Study of Cloud and Precipitation Processes Using a Global Cloud Resolving Model

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The objective of this project is to better understand cloud and precipitation processes on the Earth and to improve their treatment in climate models by global cloud-resolving approach. In the FY2012, we focused on Madden-Julian Oscillation (MJO) case studies for our objective. Two groups of MJO simulations were executed using Nonhydrostatic Icosahedral Atmospheric Model (NICAM): (1) Year of Tropical Convection (YOTC) cases proposed by an international model inter-comparison project and (2) Cooperative Indian Ocean experiment on intreaseaonal variability in the year 2011 (CINDY2011) / Dynamics of the Madden-Julian Oscillation (DYNAMO) cases. CINDY2011 is an international observation project led by JAMSTEC. By conducting a number of sensitivity experiments, we found that the reproducibility of the simulated MJO events were sensitive to some cloud microphysics parameters. Based on the results, the most appropriate settings were selected for the control runs, and realistic convective behavior of MJO was obtained. In order to understand basic propagation properties of topical large-scale convective disturbances including MJO, aquaplanet experiments varying the rotation of the Earth were also conducted.

Keywords: cloud and precipitation processes, global cloud resolving model

1. Introduction

Understanding of cloud and precipitation processes based on most up-to-date observational products and numerical simulations are critical to reliable prediction of global climate change. Our research group has been developing a global cloud resolving model, Nonhydrostatic Icosahedral Atmospheric Model (NICAM, Satoh et al. 2008[1]). NICAM is unique in explicitly calculating cloud and precipitation processes on the whole globe. The simulations using the Earth Simulator have created a number of research products (e.g., Tomita et al. 2005[2]; Iga et al. 2007[3]; Miura et al. 2007[4]; Oouchi et al. 2009[5]; Noda et al. 2010[6]; Yamada et al. 2010[7]). In this project, special emphasis are on evaluations of simulated cloud and precipitation processes in comparison with in-situ observation and new satellite data (Satoh et al. 2010[8], 2011[9], 2012[10]). In the FY2012, we put most resources into simulations of recently observed Madden-Julian Oscillation (MJO; Madden and Julian 1971[11], 1972[12]) events. Because of its significant impacts on the global weather and climate, the importance of understanding and accurate prediction of MJO are now increasingly recognized (Gottschalck et al. 2010[13]). Several international observation projects targeted to MJO have been launched in these years (Zhang et al. 2013[14]), two of which we have been participated in (Satoh et al. 2010[8], 2011[9], 2012[10]). We have been also conducted idealized (e.g., aquaplanet) experiments to help understand basic properties of MJO and tropical convective disturbances in the real atmosphere. These topics are reported in the following sections.

2. Simulations of the MJO events in the YOTC period

MJO is an intraseasonal atmospheric variability with a life cycle of 30–60 days, visualized in the tropical Indian and Pacific Oceans as an eastward travelling envelope of multi-scale cloud clusters (Nakazawa 1988[15]), typically a few to several thousands of kilometers wide in longitude. MJO impacts on the tropics with heavy rainfall, triggers tropical cyclones (Maloney and Hartmann 2001[16]), and induces Rossby-wave trains that occasionally sustain anomalous conditions in the extra-tropics, e.g., heat/cold waves (Mori and Watanabe 2008[17]). Representation of the MJO remains problematic in many general circulation models (Hung et al. *in press*[18]) due to the insufficient understanding of its mechanism; especially, vertical profiles of heating by convective processes are poorly understood. The diabatic heating critically affects the behavior of convective disturbances in the tropics, but it cannot be measured directly in the observations. In the conventional climate and operational models, where clouds are not resolved, diabatic heating is represented by cumulus parameterization, and uncertainty due to the cumulus parameterization is significant (Lin et al. 2006[19]). With such a background, modeling centers are collaborating under the "Vertical Structure and Diabatic Processes of the MJO *A Global Model Evaluation Project"* organized by the MJO Task Force and Year of Tropical Convection (YOTC). YOTC is a multi-national virtual intensive observation project, which built up high-resolution satellite, analysis, and forecast data for the period of May 2008–April 2010. We took part in this model inter-comparison project and submitted our simulation dataset. The target two MJO events occurred successively from October 2009 to January 2010 in the YOTC period (Figs.1 and 2). Our dataset was the only global cloud-resolving model product, which is highly useful for this purpose. In addition, these simulations provided important basis for the MJO ensemble experiments executed on the K-computer.

3. Simulations of the MJO events observed in the CINDY2011/DYNAMO period

Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY2011) was an international field project led by JAMSTEC, in coordination with the United States project, Dynamics of the Madden-Julian Oscillation

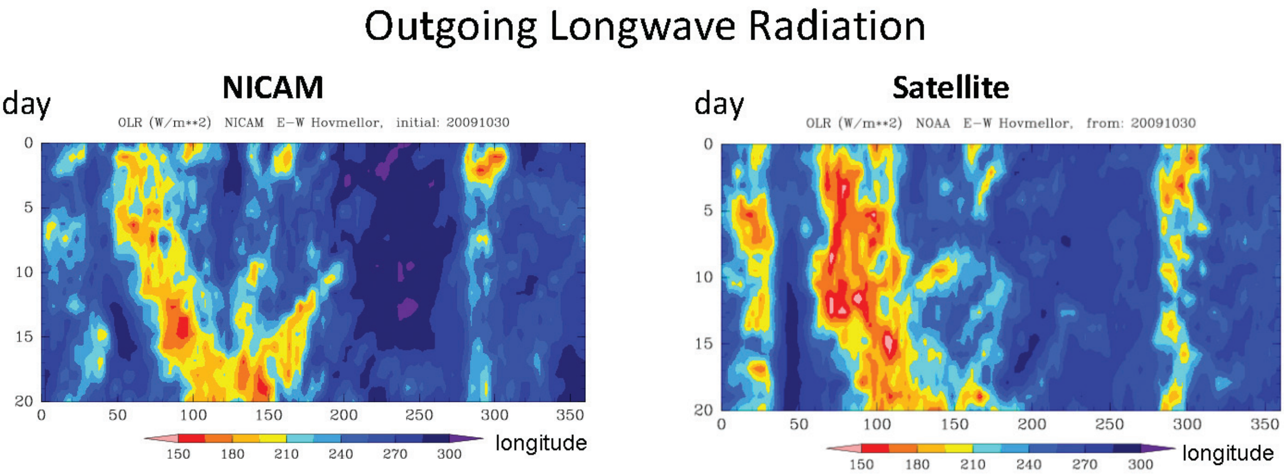

Fig. 1 Longitude-time section of outgoing longwave radiation by NICAM and satellite observation of a target MJO CASE, 30 Oct - 18 Nov, 2009. Lower values (red) correspond to high cloud tops.

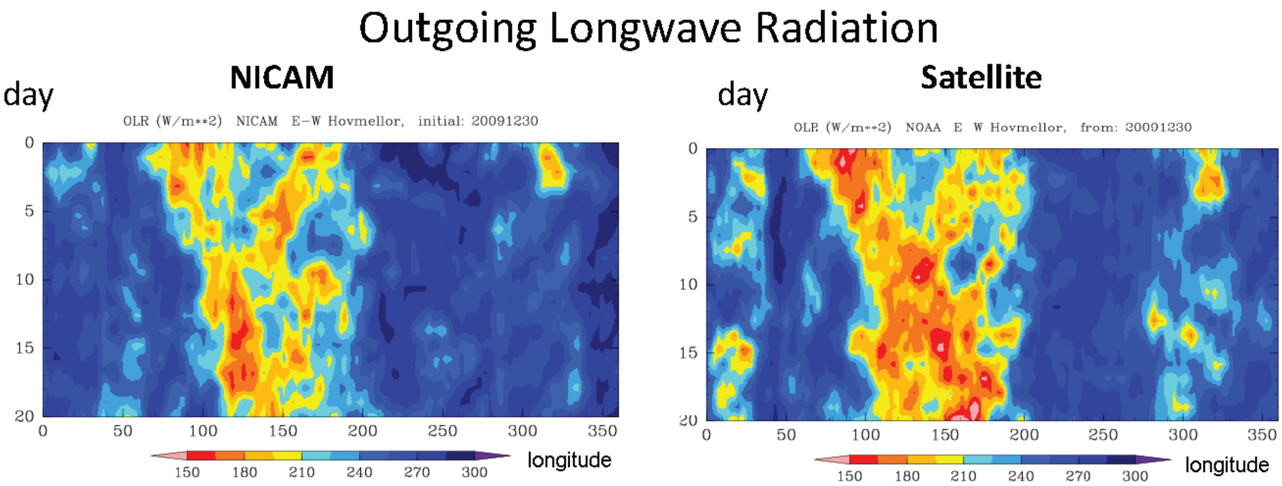

Fig. 2 Same as Fig.1 but for a different MJO case, 30 Dec 2009 - 18 Jan 2010.

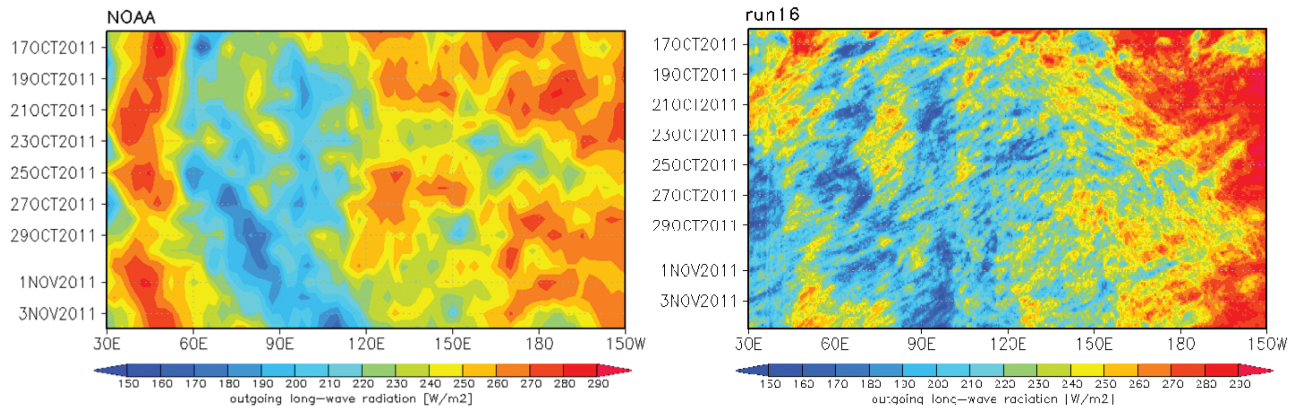

Fig. 3 Longitude-time cross section of the outgoing longwave radiation averaged between 10°S and 10°N. (Left) NOAA OLR data. (Right) NICAM 7-km run.

(DYNAMO) and other research groups (Yoneyama et al. 2013[20]). The primary objective of CINDY2011/DYNAMO was to collect observational data associated with the onset processes of MJO over the Indian Ocean, and deepen our understanding of MJO. Another major purpose was to improve representation/forecasts of MJO in the models. Our research group took part in CINDY2011 from its early planning stage.

The intensive field observation was deployed over the broad tropical domain including the Indian Ocean during October 2011–January 2012. The onsets of the MJO events were observed three times during the intensive observation period (IOP; Yoneyama et al. 2013[20]). It is expected that analyzing the obtained data will bring a breakthrough in the research of the MJO onset. Because the numerical simulation can generate data that is uniform spatially and temporally and is consistent physically, it will be very helpful if high-resolution numerical simulations complement the observation. We run the NICAM with the 7-km and 14-km grid intervals on the Earth Simulator.

To start with, we performed a lot of 14-km mesh runs with different parameter values in a cloud microphysics scheme because NICAM could not simulate the first MJO event in CINDY2011 with its default parameter sets. It should be noted that the “default” setting is different from those used in a successful MJO simulation by Miura et al. (2007[4]). An interesting finding from this sensitivity runs was that the reproducibility of the MJO event by NICAM was strongly sensitive to a few parameters in a microphysics scheme. After setting those parameters to the values in which the behavior of the simulated MJO was only weakly sensitive to small modifications in those parameters, we moved on to the simulations for the data product.

We performed two 7-km mesh runs with different initial and boundary conditions. The first run started from the conditions of 00UTC 16 October 2011 and the other started from those of 00UTC 15 November 2011. Figure 3 shows the longitude-time cross section of the outgoing longwave radiation averaged between 10°S and 10°N in simulations of the first MJO event in comparison with a satellite observation. The onset of the MJO event was reproduced realistically at about 60°E around 26 October (Fig. 3). The slow eastward movement of the packet of the enhanced convective activity was also simulated well. These simulation data will be used to investigate the onset mechanisms of MJO in collaboration with the CINDY2011 observation group.

4. Aquaplanet experiments

Organized meso- to large-scale precipitation systems (PSs) are frequently observed in the tropics. These PSs propagate in the zonal or sometimes meridional directions, making complicated features of equatorial dynamics. However, they are grouped into, at least, three types, when the propagation directions are limited to the zonal direction; (i) eastward-propagating (EP) PSs with speeds of about 15–25 m s^{-1} (e.g., Wheeler and Kiladis 1999[21]), which are called super clusters (SCs), (ii) EP PSs with speeds of less than 10 m s^{-1}, which are called MJO, and (iii) westward-propagating (WP) PSs with similar absolute speeds to SC-like PSs. Compared with the EP PSs such as SCs and MJO, the researches on WP PSs are few. Here, we tried to study the formation of WP PSs. At least, two explanations were made; (A) a WP part of splitting PSs (e.g., Yoshizaki 1991a[22], 1991b[23]) and (B) waves like equatorial Rossby ones or inertial-gravity ones modified by heating (e.g., Wheeler and Kladis 1999[21], Kiladis et al. 2009[24]). In order to argue which explanation is acceptable, the impacts of the propagation property of tropical PSs on the Earth rotation (Ω) were studied, utilizing the aquaplanet simulations using NICAM with a horizontal resolution of 56 km. By setting the Ω with a range between 0–10, where the present Earth rotation is 1, 80-day simulations were conducted with motionless initial conditions. A sea surface temperature (SST) was assumed to be zonally uniform, varying symmetrically about the equator in the meridional direction. For the symmetric components about the equator, such as precipitation and zonal velocity, the EP PSs were more organized than the WP PSs as the Ω increases. However, the propagation speeds of WP PSs ranged between 15–25 m s^{-1}, similarly to those of EP PSs (Fig. 4). That is, the

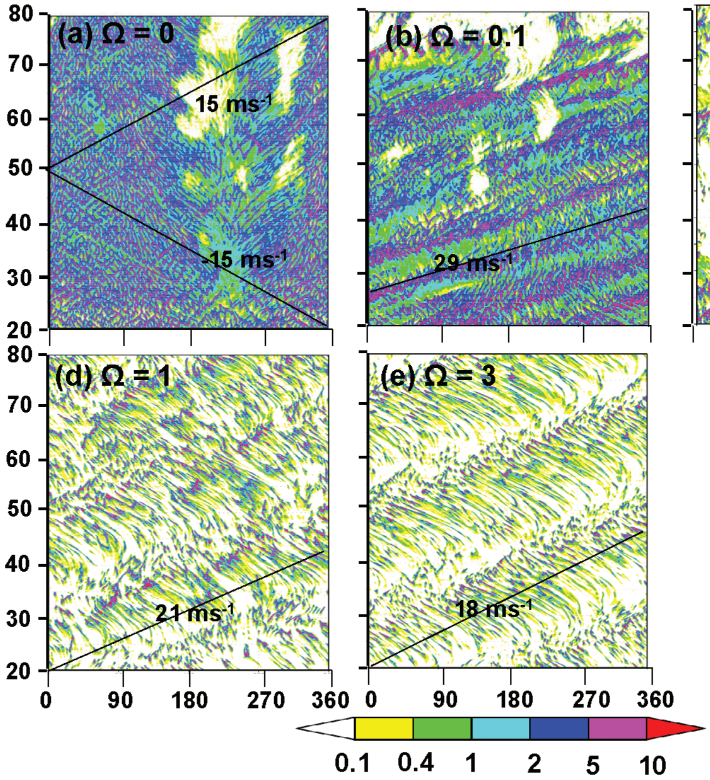

Fig. 4 Longitude - time sections of precipitation (mm h^{-1}) averaged between 3°S and 3°N for the cases of (a) Ω = 0, (b) Ω = 0.1, (c) Ω =0.4, (d) Ω = 1, and (e) Ω = 3. Anomalies from the averages in 20–80 days are plotted.

WP property of PSs was not dependent on the Ω. This indicates that the WP PSs are a WP part of splitting PSs.

5. Summary

The goal of this research project is to evaluate cloud and precipitation processes in the global cloud-resolving model NICAM and to improve these processes in the model. The key issues are: (1) evaluation of the high-resolution simulation results using in-situ and satellite observations, (2) improvement of the model physics in perspective of reliable future climate prediction, and (3) basic understanding of multi-scale mechanisms of organized clouds and precipitation in the tropics. In the FY2012 we engaged in these subjects with global 7-km and 14-km simulations of significant MJO events that occurred in recent years. MJO is a key phenomenon in extended-range weather forecasts because of its significant impacts on global weather and climate (Gottschalck et al. 2010[13]; Zhang et al. 2013[14]). This is timely for us to take part in the ongoing international projects targeted to MJO understanding/forecasts. The simulation data for the CINDY2011/DYNAMO IOP will be evaluated in comparison with in-situ observation data which is released in FY2013. Submission of our the simulation results for the YOTC period to the model inter-comparison project "Vertical Structure and Diabatic Processes of the MJO *A Global Model Evaluation Project"* made unique contribution to the international research community. The data will be used for investigation of multi-scale processes in the MJO initiation, development, eastward propagation (Kikuchi and Wang 2010[25]; Miyakawa et al. 2012[26]) in forthcoming studies. We have been investigated the impacts of physical processes on the simulated global properties of clouds, mainly in terms of cloud-radiation interactions that is important to climate change (Satoh et al. 2012[10]). In the FY2012, impacts of cloud microphysics settings on convection associated with MJO were intensively investigated. A significant finding is that the cloud properties in the simulated MJO events were highly sensitive to a few cloud microphysics parameters. Further investigation is warranted to improve overall aspect of cloud properties in the model, which leads to more reliable future climate prediction. In order to understand basic properties of tropical large-scale convective disturbances including MJO, aquaplanet experiments have been conducted (Satoh et al. 2011[9], 2012[10], Yoshizaki et al. 2012a,b [27, 28]). In the FY2012, propagation properties of convective disturbances were investigated varying the rotation of the Earth, Ω. It was found that the eastward-propagating convective systems were more organized than the westward-propagating counterpart as the Ω increases and that the propagation properties of the westward-propagating systems did not depend on Ω.

CINDY2011: Cooperative Indian Ocean experiment on intreaseaonal variability in the year 2011 (http://www.jamstec.go.jp/iorgc/cindy/index_e.html)
DYNAMO: Dynamics of the Madden-Julian Oscillation (http://www.eol.ucar.edu/projects/dynamo/)
YOTC: Year of Tropical Convection (http://www.ucar.edu/yotc/

index.html)

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全球雲解像モデルを用いた雲降水プロセス研究

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本プロジェクトは、地球上の雲降水プロセスの理解を深め、それらの気候モデルにおける扱いを改善することを目的とする。全球雲解像モデルによる数値計算を研究手法として用いる。平成 24 年度はマッデン・ジュリアン振動（MJO）を主な対象とし、全球雲解像モデル NICAM を用いた以下の２系列の事例計算を行った。(1) 国際モデル比較プロジェクトで採用された Year of Tropical Convection（YOTC）期間の MJO 事例。(2) JAMSTEC が主導した国際集中観測プロジェクト Cooperative Indian Ocean experiment on intreaseaonal variability in the year 2011（CINDY2011）/Dynamics of the Madden-Julian Oscillation（DYNAMO）期間の MJO 事例。(2) において MJO に伴う雲降水現象の雲微物理パラメタに対する系統的な感度実験を行い、いくつかのパラメタに対し高感度であることが分かった。調査の結果に基づいたパラメタ値を用い、(1) (2) において現実的な MJO を再現することができた。MJO を含む熱帯大規模擾乱の基本的な伝播特性を理解するために、地球の回転速度を変えた水惑星数値実験も行った。

キーワード: 雲降水プロセス, 全球雲解像モデル