Modeling study on the transport of summer dust and anthropogenic aerosols over the Tibetan Plateau". In: *Atmospheric Chemistry and Physics* 15 (2015), pp. 12581–12594.

[10] Y. Miyamoto and T. Takemi. "A Triggering Mechanism for Rapid Intensification of Tropical Cyclones". In: *Journal of the Atmospheric Sciences* 72 (2015), pp. 2666–2681.

[11] Y. Miyamoto et al. "A linear thermal stability analysis of discretized fluid equations". In: *Theoretical and Computational Fluid Dynamics* 29 (2015), pp. 155–169.

[12] Y. Miyamoto et al. "Does convection vary in different cloud disturbances?" In: *Atmospheric Science Letters* 16 (2015), pp. 305–309.

[13] S. Nishizawa et al. "Influence of grid aspect ratio on planetary boundary layer turbulence in large-eddy simulations". In: *Geoscientific Model Development* 8 (2015), pp. 3393–3419.

[14] S. Nishizawa et al. "Martian dust devil statistics from high-resolution large-eddy simulations". In: *Geophysical Research Letters* 43 (2016), pp. 4180–4188.

[15] Y. Sato et al. "Horizontal Distance of Each Cumulus and Cloud Broadening Distance Determine Cloud Cover". In: *Scientific Online Letters on the Atmosphere* 11 (2015), pp. 75–79.

[16] Y. Sato et al. "Impacts of cloud microphysics on trade wind cumulus: Which cloud microphysics processes contribute to the diversity in a large eddy simulation?" In: *Progress in Earth and Planetary Science* 2(23) (2015).

[17] Y. Sato et al. "Unrealistically pristine air in the Arctic produced by current global scale models". In: *Scientific Reports* 6(26561) (2016).

[18] H. G. Takahashi et al. "An Oceanic Impact of the Kuroshio on Surface Air Temperature on the Pacific Coast of Japan in Summer: Regional H2O Greenhouse Gas Effect". In: *Journal of Climate* 28 (2015), pp. 7128–7144.

[19] B. Wang and Y. Kajikawa. "Reply to Comments on 'Interdecadal Change of the South China Sea Summer Monsoon Onset". In: *Journal of Climate* 28 (2015), pp. 9036–9039.

[20] T. Yamashita et al. "A numerical study on convection of a condensing CO2 atmosphere under early Mars like conditions". In: *Journal of the Atmospheric Sciences (in press)* (2016).

[21] T. Yamaura and Y. Kajikawa. "Decadal change in the boreal summer intraseasonal oscillation". In: *Climate Dynamics (in press)* (2016).

[22] H. Yashiro et al. "Performance evaluation of throughput-aware framework for ensemble data assimilation: The case of NICAM-LETKF". In: *Geoscientific Model Development* 9 (2016), pp. 2293–2300.

[23] H. Zhao, R. Yoshida, and G.B. Raga. "Impact of the Madden?Julian Oscillation on Western North Pacific Tropical Cyclogenesis Associated with Large-Scale Patterns". In: *Journal of Applied Meteorology and Climatology* 54 (2015), pp. 1413–1429.

Conference Papers

[24] Y. Hisashi et al. "Performance Analysis and Optimization of Nonhydrostatic ICosahedral Atmospheric Model (NICAM) on the K Computer and TSUBAME2.5". In: *Proceedings of the Platform for Advanced Scientific Computing Conference*. PASC '16. 2016, 3:1–3:8.

Invited Talks

[25] Y. Kajikawa. *Deep Moist Convections in the Sub-kilometer Global Simulation.* Tropical Precipitation Systems Workshop 2015 on Intra-seasonal to seasonal climate variation and prediction, Yokohama, Japan, Sep. 3-4. 2016.

[26] Y. Kajikawa et al. *Resolution dependence of deep convections in a global simulation from over 10-kilometer to sub-kilometer grid spacing.* JpGU Annual meeting 2016: International Session, Chiba, Japan, May 22-26. 2016.

[27] Y. Miyamoto et al. *Convection on the globe in the subkilometer global simulation.* NTU seminar at the deparment of atmospheric science, National Taiwan University, Taiwan, October 5-6. 2015.

[28] S. Nishizawa et al. *High resolution Large eddy simulation on Martian planetary boundary layer.* JpGU Annual meeting 2016: International Session, Chiba, Japan, May 22-26. 2016.

[29] S. Nishizawa et al. *High-resolution modeling and big data analysis at RIKEN AICS.* 4th ENES Workshop on High Performance Computing for Climate and Weather, Toulouse, France, Apr. 6-7. 2016.

[30] H. Yashiro. *Towards Extreme-Scale Weather and Climate Simulation: The Post K Supercomputer and Our Challenges.* ISC High Performance, 2016 Conference, Frankfurt, Germany, June 21. 2016.

Posters and Presentations

[31] S. A. Adachi et al. *Application of a Meteorological Large Eddy Simulation Model to Practical Atmospheric Phenomena.* 13th Atmospheric Sciences and Application to Air Quality (ASAAQ13), Kobe, Nov. 11. 2015.

[32] S. A. Adachi et al. *Performance of SCALE on Downscaling Simulation under the Real Atmospheric Conditions.* International WS: Issues in downscaling of climate change projection, Tsukuba, Japan, October 6. 2015.

[33] S.A. Adachi et al. *Estimation of climate reproducibility in the summer season in the Western Japan by SCALE.* 2015 annual meeting of meteorological society of Japan, Kyoto, October 29. 2015.

[34] Y. Miyamoto et al. *Linear stability analysis for discretized system.* 2015 annual meeting of Japan Fluid Mechanics Society,Tokyo, September 26-28. 2015.

[35] Y. Miyamoto et al. *Predictability of deep moist atmospheric convection in a sub-kilometer global simulation.* AOGS 12th Annual Meeting, Singapore, Aug 2-7. 2015.

[36] Y. Miyamoto et al. *Predictability of onset of moist convection over the global atmosphere.* 2015 annual meeting of meteorological society of Japan, Tsukuba, May 21-24. 2015.

[37] Y. Miyamoto et al. *The global atmospheric simulation with less than 1km resolution.* The 30th TSFD Symposium (Turbulence simulation and flow design - climate change and flow analysis), Tokyo, March 12. 2015.

[38] S. Nishizawa et al. *High resolution LES experiment on Martian PBL.* Japanese-French model studies of planetary atmospheres, Kobe, Japan, May 11-15. 2015.

[39] S. Nishizawa et al. *Our model development activity in RIKEN AICS:introduction of SCALE and SCALE-LES.* Japanese-French model studies of planetary atmospheres, Kobe, Japan, May 11-15. 2015.

[40] S. Nishizawa et al. *Research and development of a meteorological simulation model for future meteorological simulations.* International WS: Issues in downscaling of climate change projection, Tsukuba, Japan, October 6. 2015.

[41] Y. Sato et al. *Effect of spreading of shallow cloud and their distance on the cloud cover ratio.* JpGU Annual meeting 2016: International Session, Chiba, Japan, May 22-26. 2015.

[42] R. Yoshida et al. *Implementation of domain nesting method in SCALE-LES and its evaluation.* 2015 annual meeting of meteorological society of Japan, Tsukuba, May 21-24. 2015.

[43] R. Yoshida et al. *Super-high resolution experiment by using SCALE-LES*. The 2nd seminar for meso-scale meteorology, Kagoshima, June 6. 2015.