Computational Climate Science Research Team

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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 aim to construct a new climate model based on the further theoretically physical principles. Conducting such a 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 new numerical techniques should be needed under the collaboration of hardware research and software engineering for the effective use of them on the future HPC, including 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 make a next-generation climate model. The establishment of the above basic and infrastructure research on K Computer is strongly required, because this research leads to post K (Exa) computer or subsequent ones in the future.

We have been continuing to conduct five ongoing projects and started one project from 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).
2. Grand challenge run for sub-km horizontal resolution run by global cloud-resolving model:
   In order to achieve an outstanding simulation on K computer in climate field, our team are conducting and analyzing the simulation with super-high resolution. This work are done in cooperation with the SPIRE3.
3. Feasibility study of Exa-scale computing using the general circulation model:
   The project of G8 Research Councils Initiative "ICOMEX" has been started from 2011 autumn. Through this project, a part of our team does the feasibility study of Exa-scale computing by the global cloud resolving model and conduct the inter-comparison between the existing icosahedral models.
4. Feasibility study to the future HPCI:
   In order to clarify what can be contributed from computational science to the socio/scientific field, "the Feasibility Study to the future HPCI" funded by MEXT has started from this fiscal year. RIKEN/AICS are now leading the investigation of contribution from the application side. The executive office was established in our team. We are organizing the application community of computational sciences.
5. 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 of.

3. Research Results and Achievements

3.1 Construction of a new library for climate study

SCALE library development

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 and developed new ones which are suite on massive parallel computers especially K computer. In order to validate the schemes and test their performance in atmospheric simulations, we have been developing an atmospheric large-eddy simulation model (named SCALE-LES) as a part of the SCALE library. The SCALE library and the SCALE-LES model are currently available as open source software at our web site (http://scale.aics.riken.jp/). It is also installed on K computer and is available for K computer users as an AICS Software (http://www.aics.riken.jp/en/kcomputer/aics-software.html).

Stratocumulus simulations by SCALE-LES

By using SCALE-LES model, we investigated shallow clouds such as stratocumulus which have important role in energy budget of the Earth through radiative process. Stratocumulus has two types of famous structure: closed- and open-cells. We succeeded to simulate the closed- and open-cells (Fig. 1) with a 35m- (in horizontal) and 5m- (in vertical) resolution simulation. Experimental settings are basically follows the DYCOMS-II RF02 setup (Ackerman et al. 2009).

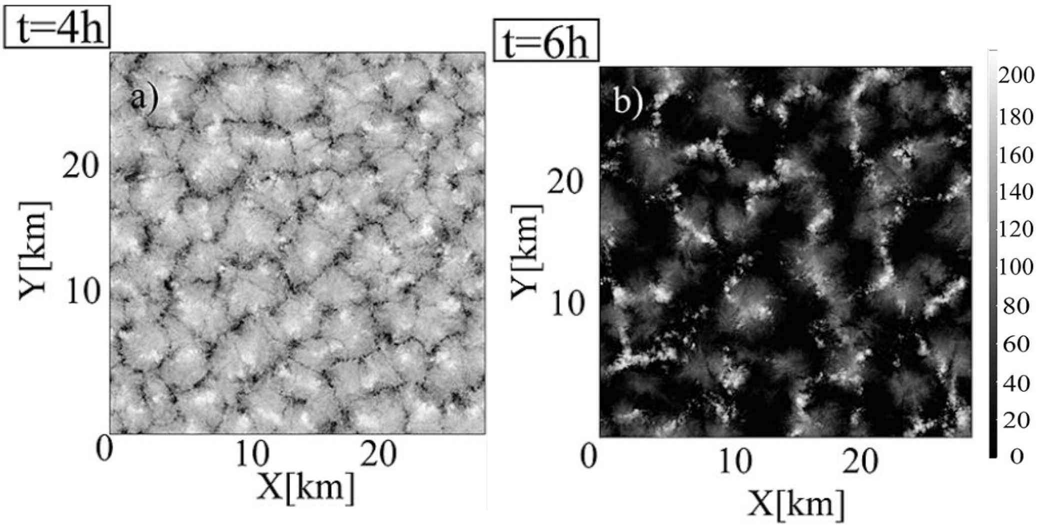

Figure 1. Horizontal distribution of radiance at 660 nm wavelength of simulated stratocumulus at 4 and 6 hours after the start of simulation. (a) Closed- and (b) open-cell structure is well simulated. Unit is W m^{-2} str^{-1} μm^{-1}.

We plotted the two cloud growth diagrams named Contoured Frequency Optical Depth Diagram (CFODD) and correlation pattern between effective radius (Re) and Cloud Optical Depth (COT) (RE-COT pattern). The former was firstly proposed from the results of satellite remote sensing by Nakajima et al. (2010) and Suzuki et al. (2010) and the latter proposed by Nakajima and Nakjaima (1995). All of them inferred that growth processes of cloud particles can be obtained from the analysis of the CFODD and the RE-COT pattern, but they did not confirm the validity of their inference because satellite remote sensing did not obtain temporal sequence of the CFODD. We also obtained temporal sequence of the CFODD diagram (Fig. 2 a-d) and RE-COT pattern (Fig. 2 e-g). As the result we show temporal evaluation of lifecycle of individual clouds from non-drizzling mode to drizzling mode and decaying mode. The results supported the inference of the previous studies.

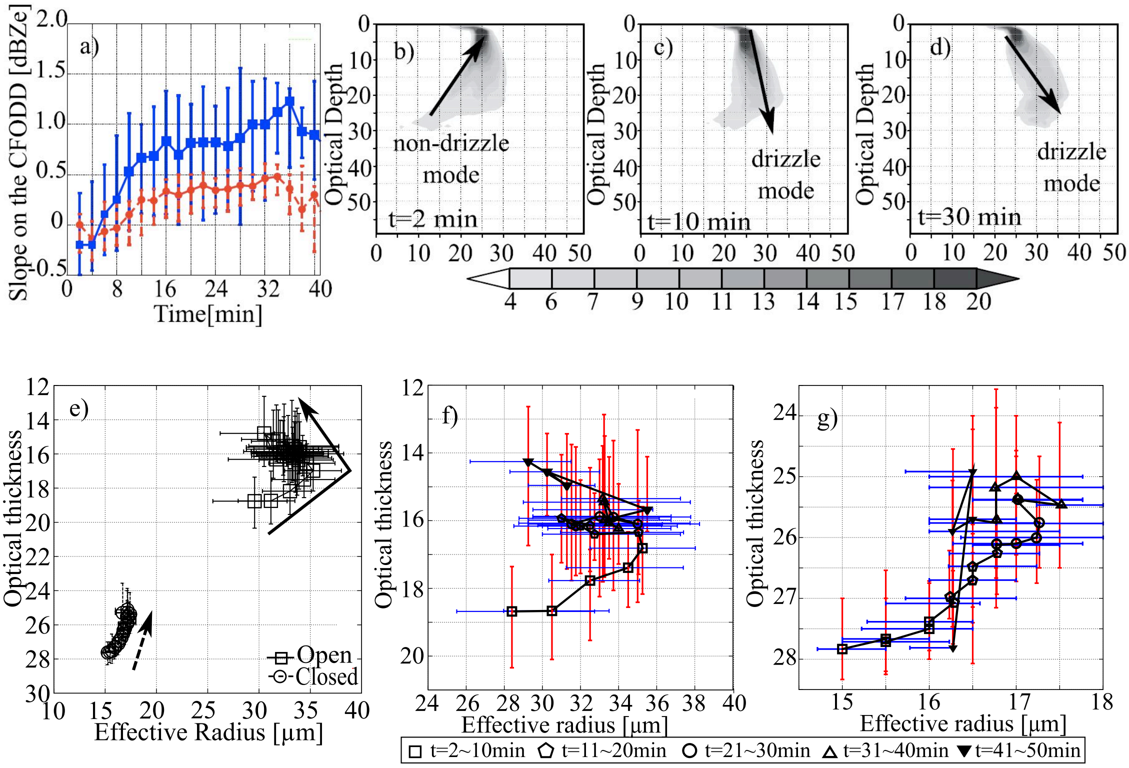

Figure 2. (a) Temporal evolution of the slope of the peak position of radar reflectivity on the CFODD created by the signals of individual clouds in the closed-cell (red line) and open-cell (blue line) cased and the CFODD of individual clouds averaged for all individual clouds in the closed-cell case at (b) t = 2 min, (c) t = 10 min, and (d) t = 30 min after each individual cloud was detected. (e) Trajectory of the center point of each cloud on the RE-COT pattern, averaged for all individual clouds of the open-cell (solid line with open square) and closed-cell (dotted line with open circle) cases, and the same figure but expanded to (f) the open-cell case and (g) closed-cell case at t = 2~10 min (open square), t = 11~20 min (pentagon), t = 21~30 min (circle), t = 31~40 min (closed triangle), and t = 41~48 min (closed triangle). Error bars in (a), (e), (f), and (g) indicate the upper and lower quartiles. The arrow in (b), (c), and (d) indicate the arrow corresponding to non-drizzling and drizzling stages in Fig. 1d, respectively. Arrows in (e) show the direction of movement of the trajectory on the RE-COT pattern.

We compare the cloud growth process obtained from the CFODD and that from the RE-COT pattern. From the comparison, we find that the transition from non-drizzling mode to drizzling mode can be obtained more efficiently from CFODD than from RE-COT pattern. We inferred that the difference is derived from difference of the information used for creating the diagrams. Vertical information included in CFODDs is important for obtaining cloud growth process. This inference suggests that vertical information of inner cloud should be obtained from next generation satellite (e.g. Himawari-8, Himawari-9). This is an example of the contribution of computational science to cloud and aerosol science, and indicates that numerical simulations can be used to augment satellite observations.

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

Improvement of the performance of NICAM on the K computer

We continue development for both scientific and computational performance improvement of atmosphere model. NICAM (Nonhydrostatic Icosahedral Atmospheric Model) is the global model in out target application. We achieved 10% of performance efficiency/PEAK of NICAM on the K computer with the small number of nodes. The detail is reported in the last year. Here we show a result of strong scaling test in Fig.3. The problem size of the test is about 260 billion grid, which means 14km of horizontal grid spacing, 94 of vertical layer (the layer thickness is 100-300m at the troposphere). NICAM has the parameter for the gird division level (glevel) and region (node) division level (rlevel). The number of horizontal grid is determined by (2^(glevel-rlevel)+2)^2 x 10x4^rlevel/process. The result shows good speedup from 80 nodes (glevel=9, rlevel=2, number of horizontal grid is 16900gridx2/node) to 2560 nodes (1156grid/node) of the K computer. However, the effective speedup was not provided using more nodes. This is because the ratio of the communication time increases in comparison with floating-point operation time. The communication time occupies 5% and 25% of main loop in 80 nodes and 2560 nodes, respectively. The ratio reaches over 50% in 20480 nodes (324grid/node) and 81920 nodes (100grid/node). Further improvement of strong scaling is necessary for the climate simulation, which requires O(10^5) - O(10^7) of steps. The challenges of development are reduction of the communication frequency and reduction/concealment of packing/unpacking cost.

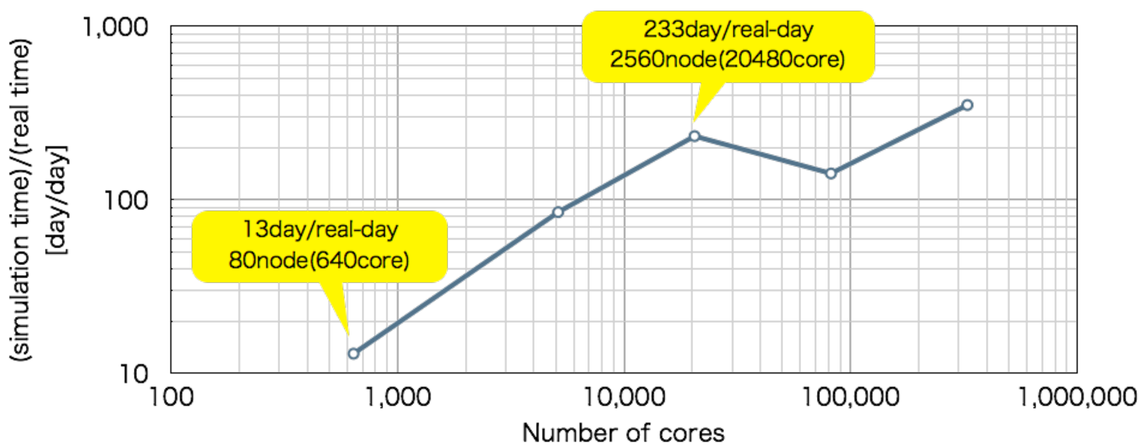

Figure 3. A result of strong scaling experiment on the K computer.

Analysis of global sub-km experiment

We have performed a simulation of global atmosphere with the world-highest resolution (the grid spacing is 870 m) using NICAM. The overview of the simulation has been reported in the last year. We have published a research paper in September 2013, which first succeeded in describing the mean structure of the deep moist atmospheric convection on the globe.

Based on this research, we further conducted an analysis focusing on the convection existing in various cloudy disturbances that cause severe natural disasters such as a typhoon. By considering four representative disturbances: Madden-Julian Oscillation (MJO), Tropical Cyclone (TC), Mid-latitudinal Lows (MDL) and Fronts (FRT) (see Fig.4), we found that the convection in the tropical disturbances (MJO and TC) has tall structure in contrast to that in the mid-latitudinal disturbances (MDL and FRT). More specifically, the MJO convection is strong and formed by large convective available potential energy (CAPE), whereas that in TC is weak and forced by strong low-level convergence. The convection in MDL and FRT is characterized by strong vertical wind shear that approximately correspond to large temperature gradient in the meridional direction. The findings provide useful information for development of cumulus parameterization and better understanding of interaction between the convection and disturbances.

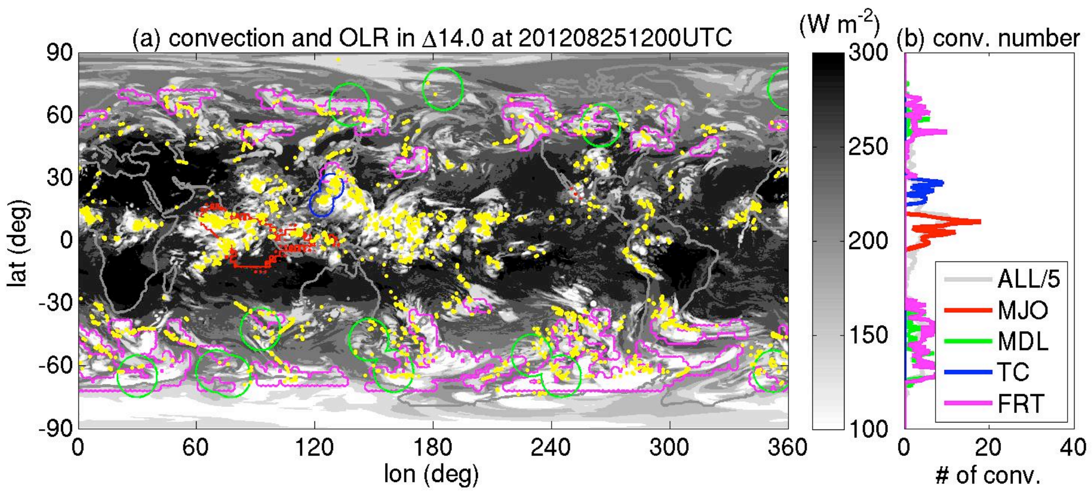

Figure 4. (a) Global distribution of the detected cloudy disturbances and convection overwritten on the Outgoing Longwave Radiation (OLR) in the simulation (gray shaded). The red, blue, green, and magenta contour represents MJO, TC, MDL and FRT, respectively. (b) The latitudinal distribution of convection numbers.

3.3 Feasibility study of Exa-scale computing using the general circulation model

ICOMEX project

The aim of the ICOsahedral-grid Models for Exascale Earth system simulations（ICOMEX）project is development the climate models, which have an efficient computational performance and provide better scientific result of the simulation. This project is the international activity for the exa-scale computing. We performed inter-model comparison between four participated models as one of the programs of ICOMEX project. The four models, DYNAMICO (France), ICON (Germany), MPAS (US/UK) and NICAM (Japan), are evaluated by four ideal test cases of atmospheric simulation. Computational performances of those models are also measured.

The atmospheric test cases are as follows: baloclinic wave test, long-term global circulation experiment, aqua planet experiment and CMIP5-AMIP experiment. The First test is a deterministic case and the representability of the model compared to the analytical solution is evaluated. The result shows that all models reproduced expected wave pattern (See Fig.5). A detailed error analysis showed that the enhancement of the spatial resolution contributes to the accuracy. The second case is performance test of dry dynamical core (i.e., no water vapor and moist thermodynamics) of the model. The climatological state after the long-term simulation is evaluated statistically. NICAM and ICON were used for this test and the result was compared each other. From the analysis of kinetic energy spectra and wave activity, the spectrum derived from both models showed almost good agreement with the expected spectrum. However, different characteristics were seen in the high wavelength. These results suggest that not only the horizontal grid spacing but also the magnitude of the artificial numerical diffusion term is important factor to the model's "effective" resolution.

For the computational performance, the measurement result of each model mentioned that efficient usage of the memory, especially the memory bandwidth is the important issue. The knowledge provided from this project will contribute the development of the model of each research group. Continuous and wide evaluation is needed for the improvement of climate model from now on.

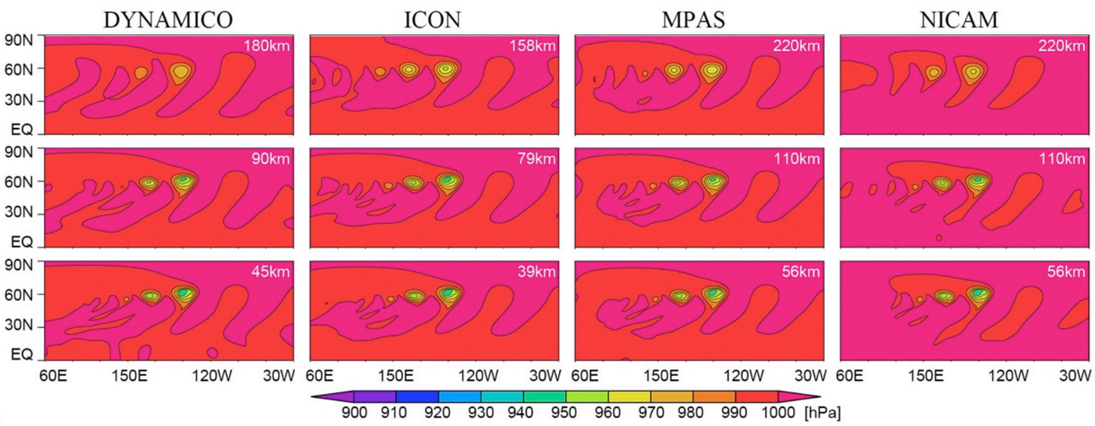

Figure 5. The simulation result of baloclinic wave test. Contour and color shows the surface pressure at the 9th day from initial state. The panels indicate the result of four model and three horizontal grid spacing.

NICAM-DC

Prior to the integration to our new library, we released a part of NICAM as an open source. The name of the package is NICAM-DC. The URL of the web site is http://scale.aics.riken.jp/nicamdc/. The dynamical core and the model framework are included in this package. The package also has the test case to evaluate the scientific performance of the model. The knowledge from the evaluation work in the ICOMEX project was used for the development of the test system. NICAM-DC is used as the benchmark and test-bed and mini-application in the fields of the computational science. For example, several groups of "the Feasibility Study to the future HPCI" used NICAM-DC to evaluate the performance of the kernel on their architectures.

3.4 Feasibility study to the future HPCI

FY2013, 6 general meetings were held and we extracted the social/science subjects, which should be resolved in the next generation HPC. We also discussed about them with the other communities. The "Road map of computational science" is published. The report including the road map can be found at http://hpci-aplfs.aics.riken.jp/ .

3.5 Hoygo-Kobe COE establish project

We succeeded to add the land-surface scheme and topography process to SCALE-LES and validate the each new scheme through several atmospheric simulations. In parallel with the SCALE-LES development, we have examined the heavy rainfall event in the Kobe city. Large amount of the rainfall is shown in June, while the rainfall intensity in June is relatively weaker than other month in boreal summer. We suggest the frontal disturbance is dominant in the rainfall event in June. On the other hand, convective heavy rainfall events are found in August and September. We performed model simulation of three heavy rainfall events in Kobe, 1) fontal rainfall, 2) convective rainfall, 3) combinational effect of typhoon and autumnal rain front by using Weather Research and Forecasting model (WRF). We confirmed the distribution of precipitation cell in the simulations and found the difficulty of simulating the developing process of precipitation cell and its temporal timing. We also conducted the climatological run during boreal summer in 2006-2013 and found the rainfall bias is shown along the mountain area. These preliminary experiments by WRF become reference to the SCALE-LES simulations in the future.

We also have regular meeting for comprehensive disaster-preparedness with Kobe University, Kansai University and public administration of Kobe City and Hyogo Prefecture, approximately once a two month.

4. Schedule and Future Plan

In the next year, we will continue to develop and update the numerical library for K computer.

At the same time, we will give an insight into what kind of the time integration method is promising on K computer and future HPC from the viewpoints of computational and physical performances. Through this project, we will organize and lead the meteorological numerical community for common library towards the post-Peta scale computing.

We especially focus on enhancing the SCALE-LES enough to simulate the atmosphere under realistic condition. Urban canopy process and several experimental tools will be incorporated in the model and validated with the moist convection case. On the COE establishment project, we have a plan to use this SCALE library to simulate the heavy rainfall in Kobe toward to the new-staged hazard map for local severe rain and floods.

We also challenge to figure out the transition process of two types of stratocumulus, open-cell and closed-cell by using SCALE-LES on K computer. Better simulation of these two clouds will bring massive progress not only for robustness of SCALE library but also for better understating of lower cloud. Latter can be applied to global climate modeling in the near future.

Grand challenge run by NICAM will be also continued in cooperation with 3rd Strategic Field Project. The statistical properties of deep convection in the different climatological disturbances will be summarized. Temporal evolution of each convection will be focused in detail.

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.

5. Publication, Presentation and Deliverables

(1) Journal Papers

[1] Sato, Y., S. Nishizawa, H. Yashiro, Y. Miyamoto, and H. Tomita, 2014: Potential of Retrieving Shallow-Cloud Life Cycle from Future Generation Satellite Observations through Cloud Evolution Diagrams: A Suggestion from a Large Eddy Simulation. SOLA, Vol10, pp. 10-14, doi:10.2151/sola.2014-003.

[2] Miyamoto, Y., M. Satoh, H. Tomita, K. Oouchi, Y. Yamada, C. Kodama and J. Kinter III, 2014: Gradient wind balance in tropical cyclones in global nonhydrostatic model simulations. Mon. Wea. Rev., 2014 ; e-View, http://dx.doi.org/10.1175/MWR-D-13-00115.1

[3] Yoshida, R., Y. Kajikawa and H. Ishikawa, 2014: Impact of Boreal Summer Intraseasonal Oscillation on Environment of Tropical Cyclone Genesis over the Western North Pacific. Scientific Online Letters on the Atmosphere, Vol. 10, pp15–18, doi:10.2151/sola.2014-004

[4] Sato, Y., S. Nishizawa, H. Yashiro, Y. Miyamoto, T. Yamaura and H. Tomita, 2014;

Development of a fully compressible Large Eddy Simulation Model, and simulations of stratocumulus life cycle – Contribution from the computational science to science of aerosol and cloud microphysics). Teionkagaku, 72, pp. 265-283.

[5] Iga, S., and H. Tomita, 2013: Improved smoothness and homogeneity of icosahedral grids using the spring dynamics method. J. Comp. Phys.

[6] Blackburn, M., D. L. Williamson, K. Nakajima, W. Ohfuchi, Y. O. Takahashi, Y.-Y. Hayashi, H. Nakamura, M. Ishiwatari, J. McGregor, H. Borth, V. Wirth, H. Frank, P. Bechtold, N. P. Wedi, H. Tomita, M. Satoh, M. Zhao, I. M. Held, M. J. Suarez, M.-I. Lee, M. Watanabe, M. Kimoto, Y. Liu, Z. Wang, A. Molod, K. Rajendran, A. Kitoh, and R. Stratton, 2013: The Aqua-Planet Experiment (APE): Control SST simulation. J. Meteor. Soc. Japan, 91A, 17-56, doi:10.2151/jmsj.2013-A02.

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[8] Miyamoto, Y. and Y. Kajikawa, R. Yoshida, T. Yamaura, H. Yashiro and H. Tomita, 2013: Deep moist atmospheric convection in a sub-kilometer global simulation. Geoph. Res. Lett., doi:10.1002/grl.50944.

[9] Seiki, T., and T. Nakajima 2013: Aerosol effect of the condensation process on a convective cloud simulation, J. Atmos. sci.,. doi: 10.1175/JAS-D-12-0195.1.

[10] Yamaura. T., Y. Kajikawa, H. Tomita and M. Satoh, 2013: Possible impact of a tropical cyclone on the northward migration of the Baiu frontal zone, SOLA, 9, 89-93, doi:10.2151/sola.2013-020.

[11] Lee, S. -S., J.-Y. Lee, K. -J. Ha, B. Wang, A. Kitoh, Y. Kajikawa and M. Abe, 2013: Role of the Tibetan Plateau on Climatological Annual Variation of Mean Atmospheric Circulation and Storm Track Activity, J. Climate, 26, 5270-5286, doi: 10.1175/JCLI-D-12-00213.1.

[12] Yoshida R. and H. Ishikawa, 2013: Environmental Factors Contributing to Tropical Cyclone Genesis over the Western North Pacific. Mon. Wea. Rev., 141, 451-467.

[13] Miyamoto, Y. and T. Takemi, 2013: A transition mechanism for the spontaneous axisymmetric intensification of tropical cyclones. Journal of the Atmospheric Sciences, 70, 112-129.

[14] Tomita, T., T. Yamaura, and Y. Kuwazuru, 2013: Decadal-scale modulation of atmospheric circulation change at the onset of the western North Pacific summer monsoon. SOLA, 9, 161-165.

[15] Nishizawa, S., Y. Sato, H. Yashiro, Y. Miyamoto, R. Yoshida and H. Tomita, Team SCALE, 2013:

Development of atmospheric LES model for large-domain and high-resolution experiments, Nagare, 32, 149-152.

(2) Invited Talks

[16] Tomita, H., Global cloud permitting model, ECMWF annual seminar on Recent developments in numerical methods for atmosphere and ocean modeling, September 2-5, 2013 (Invited)

[17] Kajikawa. Y., Interdecadal Change of the South China Sea Summer Monsoon Onset, 5th THORPEX and S2S Workshop, Jeju, Korea, November 4-5, 2013 (Invited).

(3) Posters and Presentations

[18] Yoshiaki Miyamoto and Tetsuya Takemi, A Triggering Mechanism for the spontaneous axisymmetric intensification of tropical cyclones, 2014 Ocean Science Meeting, Honolulu, Hawaii USA, 2014/2/27.

[19] Yoshiaki Miyamoto, Yoshiyuki Kajikawa, Ryuji Yoshida, Tsuyoshi Yamaura, Hisashi Yashiro, and Hirofumi Tomita, Deep moist convection in a sub-kilometer global simulation, International Workshop on Climate System Modeling, Honolulu, Hawaii USA, 2014/3/10.

[20] Yoshiaki Miyamoto, Richard Rotunno, and George Bryan, An analytical model of maximum potential intensity for tropical cyclones incorporating the effect of ocean mixing, 31st Conference on Hurricanes and Tropical Meteorology, San Diego, California USA, 2014/3/31.

[21] Yoshiaki Miyamoto and Tetsuya Takemi, A Triggering Mechanism for the spontaneous axisymmetric intensification of tropical cyclones, 31st Conference on Hurricanes and Tropical Meteorology, San Diego, California USA, 2014/4/3.

[22] Yousuke Sato, Seiya Nishizawa, Hisashi Yashiro, Yoshiaki Miyamoto and Hirofumi Tomita, Sensitivity of cloud microphysical scheme in SCALE-LES, Climate 2014, Honolulu, USA, 2014/3/11.

[23] Tomita, H., Report on Feasibility Study on Future HPC Infrastructure I, 1st International Workshop on Strategic Development of High Performance Computers, Tsukuba, March 18-19, 2013.

[24] Kajikawa, Y., Advanced Asian summer monsoon onset in recent decades,5th WMO International Workshop on Monsoons (IWM-V), Macao, China, October 28 – November 1, 2013.

[25] Kajikawa. Y., T. Yamaura, H. Tomita and M. Satoh, Possible Impact of a Tropical Cyclone on the Northward Migration of the Baiu Frontal Zone, 6th China-Korea-Japan Joint Conference on Meteorology, Nanjing, China, October 24-25, 2013.

[26] Kajikawa. Y., T. Yamaura, H. Tomita and M. Satoh, Indian summer monsoon onset in 2012 simulated by global cloud-system resolving model NICAM, Davos Atmosphere and

Cryosphere Assembly 2013, Davos, Switzerland, July 8-12, 2013.

[27] Kajikawa, Y., Advanced Asian summer monsoon onset in recent decades, Davos Atmosphere and Cryosphere Assembly 2013, Davos, Switzerland, July 8-12, 2013.

[28] Yashiro, H., H. Tomita and M. Satoh, NICAM simulations on the K computer: recent performance and activities toward to the exascale computing, 15th International Specialist Meeting on the next-generation of climate models and knowledge discoveries through the extreme high-performance simulations and big data, Berkeley CA, USA, March 20-22. 2013

[29] Nishizawa, S., H. Yashiro, Y. Sato, Y. Miyamoto and H. Tomita, Research and Development of Common Basic Library and Environment for Weather and Climate Prediction Models, 15th International Specialist Meeting on the next-generation of climate models and knowledge discoveries through the extreme high-performance simulations and big data, Berkeley CA, USA, March 20-22. 2013.

[30] Miyamoto, Y. and T. Takemi, 2013: A transition mechanism for the spontaneous axisymmetric intensification of tropical cyclones. Japan Geophysical Union 2013, Chiba, Japan, April 28-May 2, 2013.

[31] Yamaura, T. and T. Tomita, 2013: Persistence and the change of Baiu precipitation anomalies. Davos Atmosphere and Cryosphere Assembly 2013, TU-62_B4.1, 8-12 July, Davos, Schweiz.

[32] 佐藤陽祐、八代尚、西澤誠也、宮本佳明、富田浩文、Team-SCALE、計算科学から貢献する雲の本質的理解へ向けた将来展望、日本気象学会春季大会(招待講演)、東京、5 月 2013 年。

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[38] 宮本佳明, 竹見 哲也, 2013: A Triggering Mechanism for the spontaneous axisymmetric intensification of tropical cyclones, 台風セミナー2013, 京都, 2013/10/22。

[38] 佐藤陽祐，八代尚，西澤誠也，宮本佳明，富田浩文，Team-SCALE、2013: Numerical simulations of stratocumulus off the west coast of California，神戸, 2013/2/28。

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