Numerical Simulation and Comparison Study of the Atmospheric Intraseasonal Oscillation*

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ABSTRACT

Daily mean outputs for 12 yr (1978-1989) from two general circulation models (SAMIL-R42L9 and CAM2.0.2) are analyzed and compared with the corresponding NCEP/NCAR reanalysis dataset, and results in two models show clearly that the root-mean square errors (RMSEs) from the simulation of intraseasonal oscillation can take 30-40 percent of the total RMSE, particularly, the distributions of the RMSE in simulating intraseasonal oscillation are almost identical with that of the total RMSE. The maximum RMSE of intraseasonal oscillation height at 500 hPa is shown in the middle latitude regions, but there are also large RMSEs of intraseasonal oscillation wind over the tropical western Pacific and tropical Indian Oceans. The simulated ISO energy in the tropic has very large difference from the result of the NCEP/NCAR reanalysis dataset which means the simulation of tropical atmospheric ISO still possesses serious insufficiency. Therefore, intraseasonal oscillation in the weather and climate numerical simulation is very important, and thus, how to improve the ability of the GCM to simulate the intraseasonal oscillation becomes very significant.

Key words: atmospheric intraseasonal oscillation (ISO), climate simulation, general circulation model, tropical atmosphere, kinetic energy

1. Introduction

In early of the 1970s, Madden and Julian (1971, 1972) indicated the existence of tropical atmospheric intraseasonal oscillation (ISO). Afterwards, the study on the tropical ISO has been unfolded vigorously since the 1980s, and the structural feature and basic active rule of the tropical ISO were studied in many ways and understood quite clearly (Krishinamurti and Subrahmann, 1982; Murakami et al., 1984; Lau and Chan, 1985; Knuston and Weickmann, 1987; Chen and Xie, 1988; Li, 1991; Madden and Julian, 1994; Sperber, 2003). The ISO has been regarded as an important atmospheric circulation system; and its action and anomaly have great influences on the weather/climate variations. Recent studies show that the tropical ISO has important impact on the tropical climate system, and its action and anomaly not only affect the onset and activity of Asian summer monsoon, but also the occurrence of ENSO (Li et al., 1994; 2001). However, there are a lot of questions on activity and influence of the ISO, we should study them deeply, particularly the numerical simulations of the ISO. Some numerical weather prediction results show clearly that the describing (forecasting) capacity to the ISO in the model has quite important influence on the numerical forecast accuracy. The analyses of five dynamical extended forecasts show that the forecasting error of the ISO plays an important role in the whole forecasting, no matter in 3-day or in 10-day forecasting (Hendon et al., 2000). The analysis and forecasting in the NCEP also show that the major errors of dynamical extended forecasts stem from weaker tropical ISO produced by the model and the fast propagation eastwards of the ISO (Jones et al., 2000).

In the Atmosphere Model Intercomparison Program (AMIP), the simulation results of the ISO in 15 GCMs were compared and it was shown that the ISO

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signal and eastward propagation have been obtained in most of the GCMs, but strictly speaking, the major feature of tropical ISO as well as the observed was not reproduced in any one (Slingo et al., 1996). Until now, the ISO intensity is underestimated in most of the GCMs; the seasonal tendency of the ISO is also not reproduced; the period of the simulated ISO is shorter and the signal with period shorter than 30 days is too stronger than the observed one. Some simulation studies in different models have analyzed the features of the simulated ISO, but most of them are just for the numerical simulation results in shorter period (Park et al., 1990; Slingo and Madden, 1991; Li and Smith, 1995; Silvio et al., 1996; Chen et al., 2000; Maloney and Hartmann, 2001; Sperber, 2004; Li and Yu, 2001; Jia and Li, 2004). It is very necessary to analyze and compare simulated results in the longer time, and to reveal the whole feature of the simulated ISO and importance of the ISO simulation in the climate simulation/prediction.

Therefore, the ISO simulation is an international forward problem in the atmospheric sciences. The study and results concerning the ISO simulation not only play an important role in revealing feature and regularity of the ISO and understanding the climate system and its variability, but also have important significance in improving the climate simulation/prediction. In this paper, we will compare and study the importance of the ISO simulation in the climate simulation and the existing problems in the ISO simulation by using longer time simulated results with two better AGCMs (SAMIL-R42L9 and CAM2). The purpose is to provide scientific basis for improving the whole simulation ability of the AGCM and climate model. As for some physical processes to affect the ISO simulation in model and their concrete influence, we are studying and will show the results in other papers.

2. The model, simulation scheme, and analyzing method

Two atmospheric general circulation models (SAMIL-R42L9 and CAM2) are used in this study. The SAMIL-R42L9, developed by LASG/Institute of Atmospheric Physics, Chinese Academy of Sciences, is a spectral model rhomboidally truncated at zonal wave number 42 and 9 layers using a sigma vertical coordinate. The horizontal resolution of original model uses Gaussian grids (128×108), approximately 2.8125° longitude by 1.66° latitude. The model has a unique dynamic framework by subtracting "a standard atmosphere" from the set of governing equations and uses a semi-implicit time integration scheme. A K-distribution radiation scheme, Slingo's cloud diagnosis scheme, the latest parameterization of land surface process, and the parameterization of convection were adopted (Zhang et al., 2000; Wang et al., 2004). The other model, CAM2.0.2 (Community Atmosphere Model) version, is released in July 2003 which is the GCM of the fifth generation developed by NCAR, USA (Collins et al., 2003). The horizontal resolution is T42 (approximately 2.8° latitude by 2.8° longitude) with 26 hybrid vertical levels.

Both the models are run from 1 January 1978 to 31 December 1989 using the observed monthly sea surface temperature for boundary conditions. The models' ability of climate simulation is evaluated by comparing differences between the daily outputs from the two GCMs and the corresponding NECP/NCAR reanalysis dataset. Usually, the method of root-mean square error (RMSE) is a valid way to evaluate the model's simulating ability. In this study, RMSE is also applied. RMSEs ($r_m^{i,j}$) of 850-hPa zonal wind and 500-hPa height with two GCMs are computed and analyzed. The simulated results of two models are at Gaussian grids, and thus the outputs of models are converted to 2.5° latitude by 2.5° longitude grids and then $r_m^{i,j}$ is obtained.

$$r_m^{i,j} = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left(U_{\mathrm{NCEP}}^{i,j,k} - U_{\mathrm{GCM}}^{i,j,k}\right)^2},$$
$$(i = 1, \cdots, n_x; j = 1, \cdots, n_y; k = 1, \cdots, m), \qquad (1)$$

where $U_{\mathrm{NCEP}}^{i,j,k}$ and $U_{\mathrm{GCM}}^{i,j,k}$ are NCEP reanalysis dataset and converted simulated dataset of GCMs, n_x/n_y is the number of zonal/meridional grids, and m is the time length of the time series.

3. Comparing analysis of models' results on global scale

3.1 *Analysis of the results simulated by SAMIL-R42L9 model*

Figure 1 shows the distributions of RMSE of the unfiltered and the 30-60-day band-pass filtered geopotential height fields at 500 hPa simulated by SAMIL-R42L9 from 1978 to 1989. The simulated results are rather different from the NCEP reanalysis data in Fig.1a, where the maximum value of the RMSE is 180 gpm in both the Northern Hemisphere (NH) and Southern Hemisphere (SH), and the RMSE is larger over the band of 35°-65°N and 35°-65°S. The maximum centers of the RMSE are located at the North Pacific, North Atlantic, and North Europe in the NH, while in the SH, the maximum centers are situated at 45°S of the South Pacific, the South Indian Ocean, and the South Atlantic. Both the locations and the centers of the maximum values of the RMSE of the simulated ISO are almost identical in Figs.1a and 1b. In Fig.1b the RMSE reaches its maximum value 80 gpm in the NH and 70 gpm in the SH. It means that the RMSE of the simulated ISO height at 500 hPa accounts for more than one third of the total RMSE. Therefore, the failure description of simulated ISO is one of the most important reasons for inaccuracy of simulated height at 500 hPa.

Figure 2 shows distributions of the RMSE of the unfiltered and the 30-60-day band-pass filtered zonal wind at 850 hPa simulated by SAMIL-R42L9 for 1978-1989. In Fig.2a, there are larger values at the band of 35°-65°N and 35°-65°S, similar to the RMSE of simulated height at 500 hPa. However, it is more concentrated over the North Pacific, the North Atlantic, and North Europe in the NH with maximum deviation of 13 m s^{-1}. Similar to the result of height at 500 hPa, the pattern of the RMSE of ISO zonal wind is almost identical with that of unfiltered zonal wind, with its maximum center of 5 m s^{-1} at the North Atlantic. The RMSE of simulated ISO zonal wind accounts for about one third of the total RMSE in global distribution. Thus, the inaccuracy of simulated zonal wind at 850 hPa depends mostly on the inaccuracy of the simulated ISO.

The RMSE analysis of simulated data in boreal summer and winter is identical with that of the analyzed in Figs.1 and 2 (figure omitted). Comparing simulated data in boreal summer and winter, both height at 500 hPa and the zonal wind at 850 hPa show the coherent difference, i.e., the maximum values of the RMSE appear in the winter hemisphere. For example, in boreal winter the RMSE of height at 500 hPa reaches its maximum over 220 gpm in the NH and 180 gpm in the SH; while in boreal summer it is 200 gpm in the SH and 140 gpm in the NH. The maximum value of RMSE of zonal wind at 850 hPa also appears in the winter hemisphere. In boreal winter, the maximum value of RMSE of zonal wind at 850 hPa is 16 m s^{-1} in the NH and 11 m s^{-1} in the SH; but in boreal summer, it reaches 13 m s^{-1} in the SH and 11 m s^{-1} in the NH. Moreover, the analyses of the simulated ISO data using the same method can also prove that the maximum value of the RMSE of simulated ISO all appears in the winter hemisphere. In boreal winter, the maximum value of the RMSE of ISO height at 500 hPa reaches 90 gpm in the NH and 60 gpm in the SH and the maximum value of the RMSE of ISO zonal wind at 850 hPa reaches 5.5 m s^{-1} in the NH and 3.5 m s^{-1} in the SH. In boreal summer, the RMSE of ISO height at 500 hPa reaches its maximum at 80 gpm in the SH and 70 gpm in the NH, and the RMSE of ISO zonal wind at 850 hPa reaches its maximum 5 m s^{-1} in the SH and 4 m s^{-1} in the NH.

3.2 *Analysis of the simulated data in CAM2*

Using the same analysis method as in Section 3.1, we analyzed the simulated data in CAM2. The RMSEs of both 500-hPa height and 850-hPa zonal wind have almost identical results with those of the simulated by SAMIL-R42L9. Figure 3 shows distribution of the RMSE of the unfiltered and the 30-60-day band-pass filtered geopotential heights at 500 hPa simulated by using the CAM2. Figure 3a shows that the maximum band of the RMSE of 500-hPa height appears in each hemisphere. Three maximum centers of the RMSE are located at Alaska, East Greenland, and North Europe in the NH. In the SH, there are similar distributions over the South Pacific, the South Indian Ocean, and the South Atlantic with maximum center in the South Pacific. The patterns in Figs.3a and 3b are coherent with each other. Not only the maximum value bands of the RMSE are almost identical with each other, but also the locations of the maximum centers are similar. Figure 3 shows the maximum value of the total RMSE is 210 (210) gpm in the NH (SH) and the maximum value of the ISO RMSE is 70 (80) gpm in the NH (SH). The RMSE of simulated ISO 500-hPa height accounts for one third of the total RMSE, which is similar to the results of SAMIL-R42L9. Comparing Fig.3 with Fig.1, the RMSE of simulated 500-hPa height in CAM2 is a bit larger than that in the SAMIL-R42L9 (more than 20-30 gpm); but the RMSEs of simulated ISO in the two models are almost identical. Furthermore, the simulated results in the CAM2 are more polarward (about 3°-5° latitude) for the maximum value band than those in the SAMIL-R42L9.

The distributions of RMSE of 850-hPa zonal wind simulated by using the CAM2 (Fig.4) are almost identical results with those of the SAMIL-R42L9 in Fig.2. However, the maximum value band of the total RMSE is not notable in the NH and replaced with the three maximum centers, particularly in the North Pacific and the North Atlantic. The maximum value of RMSE is 13 m s^{-1} in the NH and 12 m s^{-1} in the SH in Fig.4a. In Fig.4b, it is 4.5 m s^{-1} in the NH and 4 m s^{-1} in the SH. The RMSE of ISO of simulated 850-hPa zonal wind also accounts for over 1/3 of the total RMSE. The small differences appear between Figs.4a and 2a, e.g., there are relative minimum values of the total RMSE over the South Arabian Sea and North Africa in Fig.2a, but they are notable maximum in Fig.4a; besides, it is relative maximum value from west coast of South America to Mexico in Fig.2a, whereas it is obviously minimum value in Fig.4a. It is definite that these differences can be explained by using the different methods of certain physics process in two GCM models. The former difference appears on shorter time scale but the latter one does on larger time scale. Therefore, there are not obvious differences over the South Arabian Sea and North Africa in Figs.2b and 4b. Not only the maximum values of the RMSEs of 500-hPa height and 850-hPa zonal wind but also the maximum values of the RMSEs of ISO 500-hPa height and 850-hPa zonal wind appear in the winter hemisphere, which is similar to the results in the SAMIL-R42L9. For instance, in boreal winter the maximum value of the RMSE of 500-hPa height is 240 gpm in the NH and 180 gpm in the SH, while in boreal summer it is 160 gpm in the NH and 220 gpm in the SH. Besides, in boreal winter the RMSE of ISO zonal wind at 850 hPa reaches its maximum value as high as 5 m s^{-1} in the NH and 3.5 m s^{-1} in the SH, but in boreal summer it reaches 2 m s^{-1} in the NH and 5 m s^{-1} in the SH.

4. Comparing analysis of the tropical atmospheric ISO kinetic energy

The above analyses have shown that the ability of simulating ISO is the most important for global atmospheric circulation simulation. However, the differences of simulated tropical atmospheric ISO are not clear yet. Here, the simulation of tropical atmospheric ISO is studied by using ISO kinetic energy. Note that the kinetic energy can represent well the activity of tropical atmospheric ISO.

Since the space limitation, the results only for three years (1987, 1988, and 1989) in the simulated data of SAMIL-R42L9 are arbitrarily selected for analyzing. Figures 5a-c show longitude-time sections of the kinetic energy of the atmospheric ISO from the NCEP reanalysis dataset at 850 hPa averaged over 10°S-10°N in 1987, 1988, and 1989, respectively. Although there are only three years of time-length datasets, the interannual variability is clear during the period. In 1987, the annual variability is not obvious; nevertheless the annual variability in 1988 and 1989 is very noticeable. The kinetic energy of tropic atmospheric ISO during winter and spring is higher than that during summer and autumn.

For simulated dataset in the SAMIL-R42L9, the longitude-time sections of the kinetic energy of the atmospheric ISO at 850 hPa averaged over 10°S-10°N in 1987, 1988, and 1989 are shown in Figs.5d-f. Both annual variability and interannual variability of simulated dataset are weakened, and the stronger atmospheric ISO signal appears over 0°-40°E regions.

These differences mentioned above present that there are some problems in simulated tropical atmospheric ISO in the GCM models. Figures 5g-i show the longitude-time sections of the kinetic energy difference between the NCEP dataset and simulated dataset in the SAMIL-R42L9 for the atmospheric ISO at 850 hPa averaged over 10°S-10°N in 1987, 1988, and 1989. One of the most attractive things is that some differences are higher than their original value. It illuminates that the ability of tropical atmospheric ISO simulation is very poor. On the other hand, the obvious annual variability and interannual variability of the difference field mean that the model cannot simulate tropical atmospheric ISO completely.

The comparing analysis between the CAM2 dataset and NCEP dataset shows the similar results. The CAM2 also has obvious problems in simulating tropical atmospheric ISO, which raise the other problems in simulation. Once the tropical atmospheric ISO is not depicted accurately, the middle and high latitude atmospheric ISO and global atmospheric circulation could be influenced since the tropical atmospheric ISO will affect the tropical convection and heating processes (Long and Li, 1996).

5. Conclusions

Daily mean outputs for 12 yr (1978-1989) from two GCM models (SAMIL-R42L9 and CAM2.0.2) are analyzed and compared with the corresponding NCEP/NCAR reanalysis dataset. The results clearly show that the ability of simulation of atmospheric ISO plays an important role in the numerical simulation of weather and climate. The RMSEs of simulated ISO in the two GCM models both account for 30%-40% of the total RMSE. This means that it is currently difficult for models to simulate the atmospheric ISO accurately. Besides, the simulation ability of the model depends on the accuracy of simulated atmospheric ISO directly.

The patterns of the RMSE of simulated ISO in the two GCMs are identical with those of the total RMSE. The results confirm further that the ability of simulating atmospheric ISO plays a significant role in the total simulation of the models. It is the serious challenge that how to improve the simulation of the atmospheric ISO in model.

There are still more problems in simulating the tropical atmospheric ISO. The results of the simulated ISO kinetic energy in the tropics have large deviation from the NCEP reanalysis dataset; this means there are more unsolved problems in simulating tropical atmosphere ISO in the GCM.

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