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IMPACTS OF CUMULUS PARAMETERIZATION AND RESOLUTION ON THE MJO SIMULATION

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Abstract: Madden-Julian Oscillations (MJO) in six integrations using an AGCM with different cumulus parameterization schemes and resolutions are examined to investigate their impacts on the MJO simulation. Results suggest that the MJO simulation can be affected by both resolution and cumulus parameterization, though the latter, which determines the fundamental ability of the AGCM in simulating the MJO and the characteristics of the simulated MJO, is more crucial than the former. Model resolution can substantially affect the simulated MJO in certain aspects. Increasing resolution cannot improve the simulated MJO substantially, but can significantly modulate the detailed character of the simulated MJO; meanwhile, the impacts of resolution are dependent on the cumulus parameterization, determining the basic features of the MJO. Changes in the resolution do not alter the nature of the simulated MJO but rather regulate the simulation itself, which is constrained by cumulus parameterization schemes. Therefore, the vertical resolution needs to be increased simultaneously. The vertical profile of diabatic heating may be a crucial factor that is responsible for these different modeling results. To a large extent, it is determined by the cumulus parameterization scheme used.

Key words: climatology; MJO simulation; GCM; cumulus parameterizations; resolution

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1 INTRODUCTION

The tropical intraseasonal oscillation or the Madden-Julian Oscillation (MJO) is a dominant mode of variability in the tropical atmosphere [1, 2]. At present, performances of the Atmosphere General Circulation Models (AGCM) in simulating the MJO are attracting more and more scientists' attention. One cause is that the present numerical weather prediction indicates that the forecast errors from the intraseasonal oscillation contribute largely to the whole forecast [3]. Errors from the simulation of intraseasonal oscillation can take up 30% – 40 % of the total errors in an AGCM [4]. The other cause may be the fact that most AGCMs still have difficulties in simulating the observed MJO features to date even with regard to its most prominent features, for example, the intraseasonal timescales (a period of approximately 30-60 days) and eastward propagation [5, 6]. Two factors are regarded important for simulating the MJO. One is the cumulus parameterization scheme implanted in the AGCM, which is also taken as the core factor. The other factor is a model's resolution. With regard to its impact on the MJO simulation, many studies were carried out but yielded inconsistent results [7 - 9]. In terms of the sensitivity of the AGCM-simulated MJO to convective parameterization, many studies have been conducted using a single model with different convective parameterizations [10-13]. All these studies showed that the simulated MJO is significantly affected when the convective parameterization scheme is changed. But there are still some uncertainties regarding what processes or factors in convective parameterization schemes influence the MJO simulation by AGCM.

In most previous studies, the cumulus parameterization and the resolution are usually separated from each other when their impacts on the MJO simulation are considered, whereas the sensitivity of MJO simulations to cumulus schemes may be modified by the model's resolution; similarly, the

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impacts of the model's resolution on the MJO simulation may be, to a certain extent, sensitive to the cumulus parameterization as well.

Therefore, in the present paper, the MJO, simulated by an AGCM with different cumulus parameterization schemes and different resolutions, is examined to investigate their impacts on MJO simulations. Section 2 provides information on the model, experimental design and verification data. Modeling results are presented and analyzed in Section 3. Conclusions are presented in the last section.

2 MODEL, INTEGRATIONS AND OBSERVATIONAL DATA

The model used in this study is the Spectral Atmospheric Model of the Laboratory for Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG) of Institute of Atmospheric Physics (IAP) of Chinese Academy of Sciences (hereafter referred to as the SAMIL model). The parameterization package includes the Edwards scheme for radiation [14], the Slingo scheme for cloud diagnosis [15, 16], and the Hottslag and Boville scheme for the boundary layer [17]. A simplified version of the Simple Biosphere model (SIB) model [18] is used to simulate the land surface in the model. Fuller details on the formulation of SAMIL are available in Wang et al. [19] and Wang et al [20].

Three different convective schemes, MCA [21], Zhang and McFarlane scheme [22] and Tiedtke scheme [23], and three different resolutions, $R_{15}L_9$, $R_{42}L_9$ and $R_{42}L_{26}$, are applied in this model. Six integrations are conducted in this study with these different cumulus schemes and different resolutions. Detailed parameter information of the six integrations is listed in Table 1.

Table 1 List of integrations.

n	scheme	resolution	Cumulus scheme	Horizontal resolution (Long.×Lat.)/	Vertical resolution (layers)
1	$R_{15}L_9$_M	$R_{15}L_9$	MCA	7.5×4.5	9
2	$R_{42}L_9$_M	$R_{42}L_9$	MCA	2.812 5×1.67	9
3	$R_{42}L_9$_ZM	$R_{42}L_9$	Zhang-McFarlan e	2.812 5×1.67	9
4	$R_{42}L_{26}$_M	$R_{42}L_{26}$	MCA	2.812 5×1.67	26
5	$R_{42}L_{26}$_ZM	$R_{42}L_{26}$	Zhang-McFarlan e	2.812 5×1.67	26
6	$R_{42}L_{26}$_T	$R_{42}L_{26}$	Tiedtke	2.812 5×1.67	26

Six models are integrated for a period of 12 years from 1 January 1978 to 31 December 1989, which are forced with monthly SSTs and sea ice data provided by the Program for Climate Model Diagnosis and Intercomparison (PCMDI). Ignoring the first year of integration, we diagnosed the model dataset covering the 11 years from January 1979 to December 1989. The validation data were extracted from NCEP/NCAR reanalysis [24] and the Climate Prediction Center (CPC) merged with precipitation data (CMAP) [25].

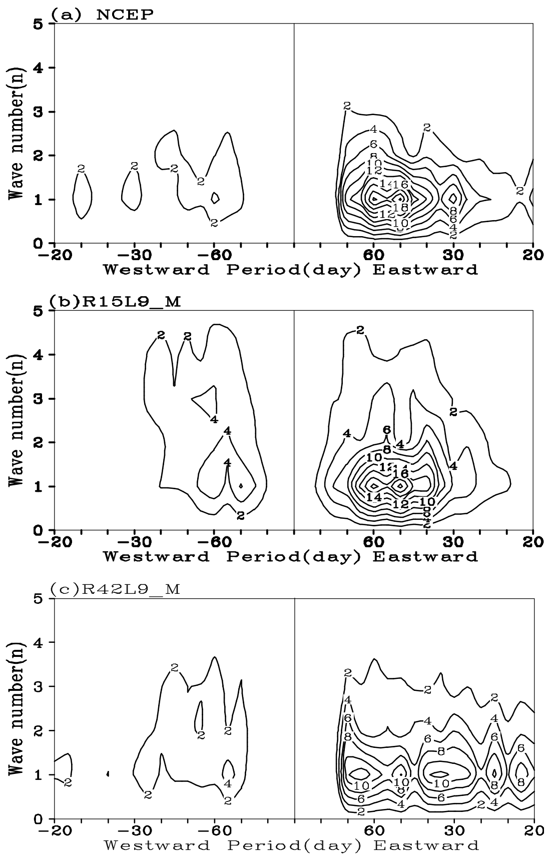
3 MODELING RESULTS

3.1 *Mean space-time spectra*

Characteristic scales and periods of propagating components in the intraseasonal variability are investigated using space-time power spectra. Fig.1 shows spatial-temporal spectra of 850-hPa zonal winds averaged between 10°S and 10°N from the NCEP reanalysis and the six simulations. The NCEP 850-hPa zonal wind spectrum, as shown in Fig.1a, is dominated by power at wavenumber 1 and eastward propagation with periods of 30 – 70 days, and the spectrum of westward propagation is much weaker than that of eastward propagation. Among the six modeling results (Fig.1b-g), three applying the MCA cumulus schemes, $R_{15}L_9$_M, $R_{42}L_9$_M, and $R_{42}L_{26}$_M, simulate spectral features similar to those by NCEP reanalysis (Fig.1b, c, e), with the strongest power in the eastward propagating disturbances on the intraseasonal time scale, though individual spectra are very different from each other due to the difference in resolution. Inter-comparisons of these three modeling results have the following two suggestions. Firstly, improving the model's horizontal resolution from R15 to R42 while keeping relatively low vertical resolution (L9) may lead to many higher frequency disturbances (<30 days) being introduced in the modeling results at the intraseasonal scale; secondly, further increasing the vertical resolution from 9 layers to 26 layers could weaken these high frequency signals and then get spectrum features more similar to those by NCEP reanalysis. Another three simulations, $R_{42}L_{9}$_ZM, $R_{42}L_{26}$_ZM and $R_{42}L_{26}$_T, do not produce reasonable spectral features (Fig.1d, f, & g). The power produced by $R_{42}L_{9}$_ZM is much smaller relative to that by NCEP reanalysis and the eastward propagating components are comparable to the westward ones. Increasing the vertical resolution from $R_{42}L_{9}$_ZM to $R_{42}L_{26}$_ZM does not improve the spectral features and the power of westward propagating wave is somewhat larger than that of the eastward propagating, contrary to that of NCEP reanalysis. Similar results are also produced by $R_{42}L_{26}$_T.

3.2 *MJO life evolution*

Investigating more detailed structure of the MJO needs an appropriate composite method. Following Maloney and Hartmann[26], a MJO index is constructed by applying Empirical Orthogonal Function (EOF) analysis to the time series of tropical mean (10°S – 10°N) 30-60 day band-passed filtered 850-hPa zonal winds and then the leading / lagging correlation between time series (PCs) of the leading two EOFs is analyzed. Results show (Figure omitted) that similar lagging correlation between the PC1 and PC2 relative to NCEP reanalysis are well simulated by three of the models, $R_{15}L_{9}$_M, $R_{42}L_{9}$_M and $R_{42}L_{26}$_M, and then the three MJO indexes, acting as a linear combination of the PC1 and PC2, can be defined from NCEP reanalysis. These three models are respectively as



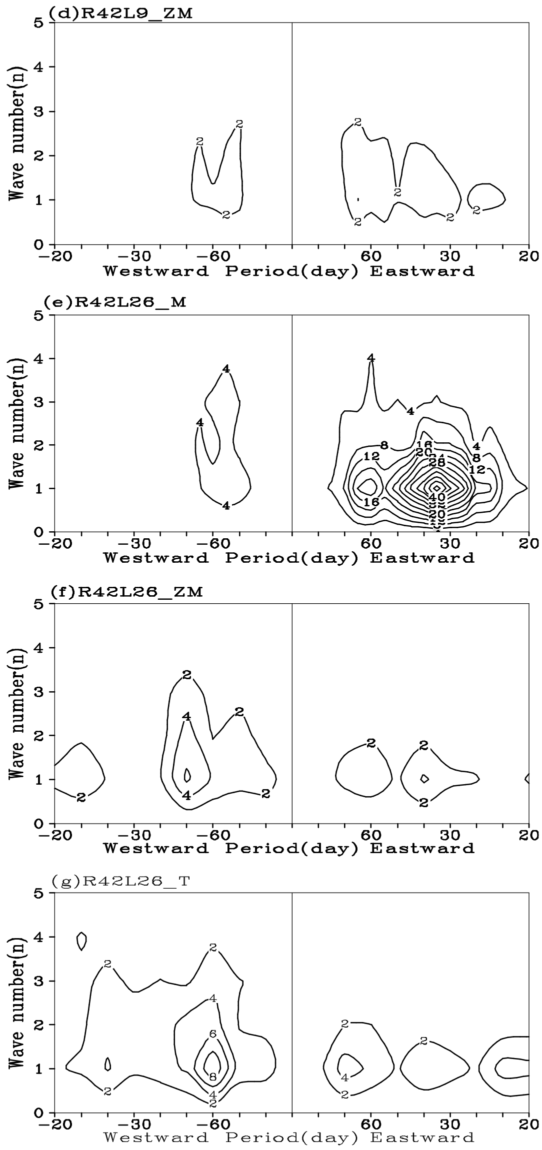


Fig.1 Mean Space-time power spectra of 850-hPa zonal winds averaged at 10°S – 10°N from NCEP reanalysis and the six integrations ($m^2\ s^{-2}$). The vertical axis denotes zonal wavenumbers and the horizontal axis represents the period with positive (negative) values representing the eastward (westward) propagating wave. The contour interval is 2 $m^2 s^{-2}$s.

follows, where t is the time in days.

NCEP：index 1(t)=PC1(t)＋PC2(t＋11)

$R_{15}L_{9}$_M：index 2(t)=PC1(t)＋PC2(t－10)

$R_{42}L_{9}$_M：index 3(t)=PC1(t)＋PC2(t＋9)

$R_{42}L_{26}$_M：index 4(t)=PC1(t)＋PC2(t＋8)

Structures and evolution of the variables associated with the MJO are studied (Figure omitted). These variables include precipitation, 850-hPa wind and 1000-hPa divergence. Here, 30-60 day filtered data has been averaged between 10°S and 10°N and then are regressed against the previously defined MJO index for

NCEP reanalysis and $R_{15}L_9$_M, $R_{42}L_9$_M and $R_{42}L_{26}$_M, and lastly regressed against the PC1 for other three simulations.

NCEP reanalysis show (Figure omitted) that the initial MJO convection appears over the Indian Ocean and then propagates eastward into central-western Pacific with amplified amplitude and then weakens and disappears when crossing the dateline. MJO convection is dominated mainly by low-level westerly anomalies, particularly over the west Pacific. Convergences in the planetary boundary layer are prior to MJO convection (not shown) that has been considered playing important roles in maintaining the eastward propagation of MJO. $R_{15}L_9$_M simulates evolutions of MJO convection and low-level winds similar to the observation; but contrary to the reanalysis, easterly anomalies at the leading edge of the rainfall dominate the low-level inflow (Figure omitted). Meanwhile, it is clear that 1000-hPa divergences are slightly prior to MJO convection, which is similar to but not so significant as NCEP results. Compared to $R_{15}L_9$_M, the MJO convection simulated by $R_{42}L_9$_M is somewhat noisy and unsystematic and similar systematic errors in $R_{15}L_9$_M can also be seen in $R_{42}L_9$_M with precipitation anomalies mainly lying in anomalous easterlies over the Pacific. The MJO precipitation and 1000-hPa convergence in $R_{42}L_{26}$_M, have much clearer structure, especially in the Pacific, indicating a more systematic coupling between the circulation and convection that results from the improvement of the model's vertical resolution. For $R_{42}L_9$_ZM, no eastward propagating signals can be seen in both 850-hPa wind and precipitation and 1000-hPa convergences are much weaker than observations. Intraseasonal signals produced by both $R_{42}L_{26}$_ZM and $R_{42}L_{26}$_T, including precipitation, low-level wind and divergence in the planetary boundary layer, show weak westward propagation consistent with the previous space-time analysis.

3.3 *Vertical profile of diabatic heating*

The heating profile has been hypothesized to be important for the MJO simulation [27]. It can be seen from diabatic heating profiles simulated by the six integrations (figure not shown) that the three models, $R_{15}L_9$_M, $R_{42}L_9$_M and $R_{42}L_{26}$_M, which use the MCA scheme and well simulate the MJO, also produce similar vertical heating profiles with a common feature, i.e. these profiles all peak near the middle and lower troposphere and show a strong vertical gradient in the troposphere. Except for these common features, modifications of the heating profile due to changes in resolution can also be seen. The $R_{15}L_9$_M and $R_{42}L_9$_M, with the same vertical resolution and different horizontal resolution, produce similar vertical structure of the diabatic heating. But the improvement in vertical resolution significantly modifies the heating profile. As shown in the results of $R_{42}L_{26}$_M, the second heating peak in $R_{42}L_9$_M disappears. In contrast, the other three integrations, $R_{42}L_9$_ZM, $R_{42}L_{26}$_ZM and $R_{42}L_{26}$_T, which fail to simulate characteristic features of MJO, also produce similar diabatic heating. One feature is that the heating is very weak; the other is that the heating profile shows a nearly uniform heating rate with height throughout the troposphere, and the height of maximum heating is much higher (200 – 300 hPa). For the ZM scheme, increasing the vertical resolution does not change the vertical structure of the heating. Study by Li [27] suggests that the maximum heating over the middle and lower troposphere can excite an unstable mode similar to the observed tropical 30-60 day oscillation. And his results are also reproduced by a sensitive experiment using an AGCM in our recent study [28]. The three simulations that produced the maximum heating at these levels of the troposphere using the MCA scheme also well simulated the most significant characteristics of the MJO, i.e. the intraseasonal time scales and eastward propagation.

For analyses of other aspects, refer to the Chinese edition of the journal.

4 CONCLUSIONS

Six integrations with different cumulus schemes and resolutions are conducted using an AGCM to investigate the impacts of MJO simulation on cumulus parameterization and model resolution. Some conclusions are as follows.

(1) Both resolutions and cumulus parameterizations can affect the MJO simulation but with different roles. Cumulus parameterization determines the basic ability of the AGCM in simulating the MJO and main characteristics of the simulated MJO. With identical physical parameterizations, there are no essential differences among simulated MJOs when resolutions are changed, but detailed characters of simulated MJOs can be significantly modulated, whereas the modulation is dependent on the cumulus parameterization.

(2) When a cumulus parameterization scheme can capture some most significant features of MJO, such as the intraseasonal timescales and eastward propagation, increasing the resolution can further improve the detailed features of simulated MJO. But it is noted that increasing the horizontal resolution is also required with the increase of the vertical resolution, because increasing the horizontal resolution alone is likely to introduce many higher frequency (<30days) and small scale noises in the simulated MJO, leading to much

sporadic looks of the MJO. Increasing the resolution has little effect on the simulated MJO when a cumulus parameterization scheme cannot produce the most basic features. Thereby, increasing the resolution based on improved performance of the cumulus parameterization scheme can further improve the ability of an AGCM to simulate reasonable MJO.

(3) The vertical profile of diabatic heating is perhaps a crucial factor that influences the MJO simulation through an AGCM. The diabatic heating profile is, to a large extent, determined by cumulus parameterization schemes. Changes in the horizontal resolution have little impacts on the heating profile, but those in the vertical can remarkably modify vertical structures of the diabatic heating and further modulate the simulated MJO.

REFERENCES:

[1] MADDEN R A, JULIAN P R. Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific [J]. J. Atmos. Sci., 1971, 28: 702-708.

[2] MADDEN R A, JULIAN P R. Description of global scale circulation cells in the tropics with 40-50 day period [J]. J. Atmos. Sci., 1972, 29: 1109-1123.

[3] JONES C, WALISER D E, SCHEMM J K, et al. Predication skill of the Madden-Julian Oscillation in dynamical extended range forecasts [J]. Climate Dyn., 2000, 16: 273-289.

[4] LI C Y, JIA X L, DONG M. Numerical simulation and comparison study of the atmospheric intraseasonal oscillation. [J]. Acta Meteor. Sinica, 2007, 21(1): 1-8.

[5] SLINGO J M, SPERBER K R, BOYLE J S, et al. Intraseasonal oscillation in 15 atmospheric general circulation models: Results from an AMIP diagnostic subproject [J]. Climate Dyn., 1996, 12: 325-357.

[6] SPERBER K R. Madden-Julian variability in NCAR CAM 2.0 and CCSM2.0 [J]. Climate Dyn., 2004, 23: 259-278.

[7] DUFFY P B, GOVINDASAMY B, IORIO J P, et al. High-resolution simulations of global climate I: Present climate [J]. Climate Dyn., 2003, 21: 371-390.

[8] INNESS P M, INNESS P M, WOOLNOUGH S J, et al. Organization of tropical convection in a GCM with varying vertical resolution; implications for the simulation of the Madden-Julian Oscillation [J]. Climate Dyn., 2001, 17: 777-793.

[9] JIA Xiao-long, LI Chong-yin, LING Jian, et al. Impacts of the GCM's Resolution on the MJO Simulation [J]. Adv. Atmos. Sci., 2008, 25(1): 139-156.

[10] WANG W, SCHLESINGER M E. The dependence on convection Parameterization of the tropical intraseasonal oscillation simulated in the UIUC 11-layer atmospheric GCM [J]. J. Climate, 1999, 12(5): 1423-1457.

[11] MALONEY E D, HARTMANN D L. The sensitive of intraseasonal variability in the NCAR CCM3 to changes in convection parameterization [J]. J. Climate, 2001, 14(9): 2015-2034.

[12] RAJENDRAN K, RAVI S, NANJUNDIAH, et al. Comparison of seasonal and intraseasonal variation of tropical climate in NCAR CCM2 GCM with two different cumulus schemes [J]. Meteor. Atmos. Phys., 2002, 79(1): 57-86.

[13] LIU P, WANG B, SPERBER K R, et al. MJO in the NCAR CAM2 with the Tiedtke convection scheme [J]. J. Climate, 2005, 18(15): 3007-3020.

[14] EDWARDS J M, SLINGO A. Studies with a flexible new radiation code I：Choosing a configuration for a large-scale model [J]. Quart. J. Roy. Meteor. Soc., 1996, 122: 689-719.

[15] SLINGO J M. A cloud parameterization scheme derived from GATE data for use with a numerical model [J]. Quart. J. R. Meteor. Soc., 1980, 106: 747-770.

[16] SLINGO J M. The development and verification of a cloud prediction scheme for the ECMWF model [J]. Quart. J. Roy. Meteor. Soc., 1987, 113: 899-927.

[17] HOLTSLAG A A M, BOVILLE B. Local versus nonlocal boundary-layer diffusion in a global climate model [J]. J. Climate, 1993, 6(10): 1825-1842.

[18] XUE Y, SELLERS P J, LINTER J L, et al. A simplified biosphere model for global climate studies [J]. J. Climate, 1991, 4(3): 345-364.

[19] WANG Zai-zhi, WU Guo-xiong, LIU Ping, et al. The development of GOALS/LASG AGCM and its global climatological features in climate simulation I: Influence of horizontal resolution [J]. J. Trop. Meteor., 2005, 21(3): 225-237.

[20] WANG Zai-zhi, YU Ru-cong, WANG Peng-fei, et al. The development of GOALS/LASG AGCM and its global climatological features in climate simulation II: the increase of vertical resolution and its influence[J]. J. Trop. Meteor., 2005, 21(3): 238-247.

[21] MANABE S, SMAGORINSKY J, STRICKLER R F. Simulated climatology of general circulation model with a hydrologic cycle [J]. Mon. Wea. Rev., 1965, 93(12): 769-798.

[22] ZHANG G J, MCFARLANE N A. Sensitivity of climate simulation to the parameterization of cumulus convection in the Canadian Climate Centre General Circulation Model [J]. Atmos.-Ocean, 1995, 33: 407-446.

[23] TIEDTKE M. A comprehensive mass flux scheme for cumulus parameterization in large-scale models [J]. Mon. Wea. Rev., 1989, 117(8): 1779-1800.

[24] KALNAY E, COAUTHORS. The NCEP/NCAR 40-Year Reanalysis Project [J]. Bull. Am. Meteor. Soc., 1996, 77(3): 437-471.

[25] XIE P, ARKIN P A. Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model output [J]. Bull. Am. Meteor. Soc., 1997, 78(11): 2539-2558.

[26] MALONEY E D, HARTMANN D L. Frictional moisture convergence in a composite life cycle of the Madden-Julian oscillation [J]. J Climate, 1998, 11(9): 2387-2403.

[27] Li Chong-yin. Convection condensation heating and unstable modes in the atmosphere [J]. Chin. J. Atmos. Sci., 1983, 7(3): 260-268.

[28] LI Chong-yin, JIA Xiao-long, LING Ji-an, et al. Sensitivity of MJO Simulations to Convective Heating Profiles [J]. Climate Dyn., 2009, 32(2):167-187.

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