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

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The goal 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. To achieve this goal, we performed series of numerical experiments using Nonhydrostatic Icosahedral Atmospheric Model (NICAM) with horizontal mesh sizes of 3.5 to 14 km. The major achievements of the FY2013 are as follows: (1) The extended simulation of the tropical convective disturbance, Madden-Julian Oscillation (MJO) for the Cooperative Indian Ocean experiment on intraseasonal variability in the year 2011 (CINDY2011) / Dynamics of the Madden-Julian Oscillation (DYNAMO) intensive observation period was conducted. The results suggested the potential ability of the global 7-km mesh model to reproduce the regulation of the MJO. (2) The impacts of the newly proposed modification in the cloud microphysical scheme on the simulated cloud and precipitation properties were examined by the 3.5-km mesh sensitivity experiments. The results show significant improvements in the statistics of the simulated cloud properties compared with the satellite observations. A pilot study of a near real-time operation of the global cloud-resolving simulation for a field campaign was also conducted.

Keywords: cloud and precipitation processes, global cloud-resolving model

1. Introduction

Recent improvements in observational technology allow high-resolution multi parameter measurements of the earth system. In particular, progress in cloud and precipitation observations by satellite missions is remarkable, which is based on the recognition of its broad impacts on global climate prediction, as well as daily weather forecasts. In JAMSTEC, the *in situ* observations including research cruise (e.g., MISMO, CINDY2011, PALAU project) have been successively conducted. The utilization of the up-to-date observation data in validating the numerical models, and to obtain deeper understanding of the processes are the necessary steps to make model predictions more reliable.

In this project, numerical experiments using Nonhydrostatic Icosahedral Atmospheric Model (NICAM, Satoh et al. 2008[1]) have been conducted to improve our understating of global cloud and precipitation processes. NICAM is unique in explicitly calculating cloud and precipitation processes on the whole globe. The simulations using the Earth Simulator derived innovative research results (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 particular, series experiments targeted to the observation periods of the JAMSTEC field programs were executed and analyzed in

comparison with in-situ observation and satellite data (Satoh et al. 2010[8], 2011[9], 2012[10], 2013[11]).

In the FY2013, one of our targets was the recently observed Madden-Julian Oscillation (MJO; Madden and Julian 1971[12], 1972[13]) events that occurred during the CINDY2011/DYNAMO period (Yoneyama et al. 2013[14]). As the extension from the results obtained by the FY2012, we challenged the problem of the regulation of the MJO convective organization over the Indian Ocean and its eastward migration toward the Western Pacific. Another series of simulations with the 3.5-km mesh size had been performed to investigate TC genesis process that was observed during the field program PALAU2008. The simulation data was also quantitatively evaluated in comparison with satellite data (Hashino et al. 2013[15]). In the FY2013, a new method of cloud microphysics modeling (Roh and Satoh 2014[16]; hereafter, RS2014) was implemented and tested. A pilot study of extended-range forecasts was also conducted during the field campaign PALAU2013.

2. Extended simulation of the CINDY2011/DYNAMO

The international observation campaign CINDY2011/DYNAMO was operated over the Indian Ocean in 2011–2012 to investigate physical processes of the MJO. The MJO is characterized by a large-scale, O(1,000 km) wide, packet of organized cloud systems that moves eastward at an average speed of about 5 m s^{-1}. The MJO accompanies strong winds and severe precipitations, and thus, impacts socioeconomic activity in the tropics especially. Besides its importance on human society, the physical mechanisms of the MJO has not been revealed yet and accurate predictions of the MJO evens are still a challenge. It should be emphasized that JAMSTEC was one of the leading players of the CINDY2011/DYNAMO. Three packets of organized systems of the MJO were observed during

the campaign, each called as "MJO-1", "MJO-2" and "MJO-3", respectively (Yoneyama et al. 2013 [14]).

It is thought that one of the reasons for insufficient understandings of the MJO is due to the difficulty in simulating the MJO by numerical weather prediction and climate models. If the MJO were simulated realistically, we could perform sensitivity studies by changing model parameters to identify the essential processes of the MJO. The simulation of the MJO is also being challenges for a high-resolution atmospheric model. It has been demonstrated that NICAM reproduced the eastward movement from the Indian Ocean to the maritime continent and the initiation of convection on the Indian Ocean (Miura et al. 2007[4]; Oouchi et al. 2009[5]; Miyakawa et al. 2014[17]), but it is still uncertain if NICAM has an ability to reproduce an observed 30–90-day cycle of the MJO events. Thus, using the Earth Simulator, we run NICAM for 60 days that includes MJO-1 and MJO-2 to test whether NICAM simulates MJO-2 or not.

We run NICAM on the Earth simulator, using the horizontal grid spacing of about 7 km. The time increment of the integration was 30 seconds. The initial fields of the atmospheric variables were generated by spatial interpolations of National Centers for Environmental Prediction (NCEP) final analyses. The realistic time evolution of the sea surface temperature was given by spatial and temporal interpolations of National Oceanic and Atmospheric Administration (NOAA) Optimum Interpolation Sea Surface Temperature (OI SST) data. The ocean-mixed layer was not used. The initial date was 16 October 2011 and the duration of the integration was 60 days.

Figure 1 shows the simulated outgoing longwave radiation (OLR). The onset, eastward movement, and decay of the MJO-1 are reproduced marginally. Interestingly, the onset and eastward movement of the MJO-2 are also captured although the timing of the onset is about five days earlier than the observed MJO-2. This result seems to suggest that the cause of the MJO-2 is
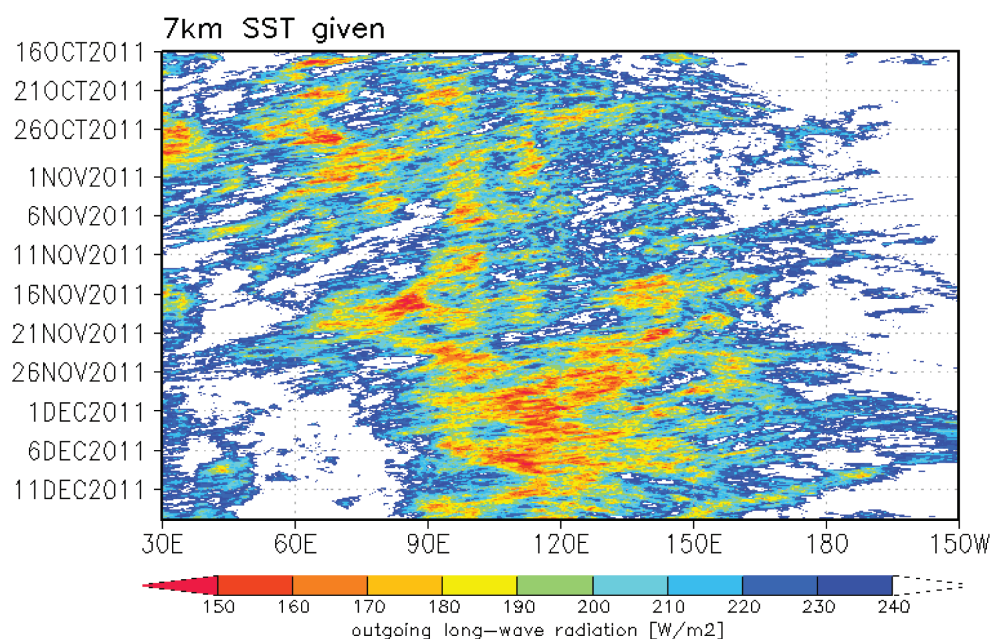

Fig. 1 Longitude-time cross section of outgoing longwave radiation simulated in the 7-km mesh run.

already included somewhere in the initial condition or in the SST time series. We cannot, of course, defy the possibility that the MJO-2 in the simulation is just an artifact. We will perform ensemble runs using the horizontal grid spacing of about 14 km, which is lower than about 7 km and allows us more simulation cases, to test if MJO-2 is a realistic one or not. In addition, sensitivity runs with different SST settings will be performed to investigate impacts of the SST evolution.

3. Evaluation and improvement in cloud microphysics

The clouds play important roles on the energy budget of the atmosphere and precipitation. The evaluation of cloud properties in General Circulation Models (GCMs) and cloud resolving models is important for analysis of the atmosphere and to overcome the limitations of observations. In this project, cloud properties simulated in the global 3.5-km mesh simulation using NICAM have been evaluated using a satellite simulator and model biases were discussed (Satoh
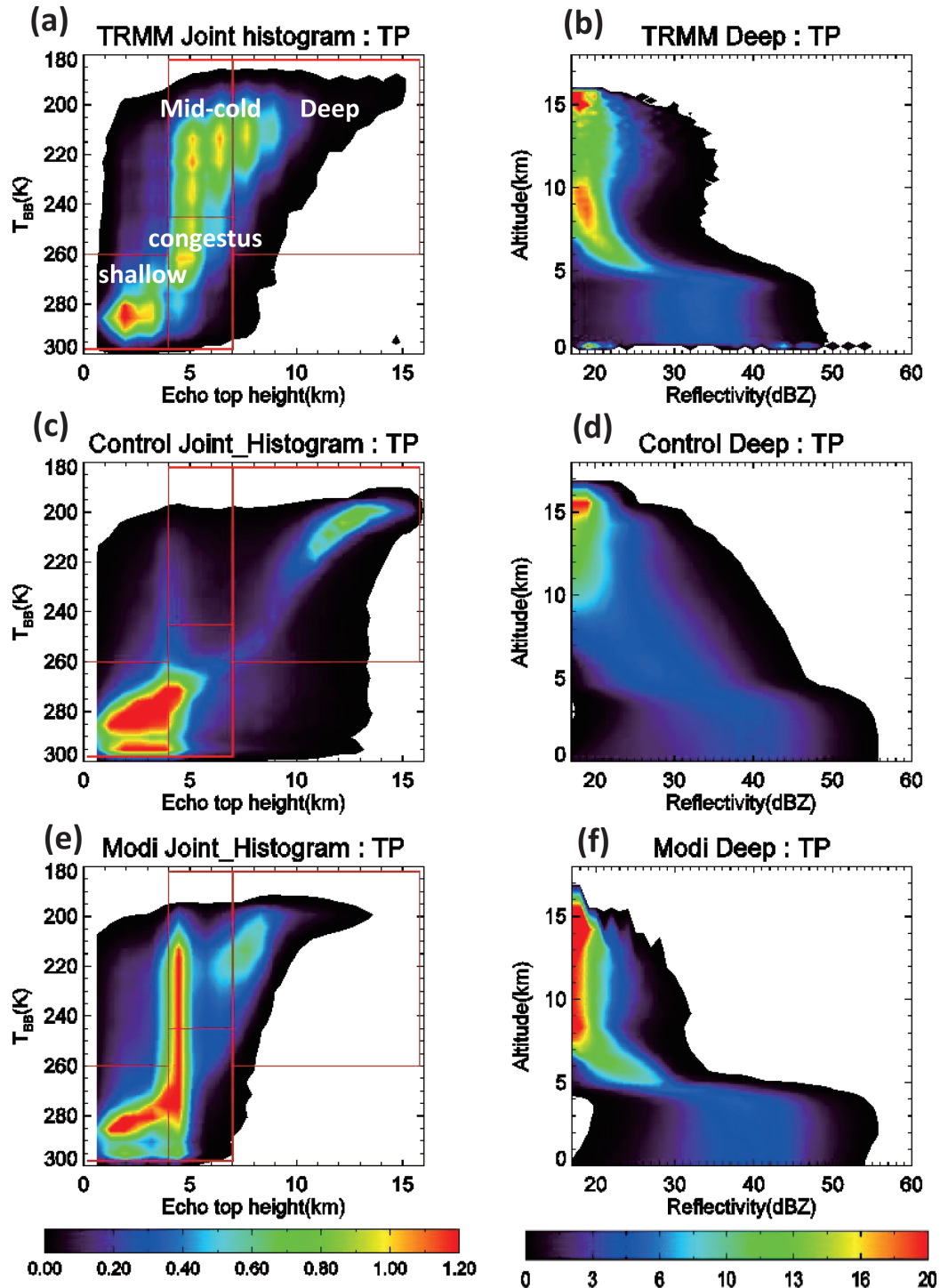

Fig. 2　The ETH–TBB joint histogram (left) and CFADs of deep clouds (right) for the TRMM observation (top), CON (middle), and MODI (bottom) in the whole tropics (20°S–20°N).

et al. 2011[9], 2012[10]; Hashino et al. 2013[15]). Recently, RS2014 proposed a new method to improve the model biases, based on the close examination of the numerical experiments using the regionally stretched version of NICAM (Tomita 2008a[18]) and the Tropical Rainfall Measuring Mission (TRMM) data. Their analysis was limited to the central Pacific domain, and global statistics were uncertain. Therefore, we applied the proposed modifications in the cloud microphysical scheme to the global 3.5-km mesh NICAM, and evaluated their impacts on (1) the echo top height (ETH) – 11μm brightness temperature (TBB) joint histograms and (2) the Contoured Frequency by Altitude Diagrams (CFADs) of deep clouds using the Satellite Data Simulator Unit (SDSU; Masunaga et al. 2010[19]). The experimental settings for the control run (CON) was documented by Satoh et al. (2010[9]) and Hashino et al. (2013[15]). A single moment bulk cloud microphysics scheme NSW6 (Tomita 2008b[20]) was used. The sensitivity tests with the modification by RS2014 (MODI) was conducted exactly the same way as CON except for the cloud microphysics scheme.

Figure 2 shows the ETH–TBB joint histogram and the CFADs of deep clouds for TRMM, CON, and MODI in the whole tropics (20°S–20°N). Deep clouds are defined as the ETH of TRMM higher than 7 km with the TBB lower than 260 K. The observed joint histogram shows the similar structure to those in RS2014 and Matsui et al. (2009[21]) (Fig 2a). Since a large part of the tropics is covered with the ocean, the overall structure of the joint histogram is similar to that of ocean cases in previous studies. The population of shallow precipitation clouds is overestimated in CON with high frequencies above the 10 km ETH, whereas there are few populations of clouds with the 5–7 km ETH and the TBB lower than 245 K (Fig. 2c). MODI reduced the biases of CON in shallow clouds and deep

clouds above the 10 km ETH, and improved the frequencies of congestus clouds (Fig. 2e). The observed CFADs of deep clouds have concentrated frequencies with the range of radar reflectivity between 17 and 23 dBZ above the 5 km altitude (Fig. 2b). The maximum radar reflectivity above the 7 km height is almost 35 dBZ. In CON, widespread distributions of frequencies above the 5 km altitude and the overestimation of average and maximum radar reflectivity of the CFADs of deep clouds are found (Fig. 2b, d). In MODI realistic structure of CFADs is reproduced (Fig. 2b, f). However, maximum radar reflectivity in MODI is 32 dBZ, slightly lower than that in the observation. One of possible reasons for the lower maximum radar reflectivities is the absence of hail category in NSW6. The extreme precipitation in convective systems is often accompanied with large ice particles with high density like hails. Inclusion of hail category may be important to representation of extreme cases. In conclusion, the modified microphysics significantly improved the statistical properties of cloud and precipitation in the model. A satellite simulator and satellite observations are good tools for the evaluation and improvement of microphysics in a global high-resolution model.

4. A 15-day forecast during the PALAU2013

In the FY2013, the field campaign PALAU2013 was operated during May to July. The sounding network was deployed in Palau and Philippines, and on the research vessel Mirai (135°E, 12°N; MR-1303). Week-long near real-time forecasts using the regionally stretched grid version of NICAM have been daily operated during the observation period in support of the field operation. However, the nonuniform grid system is not suitable to extended-range forecasts. Therefore, a 15-day long forecast using the global 14-km mesh grid NICAM was executed for the
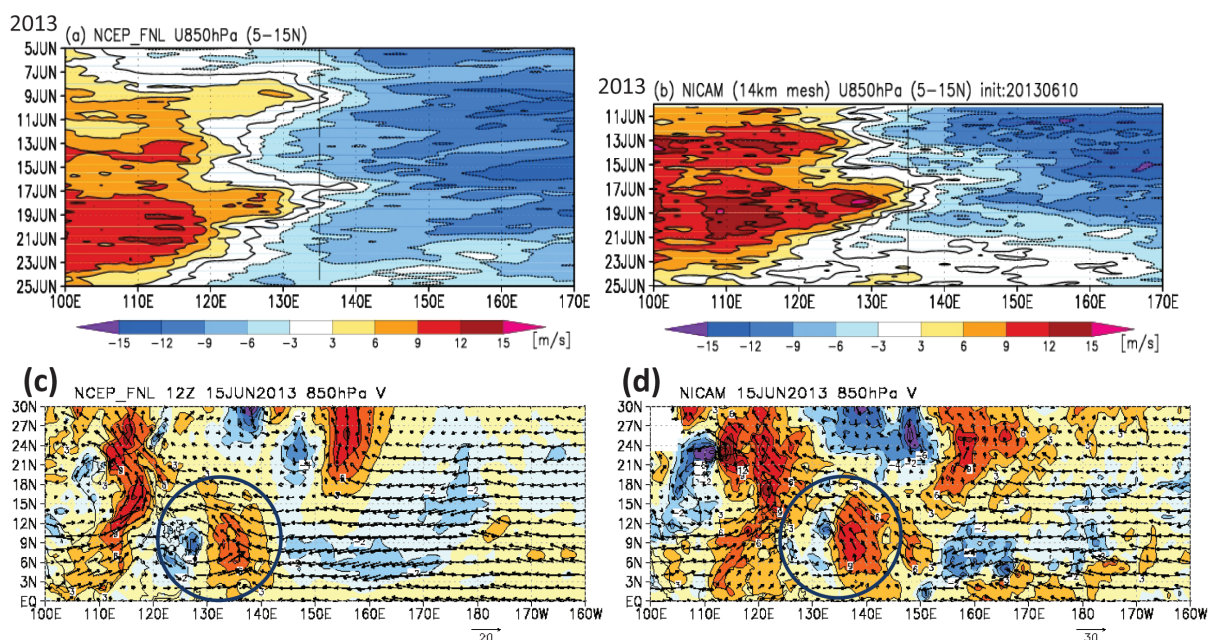

Fig. 3 Time-longitude plots of zonal wind at 850 hPa in (a) NCEP final analyses and (b) the 15-day NICAM forecast, averaged in 5°–15°N. Meridonal velocity (color) and wind vector at 850 hPa on 15 June 2013 in (c) NCEP final analyses and (d) the NICAM forecast.

first time.

Figure 3 show the time-longitude sections of observed and simulated low-level winds. Convective burst associated with the development of typhoon Yagi (TY1303) occurred on 7 June around the observation site, which led to South China Sea (SCS) monsoon onset, as seen in the abrupt acceleration of westerlies (Fig. 3a). After the passage of Yagi, the active period of intraseasonal variability (ISV) set in. The simulation was initialized on 10 June with an intention to gain information on the ongoing atmospheric variations and possible weather events. The forecasts captured the weakening of westerlies due to the inactive period of ISV/MJO in the second half of June (Fig. 3a, b). This suggests the potential ability of the model for subseasonal forecasts of large-scale disturbances, such as ISV or MJO (Miura et al. 2007[4]; Miyakawa et al. 2014[17]). The forecast also reproduced westward-propagating wave disturbances and its development into TY1304 close to the observation site around 17 June (Fig. 3c, d).

Since deterministic forecast has an intrinsic limitation in the predictability of mesoscale weather events, ensemble forecasts using the ES is planned as the next step, as well as the physically based sensitivity tests to understand the multi-scale interaction between convection and large-scale fields, as observed during the PALAU2013 field campaign.

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/)
MISMO: Mirai Indian Ocean cruise for the Study of the MJO-convection Onset
(http://www.jamstec.go.jp/iorgc/mismo/index-e.html)
PALAU: Pacific Area Long-term Atmospheric observation for Understanding of climate change (http://www.jamstec.go.jp/ iorgc/palau/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 25 年度の主な成果として（1）国際集中観測プロジェクト Cooperative Indian Ocean experiment on intraseasonal variability in the year 2011 (CINDY2011) / Dynamics of the Madden-Julian Oscillation (DYNAMO) 期間のマッデン・ジュリアン振動（MJO）を対象とする 7-km 格子を用いた延長計算を行い、MJO サイクルの再現に成功した。（2）新しい雲微物理スキームの改善手法を実装して 3.5-km 格子を用いた感度実験を行い、衛星観測との比較により雲降水特性のバイアスの大幅な軽減を確認した。また、熱帯集中観測を対象とする 15 日間の予測計算を試験的に運用した。

キーワード：雲降水プロセス，全球雲解像モデル