Development of a High-Resolution Coupled Atmosphere-Ocean-Land General Circulation Model for Climate System Studies

Project Representative

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This project consists of developing three models: a CCSR/NIES/FRCGC atmosphere-ocean-land coupled model, a cloud resolving atmospheric general circulation model, and an eddy resolving ocean general circulation model. For the atmosphere-ocean-land coupled model, a cumulus parameterization scheme has been improved with a number of modifications and the scheme finally has produced a better climate and variability of precipitation in almost all aspects than ever. In addition, there has been remarkable progress in a study of gravity waves using a vertically high resolution atmospheric model and satellite observations. For the global cloud resolving model, the seasonal march simulation in 2004 with 14 km and 7 km resolutions has been conducted. The boreal summer climatology and the statistics of onsets of tropical cyclones are in good agreement with observation data. The predictability of MJO in boreal summer has been also examined. For the eddy resolving ocean model, an eddy resolving ocean simulation of the Agulhas Current has been performed and the Natal Pluses, which are a solitary meander in the Agulhas Current, are successfully reproduced. In the Labrador Sea eddy resolving simulation, the location of the deep convection has been improved by increasing the simulation area.

Keywords: atmosphere-ocean-land coupled model, global cloud resolving model, global eddy resolving model

1. Introduction

The mission of this project is to develop advanced climate models which have a capability to explore new arena of climate simulation study by fully utilizing the Earth Simulator. This project started at the beginning of the Earth Simulator operation and three models have been developed: a CCSR/NIES/FRCGC atmosphere-ocean-land coupled model, a cloud resolving atmospheric general circulation model, and an eddy resolving ocean general circulation model. Studies with these three models are compensatory for the realization of a high-performance earth system model. That is, the first model is applicable for a long-term climate simulation with physical parameters revised through simulations by the second and third models.

2. Development of the CCSR/NIES/FRCGC coupled model

There are remarkable progresses in two studies. One is an improvement of cumulus parameterization and the other is studies of gravity waves based on dynamical models and satellite observations.

A new cumulus parameterization was developed last fiscal year. The scheme is characterized by an interactive entrainment rate with a surrounding environment. Early tests of the scheme in an atmospheric general circulation model (GCM) showed promising results in several points. However, several problems were seen such as a large overestimation of the annual precipitation over the western Pacific. This fiscal year, a number of modifications were made for the technical aspects of the parameterization [1]. Results simulated by a coupled GCM show both a better climate and variability of precipitation in almost all aspects. A double intertropical convergence zone weakens in the eastern Pacific and the south Pacific convergence zone is better represented. The seasonal and spatial variation around the maritime continent is greatly improved. Without any

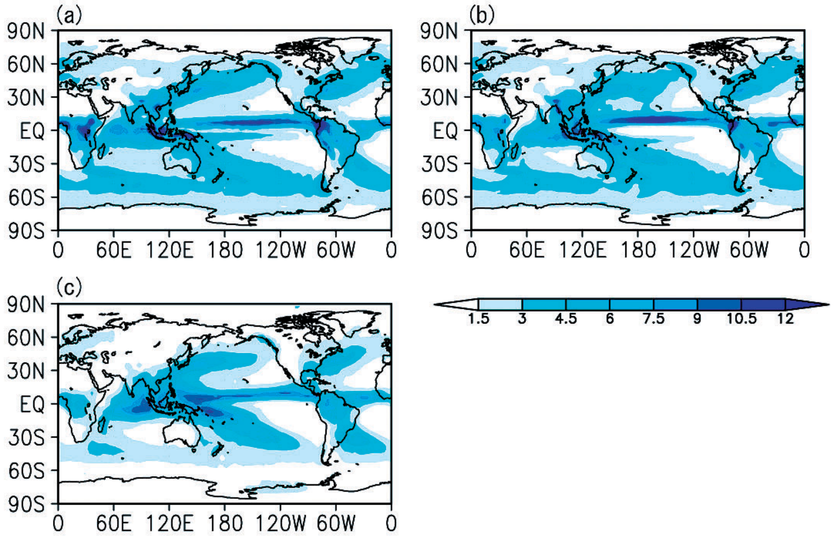

Fig. 1 The annual mean precipitation simulated by MIROC4.1 with (a) the prognostic Arakawa-Schubert scheme, (b) new scheme and (c) observation [mm/day].

empirical triggering schemes, all kinds of equatorial waves such as moist Kelvin waves and Madden-Julian oscillation are reproduced with realistic equivalent depths. This improvement will ensure better performance in global warming projections for the next IPCC report.

Northern Hemisphere mid-latitude wintertime gravity waves were studied using recent COSMIC satellite data launched in April 2006 and T106L60 CCSR/NIES/FRCGC AGCM results. The potential energy of gravity waves is mostly related to the sub-tropical jet stream. A spectral analysis of model data clearly indicated that low ground-based phase speeds of gravity waves interact with the background wind, which results in decreases of potential energy around the 0-10 m/s zonal wind line [2]. The global distribution, sources, and propagation of equatorial trapped waves (EQWs) and 3D-gravity waves are investigated using the AGCM integrated for 20 years [3]. The QBO-like oscillations with periods of 1.5-2 years were simulated well without any gravity-wave drag parameterization. The model well simulated convectively coupled EQWs with relatively realistic equivalent depths. Each EQW generation generally corresponded well with the source of each convectively coupled EQW activity in the troposphere. The propagation of Kelvin waves, MRG waves, and n = 0 eastward-propagating inertia-gravity waves is strongly influenced by the Walker circulation and the phase of the QBO. The distributions of stratospheric PE associated with EQWs are greatly affected by (1) the source distribution, (2) Walker circulation, and (3) QBO phase. EQWs with vertical wavelength ≤ 7 km contribute up to ~30% of total PE ≤ 7 km in the stratosphere. The model results were essentially consistent with recent COSMIC satellite observation data [4]. The COSMIC GPS RO data and the AGCM results shared several characteristics, and the mechanisms of these shared characteristics were well explained by analyzing the AGCM data. Watanabe *et al*. [5] conducted a 3-year integration using a much higher resolution (T213L256) AGCM. Using this model output, Tomikawa et al. [6] focused on a temperature maximum observed in the winter subtropical region around the stratopause and showed the importance of the meridional circulation appearing in the easterly wind of the stratopause semi-annual oscillation (S-SAO). We also investigated the role of 3-D propagating gravity waves and EQW on driving the QBO. They revealed that large-scale gravity waves such as Kelvin waves account for up to 30-50% forcing to drive the QBO in the westerly shear phase. On the other hand, gravity waves with zonal wavenumbers of 42-213 (AGCM with horizontal resolution larger than T42 can not simulate such waves) play crucial roles in driving the QBO in the easterly shear phase.

3. Development of the global cloud resolving atmosphere model: NICAM

In the last year, the Madden-Julian Oscillation (MJO) appeared in December 2006 was successfully simulated by the global cloud resolving model NICAM. However, it is like a short range numerical prediction simulation within about 1 month integration. In this year, we have tried to conduct a longer integration, which includes the seasonal marching for the investigation of reproducibility of basic climatology such as precipitation rate, statistical feature of tropical cyclones, and MJO in the boreal summer. For this purpose, we performed simulations of 6 months with 14 km and of 3 months with 7 km.

Figure 2 shows the obtained precipitation during June-July-August (JJA), comparing with the observational data. For the overall distribution, both of 14 km and 7 km results are in good agreement with the observational data. Although the coarser resolution model (14 km) has a slight bias of precipitation over the Indian Ocean, the higher resolution model (7 km) tends to improve this defect.

Figure 3 shows the tracking path of tropical cyclone for each month, which was analyzed from the 14 km simulation result and Table 1 shows the number of onsets of tropical cyclones for each month and each region. Although there is difference between observation and simulation results if we

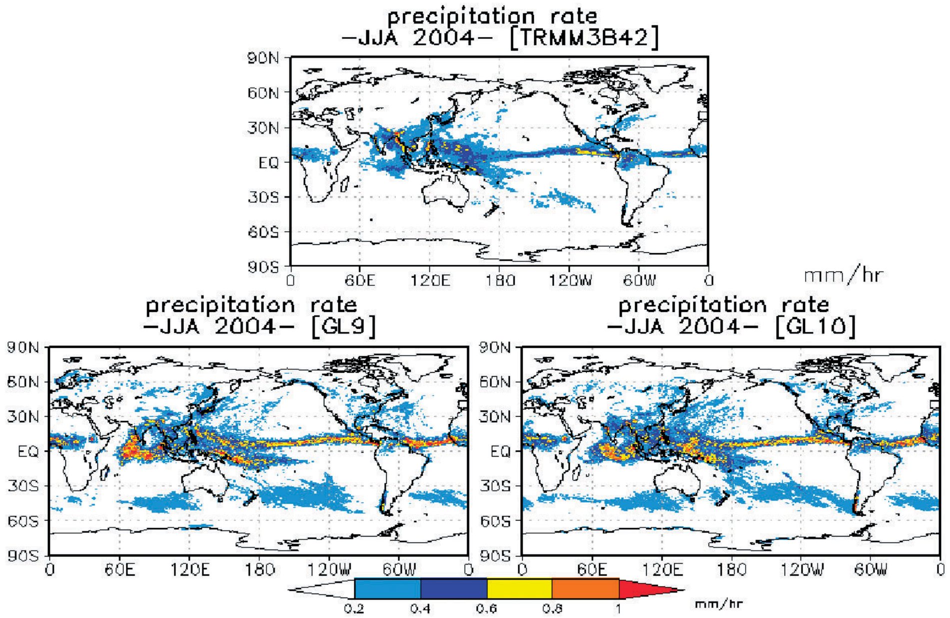

Fig. 2 Comparison of the precipitation patterns in JJA (June-July-August) / 2004. TRMM 3B42 observational results (Top). The simulation result with 14 km meshes (Bottom left). The simulation result with 7 km meshes (Bottom right).

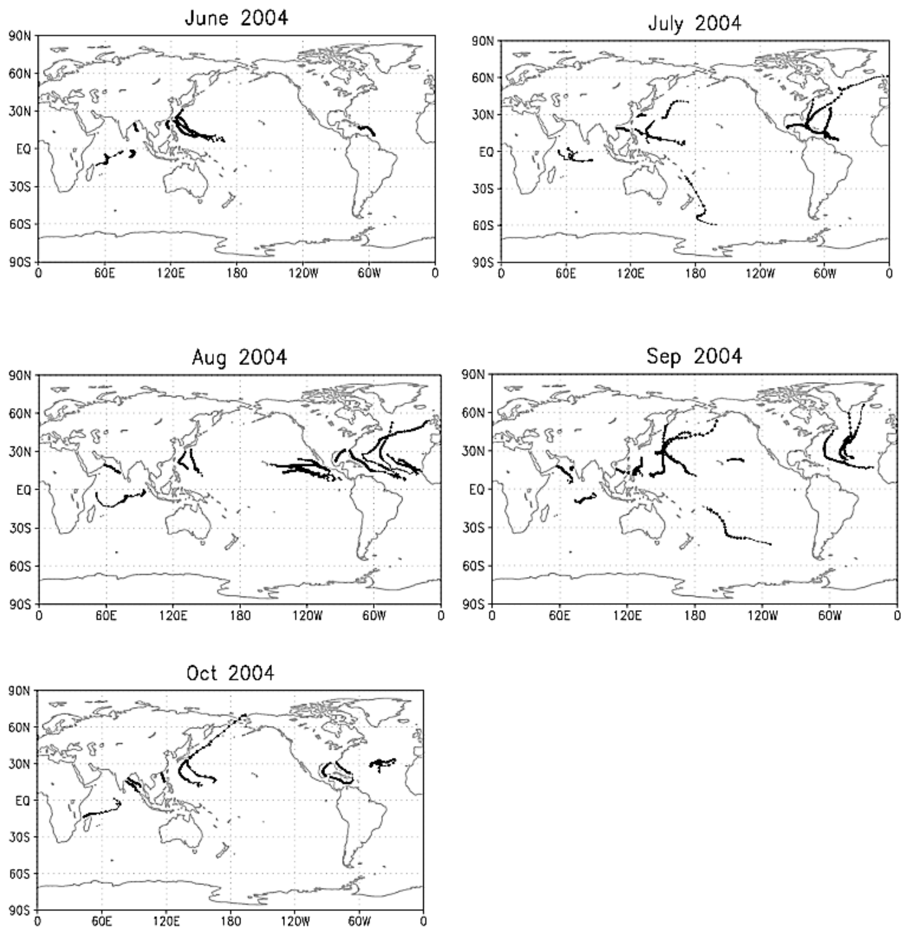

Fig. 3 Tracking of tropical cyclones for each of months obtained from the 14 km mesh simulation.

Table 1 Number of onset of tropical cyclones for each month and each region. NI: Northern Indian ocean, SI: Southern Indian ocean, SP: Southern Pacific ocean, WP: Western Pacific ocean, EP: Eastern Pacific ocean, A: Atlantic oceank, G: Globe.

	NICAM result							UNISYS							Rate (NICAM /UNISYS)
	NI	SI	SP	WP	EP	A	G	NI	SI	SP	WP	EP	A	G	
June	3			4	1		8	1	2	0	4	0	0	7	1.1
July	2		1	4		7	14	0	0	0	2	6	1	9	1.5
Aug	2			3	4	6	15	0	0	0	10	5	8	23	0.7
Sep	5		1	4	1	3	13	0	1	0	3	1	5	10	1.3
Oct	3			3		5	11	1	1	0	4	3	2	11	1
	15		2	18	6	21	61	2	4	0	23	15	16	60	

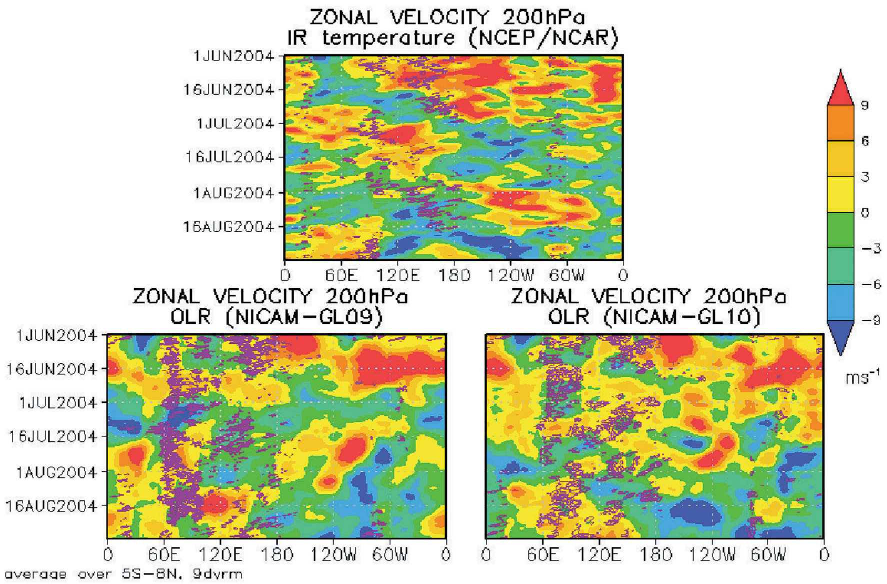

Fig. 4 Hovmoller diagram of zonal velocity at 200 hPa (Color) and Outgoing Longwave Radiation (Magenta). NCEP/NCAR reanalysis data (top), NICAM 14 km mesh result (bottom left), and NICAM 7 km mesh result (bottom right).

turn our attention to local numbers, the global feature of simulations fairly agrees with the observation.

Finally, Figure 4 shows the Hovmoller diagram of zonal velocity at 200hPa and Outgoing Longwave Radiation. The first phase of MJO was well reproduced both in 14 km and 7 km simulations. However, in the second phase, the onset timing of simulated MJO is off the observation. This may be related to limitation of predictability of MJO. However, more investigation is needed by performing a lot of cases.

4. Development of the eddy resolving ocean model

An eddy resolving ocean simulation of the Agulhas Current system is performed to investigate roles of eddy in the global thermohaline circulations. The Agulhas rings contribute significantly to the transport of the warm and saline Indian Ocean water into the South Atlantic. This inter-ocean exchange is a crucial part of the warm water route for the renewal of North Atlantic Deep Water. The Agulhas rings are created the intermittent occusion of the Agulhas restroflection loop. Natal Pulses have been suggested as triggering mechanism for this prosses. Figure 5 shows a reproduced Natal Pulse in this eddy resolving simulation. The features of the Natal Pulses are consistent with observations in the following respects: they are generated at the Natal Bight when anticyclonic eddies from the Mozambique Channel come, move downstream along the Agulhas Current at speeds about 20 km per day and grow in its horizontal size as they move.

The Labrador Sea is one of a few sites of the world ocean where open ocean deep convection occurs and this deep con-

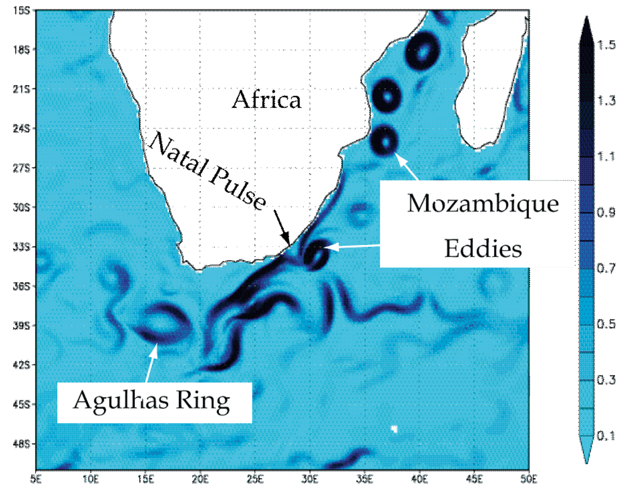

Fig. 5 Sea surface velocity (m/s) around South Africa. A Natal Pulse is found as a cyclonic meander in the Agulhas Current, associated with a Mozambique eddy.

vection causes the large loss of heat to the atmosphere and poleward heat transport by the ocean. The water mass transformation caused by the convection generates the meridional overturning circulation and, hence, the convection plays an important role in the global climate system. Eddies caused by the boundary current in the Labrador Sea is thought to be the dominant process regulating the convection process. Therefore, it is inevitable to perform eddy resolving simulation to study the effects of eddies to this convection process. Although we constructed an eddy resolving Labrador Sea model last year, the location of convection was poorly reproduced. This year, we extended the simulation area and found that the location of the convection is improved substantially. Figures 6 shows the winter mixed layer depth (MLD) obtained by the (a) old and (b) new model. The MLD is defined as depth at which potential density is 0.01 kg/m^3 heavier than the surface and this MLD represents evidence of the convection. The winter MLD of the new model reaches more than 1000 m in the western to the central part of the Labrador Basin and it is in agreement with the typical feature of observations.

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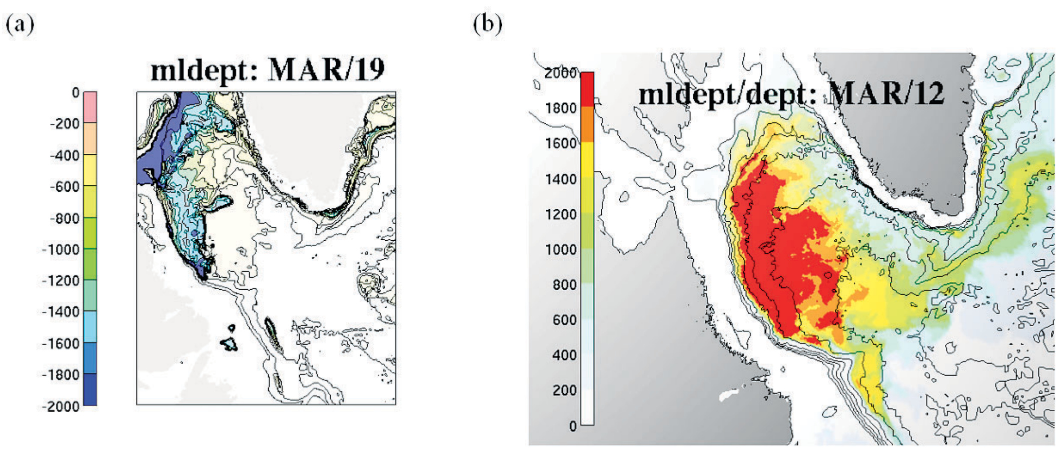

Fig. 6 Distribution of March-average mixed layer depth over the Labrador Sea; (a) the old model, (b) the new model.

気候システム研究のための
高精度大気・海洋・陸面結合大循環モデルの開発

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開発を継続していたCCSR/NIES/FRCGC大気海洋陸面結合モデル積雲対流パラメタリゼーションスキームを改良した。新しいスキームを採用したことで、結合モデルの降水の気候値とその時空間変動が、あらゆる点において、従来のスキームよりも画期的に改善されることが分かった。熱帯域でも、ダブルITCZの傾向が弱まり、SPCZ に伴う降水が良く表現され、そして、海洋大陸周辺の降水の変動が改善された。加えて、鉛直方向を高解像にした大気モデルで、従来の重力波抵抗パラメタリゼーションをとりはずして、重力波をモデルの中で陽に取り扱う実験では、衛星観測の比較を行い、成層圏での準二年周期変動(QBO)と半年周期変動(SAO)の維持形成メカニズムについて考察した。全球雲解像大気大循環モデルについては、2004年をターゲットとした季節進行実験を行った。降水量の気候値をTRMMの衛星データと比較したところ、インド洋に多少の正のバイアスがあるものの、概ね再現されていることが分かった。また、6月から10月にかけての熱帯低気圧の発生発達を詳細に調べた。地域差はあるものの全球では概ね妥当な個数が再現されていた。一方、マッデンジュリアン振動の再現性についても調べた。初期フェーズのMJOについてはよく合うものの2番目以降のMJOについてはタイミングがずれており、今後MJO予測可能性の研究はさらに推し進める予定である。渦解像海洋モデルについてはアフリカ南部アガラス海流の渦解像シミュレーションを実施し、アガラス海流の孤立した蛇行であるナタール・パルスを再現した。また北大西洋のラブラドル海の渦解像シミュレーションでは、従来のラブラドル海近辺の領域モデルから計算領域を広げることにより、ラブラドル海での対流位置が顕著に改善されることが明らかになった。

キーワード：大気海洋陸面結合モデル，全球雲解像モデル，全球渦解像モデル