Modelling the Global Monsoon System by IAP 9L AGCM①

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ABSTRACT

The global monsoon system is simulated by IAP 9L AGCM. The result indicates that the model successfully simulates the monsoon system in the lower troposphere including the classic tropical monsoon, the subtropical monsoon and the temperate–frigid monsoon. Besides, the planetary monsoon in the upper troposphere is also realistically reproduced. On the other hand, the stratospheric monsoon is poorly simulated, a further analysis reveals that this is caused by the systematic overestimation of the westerly in the model.

Key words: The global monsoon system, Monsoon, Seasonality, Simulation

1. Introduction

Monsoon is a major component of the global climate systems. Originally, monsoon is a regional concept in classic climatology, which summarizes all drastic seasonal variations over some regions in the tropics and subtropics (e.g., India and East Asia). To better understand the variations of monsoon in quantity, it is evident that some indexes reflecting the major features of monsoon must be defined. Since monsoon is characterized by the seasonal variation of wind field, in particular the reversal of wind direction, the normalized seasonality of wind field (or seasonality for simplicity), which is defined as the difference of wind field between winter and summer by its annual mean, is used to study monsoon and the seasonal variation of general circulation (Zeng et al., 1984, 1988). The results indicated that, in the lower troposphere, besides the traditional tropical monsoon, there are regions with large seasonality in the subtropics and high latitudes in both hemispheres, which is called the subtropical monsoon region and the temperate–frigid monsoon region respectively; in the upper troposphere, the subtropical monsoon combines with the tropical monsoon as a whole nonseparably planetary monsoon system; in the stratosphere, there is a belt with very large seasonality in each hemisphere, which is called the stratospheric monsoon region. Based on this, they extended the concept of classic monsoon, i.e., the regions with large seasonality are defined as the general monsoon, and the global monsoon system is composed of the general monsoon including the tropospheric and stratospheric monsoon mentioned above. Afterwards, Xue and Zeng (1999) further demonstrated the above conclusions with the climatological mean data. More recently, Li and Zeng (2000) tested the significance of seasonality through theoretical analysis and proved that monsoon can be characterized with seasonality both rationally and simply.

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At present, the atmospheric general circulation model (AGCM) is a powerful tool in research of monsoon and its variability. On the other hand, a successful simulation of monsoon by a model is an important prerequisite for reliable studies on the variability and predictability of monsoon using the model. When it is confirmed that a model succeeds in reproducing some of the essential characteristics of monsoon, one can use the model for the identification of dynamical and physical mechanisms responsible for monsoon variability. In this paper, a nine–level atmospheric general circulation model designed at Institute of Atmospheric Physics (IAP 9L AGCM) is integrated from 1958 to 1992 using the observed SST and sea ice coverage as the model's boundary conditions, the 35–year mean data of the model are used to compare with the reanalysis data from National Center for Environment Prediction / National Center for Atmospheric Research (NCEP / NCAR) to validate the model's performance in simulating the global monsoon system. In addition, the simulation errors are also analyzed.

2. The model and data

IAP 9L AGCM is a global grid–point model including the troposphere and the stratosphere, it has horizontal resolution of 4° latitude by 5° longitude and nine unequal levels in the vertical direction. Compared with most other models, this model has its unique features in dynamical frame and computational scheme (Bi, 1993; Liang, 1996). The model simulates a realistic climate mean state (Bi, 1993). Moreover, it successfully simulates the seasonal variation of East Asian monsoon (Wang and Bi, 1996).

The model has been run for 35 years from 1958 to 1992 using the observed SST and sea ice coverage as the model's boundary conditions. The 35–year climatological mean data are compared with the corresponding NCEP / NCAR reanalysis data with horizontal resolution of 2.5° latitude by 2.5° longitude. The computational formula of the normalized seasonality can be found in Zeng et al. (1998). Finally, a nine–point smoothing operator is added to the results to eliminate the small–scale perturbations.

3. The results

In order to understand clearly the global monsoon system in the model, it is necessary to examine the simulated wind field at first. As an example, Fig. 1 shows the January wind field at 850 hPa simulated by the model, together with the NCEP / NCAR reanalysis data. The model generally simulates the cyclones near Aleutian Islands and Iceland and those anticyclones over the subtropical oceans in the Southern Hemisphere. The planetary wind belts such as the westerlies over Eurasia and in mid–high latitudes of the Southern Hemisphere and the easterlies near the equatorial zone are also reproduced by the model. In July (Fig. 2) the model simulates the anticyclones over the subtropical Pacific and the Atlantic of the Northern Hemisphere although it tends to underestimate the intensity of the westerlies over the northern parts of the cyclones, the model also simulates the cyclones over the tropical Indian Ocean. Besides, the anticyclones in the Southern Hemisphere are greatly weakened from January to July and the model captures the seasonal variation. As in January, the model continues to simulate the observed planetary wind belts. The wind field at other levels of the troposphere is also simulated realistically (not shown), but the wind field in the stratosphere is poorly simulated as shown in Fig. 6.

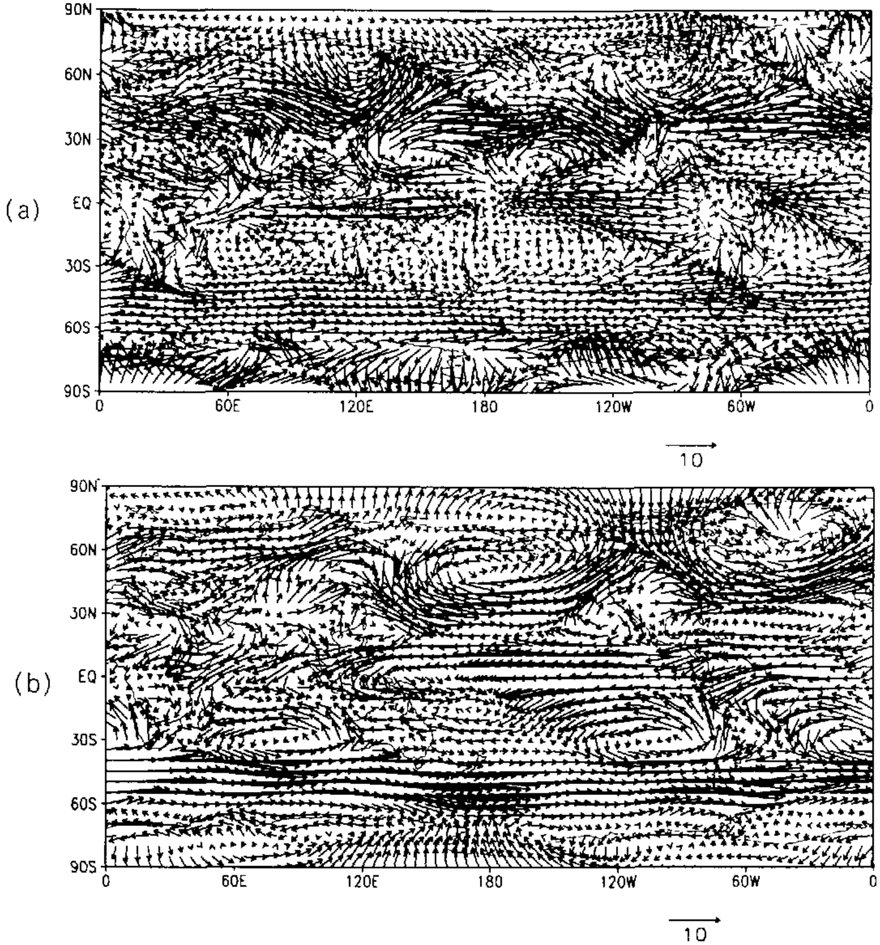

Fig. 1. Geographical distribution of 850 hPa wind in January averaged over 1958–1992. (a) Simulated by IAP 9L AGCM, (b) NCEP / NCAP reanalysis data.

Fig. 3 shows the climatological mean wind seasonality, the model reasonably simulates the classic tropical monsoon region including Asian–Australian monsoon and African monsoon with centers in the warm pool of the West Pacific and in the tropical African continent respectively. Besides, there is a belt with a smaller seasonality in the subtropics of each hemisphere, the northern belt spreads from the coast of East Asia to the North Atlantic and the southern one is almost around the parallel of 30°S, the model approximately reproduces the distribution of the subtropical monsoon, but it tends to overestimate the intensity over continents, e.g., in South America and the coastal region of East Asia, in a sharp contrast, the intensity over oceans is generally underestimated, indicating that the amplitude of annual cycle over the subtropical oceans is somewhat weaker though the model is forced by the observed SST. It is also noted that the simulated subtropical monsoon region is not clearly separated

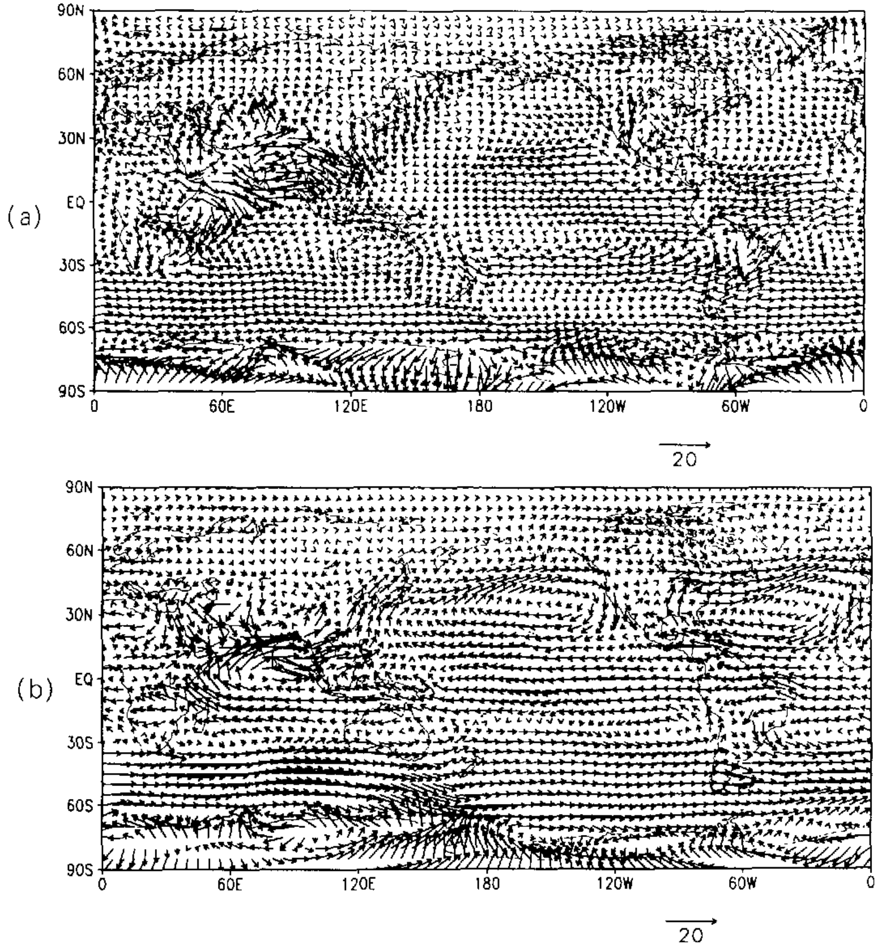

Fig. 2. As in Fig. 2, except for July.

from the tropical one especially in East Asia and Australia, this is possibly due to a relatively coarse resolution of the model to some degree since the subtropical monsoon region is separated from the tropical one by a narrow band. As regards the temperate–frigid monsoon region in high latitudes, the whole distributions are simulated by the model except that the large seasonality over the Arctic region is situated too far equatorward, furthermore, the simulated seasonality in the Northern Hemisphere is generally stronger than the observed especially over the regions from Okhotsk Sea to Alaska while it seems a little weaker over the Antarctic region.

In the middle troposphere, the subtropical monsoon tends to approach the tropical monsoon, showing that the vertical structure in the subtropical monsoon region bears a distinct baroclinity which is well captured by the model (not shown). At 200 hPa (Fig. 4), while the intensity of the temperate–frigid monsoon becomes weaker than that at the lower level, the tropical monsoon and the subtropical monsoon combine together into a nonseparably

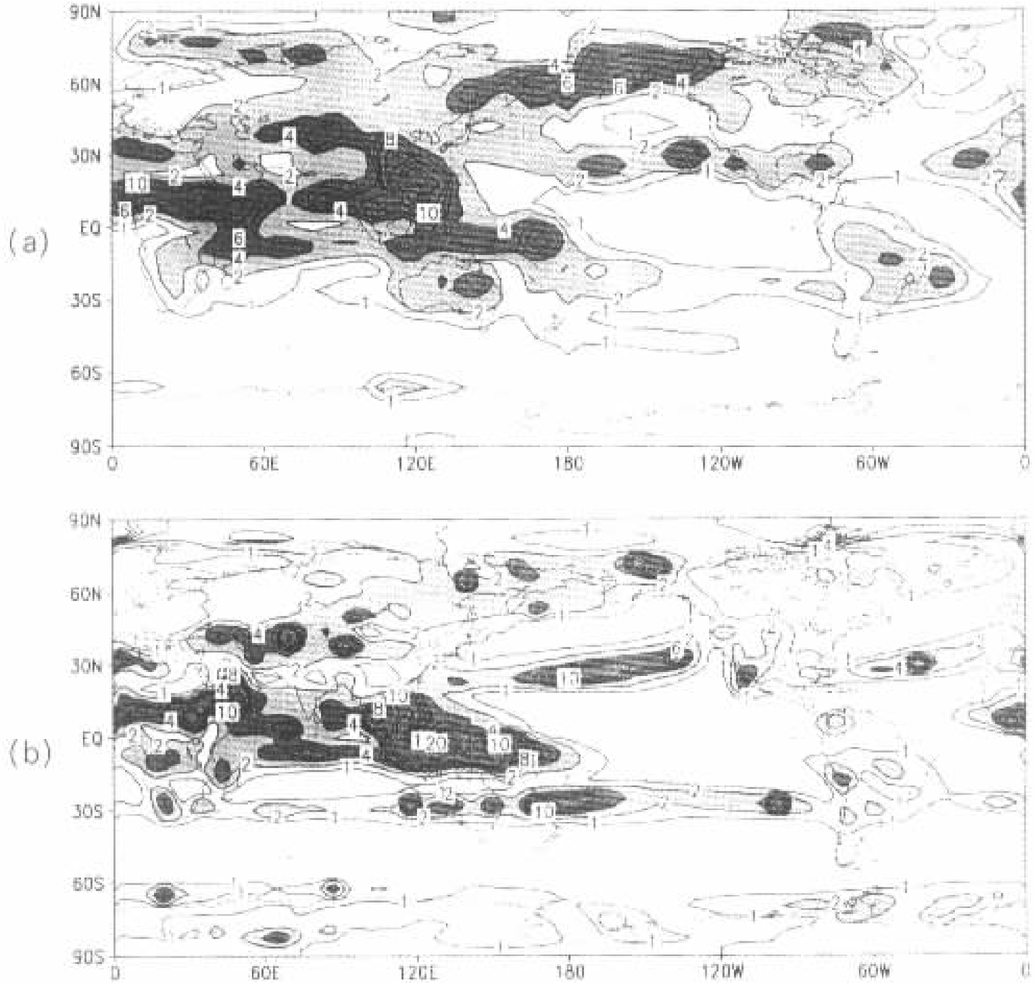

Fig. 3. Geographical distribution of 850 hPa wind seasonality averaged over 1958—1992. (a) Simulated by IAP 9L AGCM, (b) NCEP / NCAR reanalysis data.

planetary monsoon though there remains a trace of large seasonality in the southern subtropics, the model successfully reproduces the distribution of the planetary monsoon, but the intensity in the Western Hemisphere is too weak, the intensity in high latitudes is also underestimated.

At 50 hPa (Fig. 5), i.e., in the middle stratosphere, there are two well—defined belts with very large seasonality in the subtropics separated by the equatorial zone with low values. As pointed out by Zeng et al. (1998), this kind of distribution results from the opposite circulation between summer and winter in the middle stratosphere. Unfortunately, unlike the situation in the troposphere, the simulated result is far from satisfaction, the model fails to simulate the two belts with very large seasonality. In particular, instead of low values in the observation, the erroneously large values appear in the tropics in the model.

Because the seasonality of large—scale monsoon is mainly determined by the zonal wind (Xue and Zeng, 1999), a further analysis of the zonal wind distribution may provide us some clew to the simulation errors in the stratosphere. Figure 6 shows the latitudinal distribution of

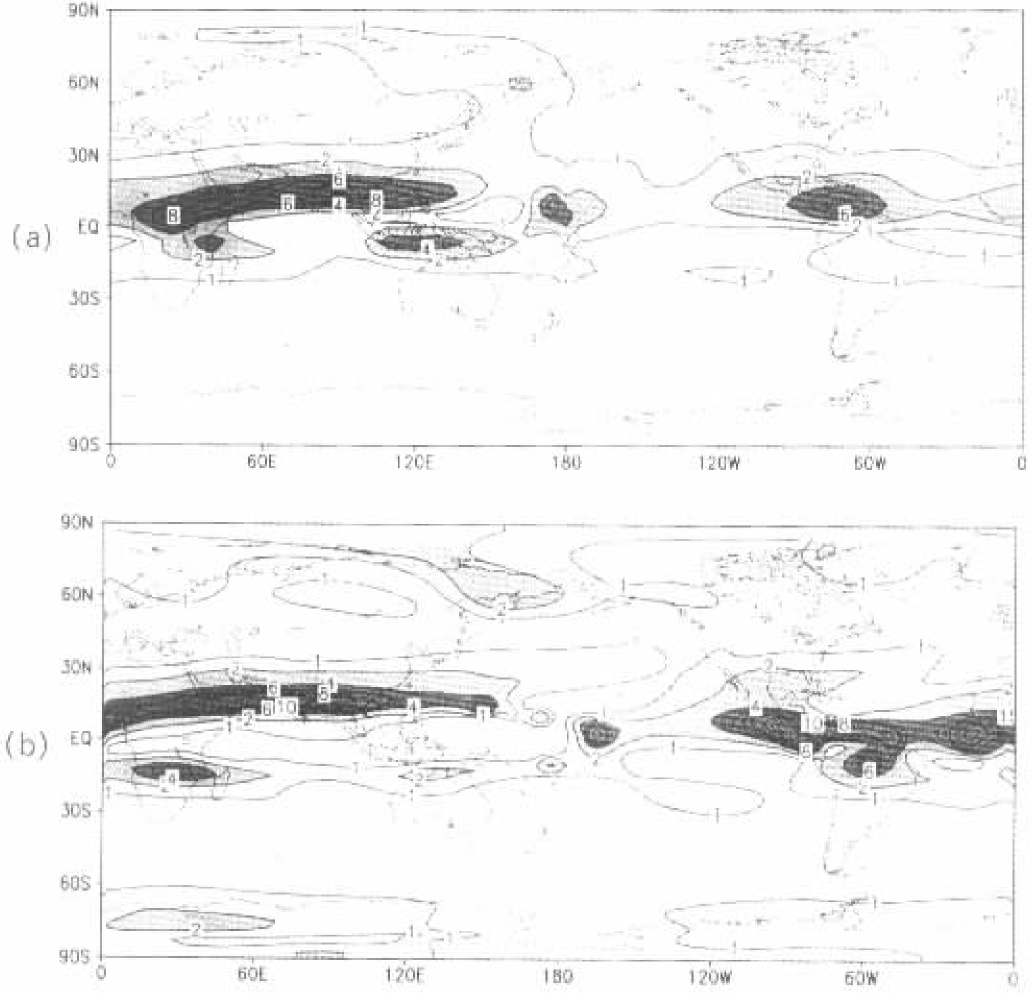

Fig. 4. As in Fig. 3, except for 200 hPa.

the zonally averaged zonal wind in January and July. Except in high latitudes of the winter hemisphere where the westerly jet is located, either in January or in July, the intensity of the simulated westerly is systematically stronger than the reanalyzed, so that the easterly between the tropics and the subtropics in the summer hemisphere is distorted into the westerly by the model, moreover, the westerly jet in the winter hemisphere is 30° equatorward of its observed position. As noted earlier by Bi (1993), this is related to the computational scheme of continuity equation and the boundary condition at the upper level of the model. As a result, systematic biases are produced in the model. On the contrary, the simulated zonal wind in the troposphere is in general agreement with the observation. It may also be noted that there are only two sigma levels in the stratosphere in the model, the wind data at 50 hPa are obtained from the interpolation of these two levels, hence a coarse vertical resolution in the stratosphere may also result in some errors in wind field.

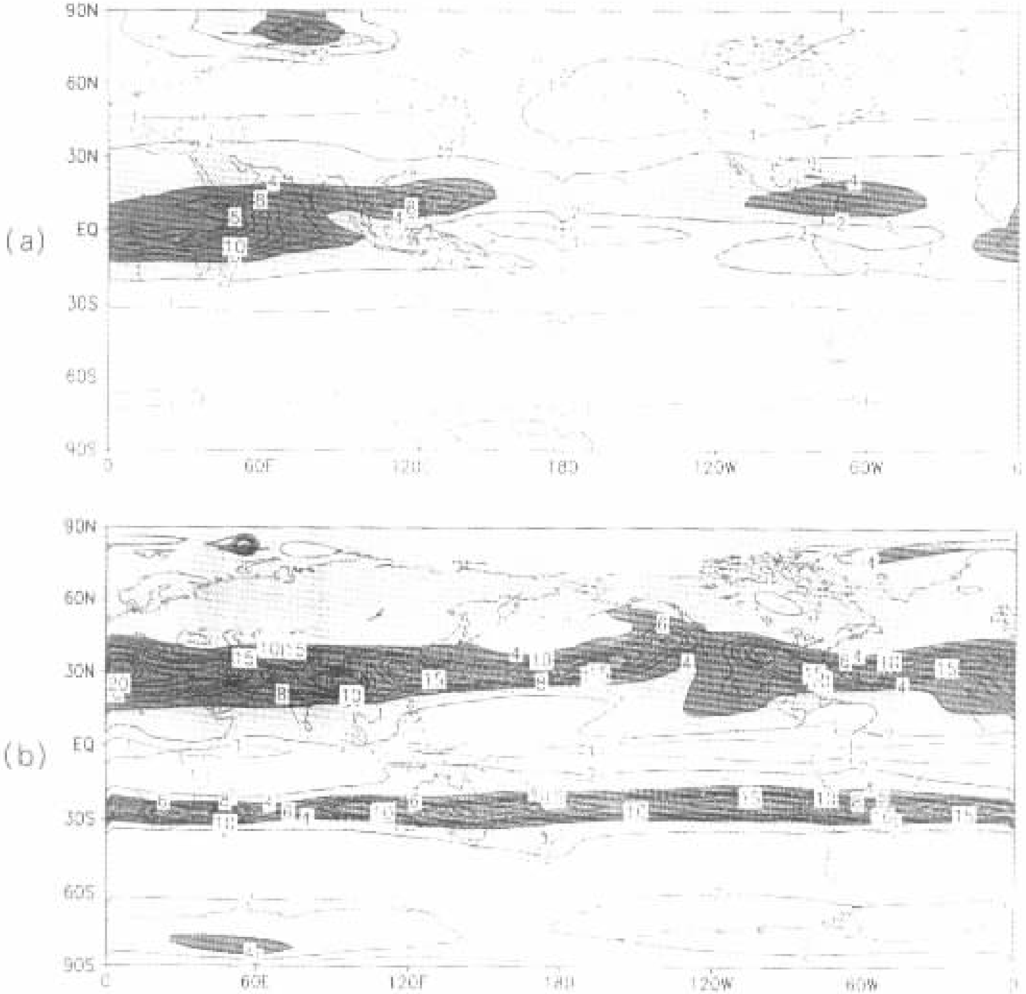

Fig. 5. As in Fig. 3, except for 50 hPa.

4. Summary

The global monsoon system illustrates comprehensively the seasonal variation of general circulation of the atmosphere. It is essential to evaluate a model's performance in simulating the global monsoon system before we use the model to study its variability and predictability. By comparing the simulated result by IAP 9L AGCM with the corresponding reanalyzed data, we find that though the model tends to overestimate the intensity over the subtropical continents and the Northern high latitudes and to underestimate the intensity over the subtropical oceans and the Antarctic region, the model is successful in simulating the distributions of the monsoon system in the lower troposphere. Besides, the simulated planetary monsoon in the upper troposphere is also in good agreement with the observation. In contrast with the realistic simulation in the troposphere, the stratospheric monsoon is poorly simulated by the model due to the systematic overestimation of the westerly in the model. It is suggested that improvements including the computational scheme of continuity equation, the

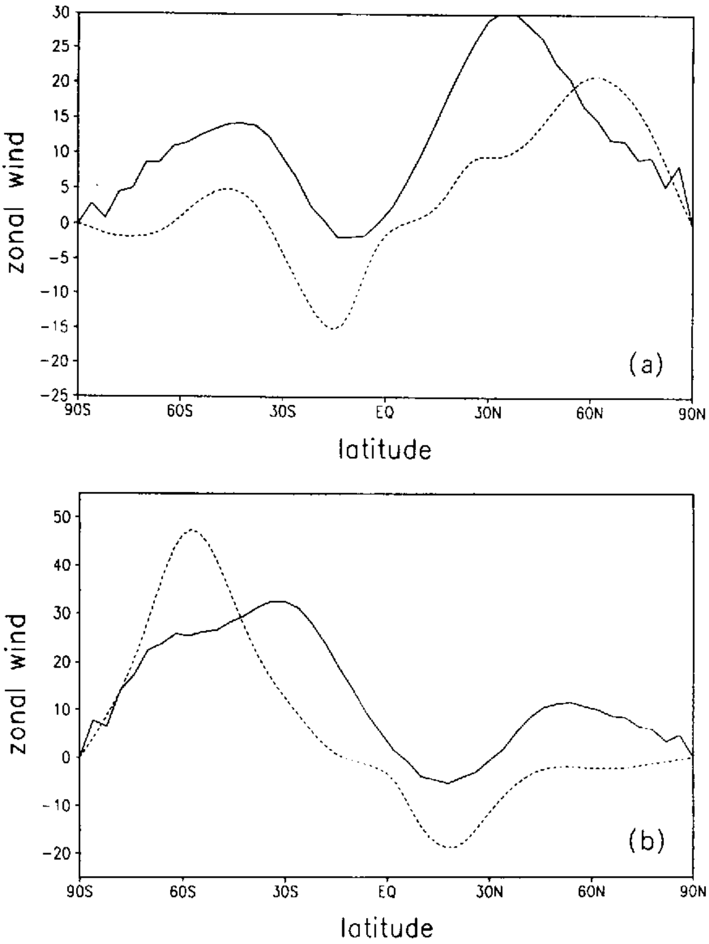

Fig. 6. The zonal average of the simulated (solid line) and the reanalyzed (dashed line) zonal wind at 50 hPa. (a) January, (b) July.

upper boundary condition and the vertical resolution in the stratosphere should be made in order to catch up with the successful simulation in the troposphere.

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利用 IAP 九层大气环流模式模拟全球季风系统

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摘 要

用 IAP 九层大气环流模式模拟了全球季风系统。结果表明，模式成功模拟出对流层低层的季风系统，包括经典的热季风以及副热带季风和温寒带季风。此外，模式也真实再现了对流层高层的行星季风。另一方面，平流层季风的模拟效果则较差，这与模式中西风系统性偏强有关。

关键词：全球季风系统，季风，季节变率，模拟