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Numerical Modellings of Properties of the Summer Quasi–Stationary Circulation Systems and Their Monthly Variations①

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ABSTRACT

An ocean–atmosphere and land–air coupled numerical model system is used to study the basic properties and the monthly time variations of the summer quasi–stationary circulation systems. It is found that either at the upper or at the lower levels of the atmosphere, the circulation patterns have a two–wave structure in the zonal direction at the mid and high latitudes of the Northern Hemisphere. Such a structure of circulation is totally matchable to that of the land–sea distribution there. It is proved, hence, that the land–sea distributive pattern is the fundamental cause for the summer quasi–stationary circulation pattern. The topography in the globe is the secondary factor for circulation systems. The circulation centres of the quasi–stationary systems are always located in certain areas due to the thermodynamic contrast between land and sea.

From the time evolutions of the circulation systems it is seen that the change is larger at the beginning period of the time integration, it is because of using the zonally averaged mean fields as the initial values of the model. As long as the basic simulated pattern of circulations reaches the state similar to that of the real climatic fields resulting from the coeffects of the land–sea distribution and the topography, the circulation systems modelled will change slowly and tend to a quasi–stationary state. Therefore, the time integration does not need to last for a very long time, if the purpose of numerical modellings is to test sensitivities of some factors influencing the climate, 20 model days may be enough for sensitive experiments.

Key words: Quasi–stationary circulation systems, Numerical modelling

I. INTRODUCTION

As is well known that under the coeffects of the land–sea distribution and the large and steep topography of the earth, there are always existing some quasi–stationary circulation systems in the atmosphere either in summer or in winter. For example, at the upper levels over the South Asia and the Tibetan Plateau there is a very strong high which people call the Tibetan High or the South Asian High. In the pressure field near the ground surface there can be seen two large and strong highs over the two great oceans, which are called the Pacific High and the Atlantic High, respectively. Over the continents, especially over the Europe–Asia–African continent, there is a low pressure system dominating with wide area. Due to the effects of the seasonally quasi–stationary circulation systems the monsoon

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phenomenon in the East Asia is extremely evident.

There are a good many of numerical modelling studies on the mean winter and summer climate fields in the world(see Washington and Kasahara, 1970; Stone et al., 1977; Schlesinger and Gates, 1980). In China, the scholars of the Institute of Atmospheric Physics (IAP) have done such kind of studies, too(see Ye et al.; 1991). All those studies are successful to different extents. The first author and others have conducted quite a few detailed numerical simulations of the development process of the East Asian monsoon and the effects of the topography on the diurnal changes of meteorological fields (see Kuo and Qian, 1981, 1982; Qian and Wang, 1984). Recently we resimulated the basic properties of the climate in the summer monsoon areas (see Qian and Wang, 1993). All the simulations made by the first author and others reproduced fairly the quasi–stationary circulation systems with climatic meanings. Nevertheless, the geographically distributive properties, the zonal structures of the quasi–stationary systems and their relationship with the land–sea and the topographic distributions, the time scale for the quasi–stationary systems to set up and the mechanisms of their time variations are still worth studying further.

In this paper, a zonal domain numerical model is used to simulate the zonal structures and the time variations of the quasi–stationary circulation systems in order to determine their formation time scale and to further understand the mechanisms of their time variations.

II. THE MODEL SYSTEM

The model system used in this paper is a land–air and air–sea coupled model system, in which the atmospheric model is a five–layer primitive equation model with p–σ incorporated coordinate system in the vertical. The first and the second model layers are in the p coordinate system above the 400 hPa level with an equal layer thickness of 200 hPa, therefore the model levels are equivalent to the 100 hPa and the 300 hPa standard isobaric surfaces, respectively. The fifth layer is close to the ground surface with fixed 50 hPa thickness, which is taken as the atmospheric boundary layer. Between the 400 hPa level and the top of the boundary layer, there are two layers, that is the third and the fourth layers with an equal σ thickness. It is seen that the third to the fifth model layers are in the σ coordinate system. The model includes various diabatic and adiabatic physical processes, such as the large scale and the convective cumulus condensations, the longwave and the shortwave radiations, the exchanges of the momentum, moisture and the heat fluxes between the atmosphere and the land surface and between the air and the sea. Moreover the shortwave solar radiation contains the diurnal variation (see Qian, 1985).

In order to better compute the fluxes of momentum, moisture and heat between the air and the sea and between the air and the surface, there are a soil model and a mixing layer ocean model in the model system to couple with the atmospheric model. The soil model has two layers, the first soil layer is thinner which reflects the diurnal changes of the soil temperature and the soil moisture. The second layer is thicker and represents the annual variations. The layer thickness depends on the physical properties of the underlying surfaces, therefore, it can be different for different areas. Five sorts of the underlying surfaces are distinguished in this paper, that is the clay pasture, the tropical rain forest, the desert, the muddy water and the Tibetan Plateau snow cover. Details of the soil model can be found in Qian's papers (1988, 1991). The mixing layer ocean model has also two layers, and the thicknesses are 50 m and 250 m, respectively (see Qian, 1992).

The model system has a zonal domain between 60°S and 60°N, the horizontal grid network is spherical one with a grid size of 5° lat × 5° long, the time step is 15 min., the land–sea distribution and the topography are close to the real ones.

III. EXPERIMENTAL SCHEMES

The initial fields used in the model are the multiyearly zonally averaged geopotential height field at 100, 300, 500, 700 and 1000 hPa levels and the mixing ratio field at 300, 500, 700 and 850 hPa levels. After initialization, the temperatures, the geopotential height, the velocity components and the mixing ratio at model levels can be obtained, and the surface pressure can be gotten by interpolation (see Qian, 1985). The initial sea surface temperature (SST) field is the real monthly mean SST distribution in July. The initial time is set at 12:00 GMT 26 June. The solar declination is changing each day and the solar zenith angle changes every hour which is enough to express the diurnal variations of the solar radiation.

The time integration lasts to the 35th model day. Three means are made: the 6–10 day mean, the 6–20 day mean and the 6–35 day mean. They represent the 5–day, the 15–day and the 30–day mean climate fields, and are designated by M5, M15 and M30, respectively. The first five–day results are not included in the mean fields because they are taken as the transitional state from the initial zonal mean field to the nonuniform one.

Besides the above three mean fields there are transient fields on the 5th, 10th, 15th, 20th and 35th model days, they are designated by T5, T10, T15, T20 and T35, respectively. Both of the mean and the transient fields can be used to discuss the quasi–stationary circulation system and its time variations.

In order to ease looking, a brief interpretation of the above experiments is given in Table 1.

Table 1. Experimental Schemes and Their Meanings

Mean fields	Meanings	Transient fields	Meanings
M5	6–10 day mean	T5	5th day
M15	6–20 day mean	T10	10th day
M30	6–35 day mean	T15	15th day
		T20	20th day
		T35	35th day

IV. DISCUSSIONS OF THE RESULTS

1. *Simulated Properties of the Quasi–Stationary Circulation Systems*

Figs. 1a, b, c, and d are the 100 hPa level geopotential height and temperature fields, the 200 hPa level and the boundary layer stream maps, respectively. From Fig. 1a, it is seen that the upper level summer high pressure belt is located near 35°N with three high pressure centres which distribute over the Eurasian continent, the Africa and the west coast of the North America, respectively, and have nearly equal intensities. The first and the second high centres are located in the same high body. Therefore, the quasi–stationary circulation systems in the mid and high latitudes of the Northern Hemisphere have a typical two wave structure. Similar to the structure of the height field, the two wave structure is also seen in the temperature field, that is, in the mid and high latitudes of the Northern Hemisphere, there are all cold centres over the land and warm centres over the oceans (Fig. 1b). That means that the high pressure areas correspond to the colder temperature and the low pressure areas to the warmer temperature at the upper levels of the atmosphere because of the different tropopauses.

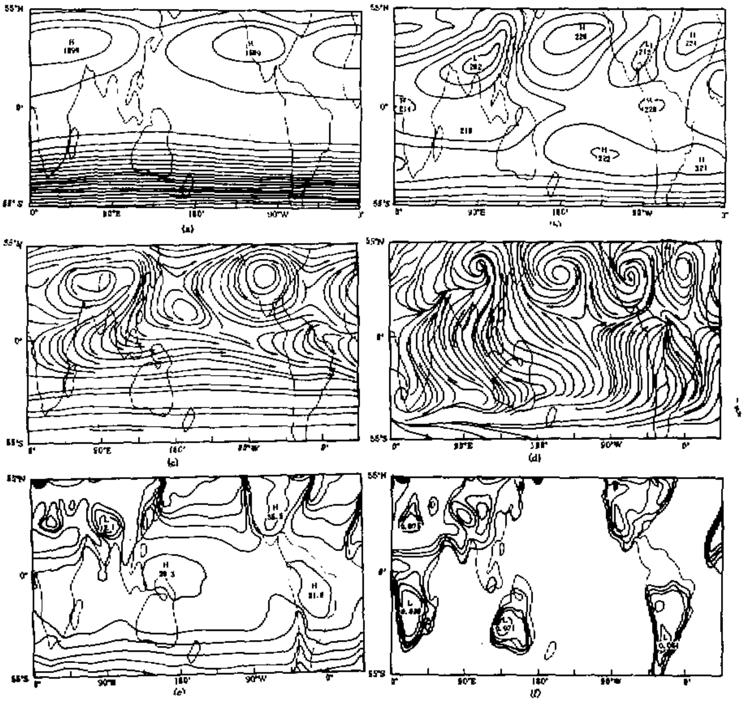

Fig. 1. The 100 hPa level heights (a) and temperature (b), the 200 hPa level (c) and the boundary layer (d) stream lines, the underlying surface temperature (e) and moisture (f). The units: height in decameters, temperature in K at the 100 hPa level and in °C at the ground surface, moisture in %.

Fig. 1c shows that the flow field at the 200 hPa level has the anticyclonic circulations over the land areas and the cyclonic circulations over the oceans. However, because of the stronger heating effects of the land in summer, the anticyclonic circulations over the land have large domains and intensities. There is no closed cyclonic circulation centre over the Atlantic Ocean due to its smaller oceanic area, while there is one over the Pacific Ocean. From the flow map, it is clearly seen again that there is a two wave structure. Especially, from the boundary flow map (Fig. 1d) the two wave structure is more clear and typical. Over the Eurasian continent and North America there are evident cyclonic circulations and over the two great oceans the anticyclonic circulations. By comparison of Fig. 1c with 1d, it is found that the flow fields at upper and lower levels are in opposite phase, meaning that the quasi–stationary circulation system has apparent baroclinicity. Over the Southern Hemisphere the circulation pattern is simple, at upper levels there are westerlies and at lower levels there are westerlies, too, at high latitudes and deflective southerlies across the equator at the mid and low latitudes.

After comparison of the simulated climate fields with the observational ones (figures omitted), we find that they are in good agreement with each other. However, some discrepancies are still seen, especially, in the locations and the intensities of the centres of the circulation systems. It indicates that the model system used in this paper has good capability to simulate *the monthly mean climate fields, but more further improvements for the model system are still* necessary.

From the above analyses, it is seen that either at upper levels or at lower levels the quasi–stationary circulation systems in the Northern Hemisphere have a two–wave zonal structure at high and mid latitudes. Such a zonal structure is very agreeable with the two–wave zonal distribution of the land and the sea in high and mid latitudes of the Northern Hemisphere. Therefore, it is reasonable to assume that the zonal structure of the quasi–stationary circulation systems is determined by the land–sea distribution, the Tibetan Plateau and the Rocky Mountains do not influence it, however, they can influence the interior structures, especially, the domains and the central intensities of the circulation systems. In the Southern Hemisphere oceans occupy almost the whole area, the land–sea contrast is not remarkable, therefore, the quasi–stationary circulation systems have a quasi–zonal structure.

From the simulated results of M5 and M15 (figures omitted) it is seen that the circulation systems as shown in Figs. 1a to 1d are also found, and their positions have no much changes, either. It is again proved that the simulated circulation systems are quasi–stationary. Therefore, we can conclude that if the purpose of the numerical modelling is only to simulate the mean properties of the quasi–stationary circulation systems such as in some sensitive experiments, the time integration after 20 model days may stop in order to save computer resources and it does not lose the representations.

Figs. 1e and 1f show temperature and moisture distributions of ground and sea surfaces. From Fig. 1e it is found that the SSTs computed by the oceanic mixing model have the basic distributive properties of the summer SST and change very little. Over the land the surface temperatures are mainly determined by the properties of the underlying surfaces and the heights above the mean sea level. There are high temperature centres over the Sahara desert and the North and the South American central areas, while over the Tibetan Plateau there is a low temperature centre. In the figure is also seen the evident discontinuous belt of temperature along the coastal areas in the Northern Hemisphere, which represents the large thermal contrast between the land and the sea. In the Southern Hemisphere with large oceanic areas the temperature contrast between the land and the sea is much smaller. Fig. 1f shows that the soil in the interior of the land, for example, in the Sahara desert, the South Africa, the North and the South America and Australia, is very dry. In the Tibetan Plateau, the soil moisture is large, and in the oceans it is saturated. Such distribution of the soil moisture depends on the model precipitation besides the different initial moisture of the underlying surfaces. In the places where the precipitation is much, the soil moisture is large and the temperature is low, on the contrary, where the precipitation is little there the soil moisture is low and the temperature is high.

2. *Properties of Time Variations of the Quasi–Stationary Circulation Systems in the Monthly Time Scale*

It has been pointed out early in this paper that in the model physics the solar radiation contains the diurnal change as well as the seasonal variation. The diurnal change is favourable at the beginning of the time integration for the zonally averaged initial fields to become a zonally nonuniform climate state and makes such transfer more rapid than that in the case without the diurnal change (see Kuo and Qian, 1982). In other words, the diurnal change of the solar radiation much shortens the time integration to reach the quasi–equilibrium state. The simulated results in this paper show that a 5 model day time integration is enough to

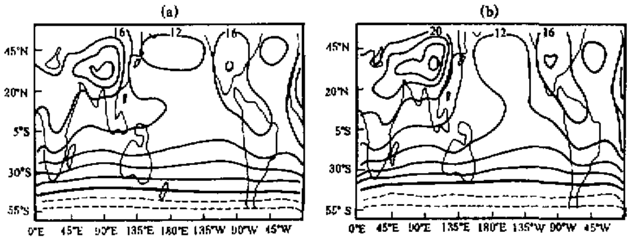

Fig. 2. Temperature fields (°C) at the 850 hPa of T5 (a) and T35 (b).

make the zonally uniform mean fields become the zonally nonuniform fields with quasi–stationary circulation systems. Figs. 2a and b are the temperature fields at the 850 hPa level of T5 and T35. It can be seen that the time difference between the two experiments is one month though, the temperature structures are very similar to each other. That means that the basic seasonal properties of the climate field are easy to be stimulated by the land–sea and the topography distributions, however, the diurnal change of the solar radiation is necessary to be taken account.

The time variations of the quasi–stationary circulation systems in the monthly time scale is caused mainly by the change of the solar declination. The earth–atmosphere system obtains different net radiative energy under different solar declinations. When the net radiation is positive, the earth–atmosphere system is heated and vice versa. After the Summer Solstice, the solar declination decreases gradually, the solar radiation received by the earth–atmosphere system in various places becomes smaller and smaller. However, the solar declination is still larger in July, therefore, the absorbed solar radiation in the Northern Hemisphere is always greater than the lost longwave radiation, and the heat budget is positive. Therefore, the thermal effects over various places are still very strong and the quasi–stationary circulation systems intensify with the time integration. However, the intensification speed decreases with the time integration and a quasi–equilibrium state is gradually reached. The experimental results prove this point.

From the results of T experiments, it is seen that the intensity of the warm centre at the 850 hPa level over the Asian continent increases with time. Table 2 shows the characteristics of temporal variation of the warm centre. From Table 2, it is found that the centre intensity increases from 30.8°C to 33.3°C in 30 model days, averagedly it increases by 0.42°C every 5 days. The main change takes place in between of 15 and 20 days, during this period, the centre increases by 0.7°C, while in 20 to 35 days, it only increases by 0.9°C with an increment of 0.3°C per 5 days, that is, only 0.06°C per day. From the distributive patterns, it is seen that the pattern on day 20 is already very close to that on day 35 (not shown), especially the low temperature centres over the Pacific Ocean where the temperature difference is only 0.2°C and over the Atlantic Ocean where the difference is 0.1°C. Therefore, the differences of the patterns and the warm or the cold temperature centres between T20 and T35 are very small.

Table 2. Time Variations of the Warm Centre over the Asian Continent at the 850 hPa Level (°C)

Time (days)	5	10	15	20	35
Intensity (°C)	30.8	31.2	31.7	32.4	33.3

The intensity of the East Asian summer monsoon can be identified by the zonal pressure or the temperature gradient. In this paper, we take the temperature difference at the 850 hPa level between the warm centre over the Asian continent and the cold centre over the Pacific Ocean as the intensity index of the Asian Monsoon (AMI). Then from the T experiments we can obtain the time variation of the AMI as shown in Table 3.

From Table 3 it can be seen that the intensity index of the Asian Monsoon (AMI) changes greatly in the first 15 days, up to the 20th day it reaches basically a stable state, from the 20th day to the 35th day it changes only 0.7°C with a mean of less than 0.05°C per day.

Table 3. Time Variations of the Intensity Index of the Asian Monsoon (AMI) at the 850 hPa Level

Time (days)	5	10	15	20	35
AMI(°C)	20.8	22.5	23.6	24.2	24.9

Above analyses of the T experiments show that the time variations of the quasi–stationary circulation systems mainly take place in the first 20 days of the time integration and in the last 15 days they are very small. It again proves that a time integration of 20 days has already simulated the mean climatic properties of the quasi–stationary circulation systems.

3. *Regional Characteristics of the Quasi–Stationary Circulation Systems*

It can be seen from the results of either T or M experiments that the time variations of the quasi–stationary circulation systems have apparent regional characteristics. The regions with large thermal differences between the land and the sea are usually the regions with the most evident time variations. Moreover, the time variations over the oceans and over the land are usually in opposite tendency. Figs. 3a and b are the differences of the mean temperatures at 100 and 700 hPa levels, respectively, between M30 and M5 experiments. It can be seen from Fig. 3a that the temperature changes over the East Asian continent and over the western Pacific are very evident but with opposite signs at the upper level. At low latitudes, the Atlantic Ocean and its coastal areas are the regions with the most evident changes of temperatures. However, Fig. 3b indicates that the Europe–Asia–African continents are the regions with evident increases of temperatures and the oceans with temperature decreases at the lower level. Temperature changes at upper and lower levels are in opposite phases, but the distributive regions are basically the same. If we compare the results of M30–M5 with those of M15–M5 (not shown), we would find that patterns of temperature variations are basically the same, which shows that the time variations always take place in some special regions.

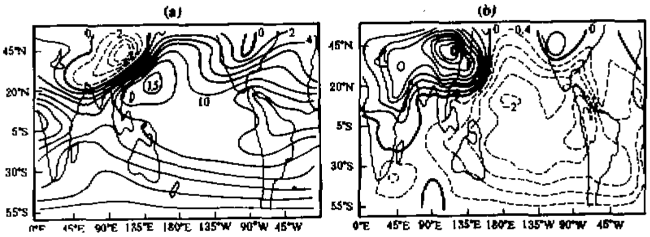

Fig. 3. *Differences of mean temperatures at 100 hPa (a) and 700 hPa (b) between M30 and M5 in °C.*

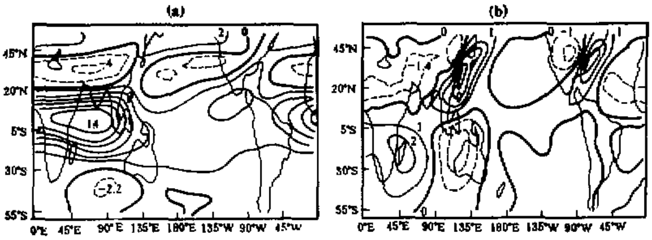

Fig. 4. Differences of *u*(a) and *v*(b) components between M30 and M5 at the 100 hPa level in m / s.

Fig. 4. illustrates the differences of *u* and *v* components at the 100 hPa level between M30 and M5. It is shown that the easterlies increase between 20°N and 45°N, while the westerlies increase north of 45°N and south of 20°N, especially, over the Indian and the Atlantic Oceans. Over the mid and the south Pacific, the changes are little. Such distributions of the differences indicate that the three wind bands have seasonal northward movements. In the map of the *v*–component differences, there are all the increasing southerly winds over the East Asia and the east coast of the North America, the regions are narrow and long with a south–north orientation. Over the other places the northerly winds increase. The case is basically opposite in the Southern Hemisphere. The *v*–components change very little over the Pacific. From Fig. 4b. it is also seen that the time variations of the *v*–components have a zonal two–wave structure as well.

Above analyses indicate that the time variations of the quasi–stationary circulation systems possess the evident geographically distributive properties. In fact, it is the regions with the most evident time variations where the centres locate. Therefore, either the circulation systems themselves or their time variations depend mainly on the land–sea distribution and the topography, and the former has more apparent effects than the latter.

V. CONCLUSIONS

Under the effects of the land–sea distribution and the topography, the quasi–stationary circulation systems are always to form their centres over the most favourable regions. At the mid and the high latitudes of the Northern Hemisphere, they have a two–wave structure in the zonal direction both at high and lower levels which is totally coincides with the two–wave structure of the land–sea distribution there. It is seen, therefore, that the thermal difference between the land and the sea is the dominant cause for the generations of the quasi–stationary circulation systems, and the topography is the second factor. From the speeds of the time variations of the quasi–stationary circulation systems it can be concluded that the larger variations take place at the beginning of the time integration, this is because that the model uses zonally averaged initial fields. As long as the simulated fields have basically similar patterns to the observational ones under the combined effects of the land–sea distribution and the topography, the variation speeds of the systems become slow and a quasi–stationary state is gradually reached. The experiments prove that after 20 model days of the time integration, the changes are almost negligible. The time variations of the circulation systems have evident geographical distributions and the centres of the variations are basically coincident with those of the systems.

REFERENCES

Kuo, H. L. and Y. F. Qian (1982), Numerical simulation of the development of mean monsoon circulation in July, *Mon. Wea. Rev.*, **110:** 1879–1897.

Kuo, H. L. and Y. F. Qian (1981), Influence of the Tibetan Plateau on cumulative and diurnal changes of weather and climate in summer, *Mon. Wea. Rev.*, **109:** 2337–2356.

Qian, Y. F. and Q. Q. Wang (1984), A numerical simulation of diurnal variations of meteorological fields in summer, *Adv. Atmos. Sci.*, **1:** 40–52.

Qian, Y. F. and Q. Q. Wang (1993), Simulated properties of the climate in the summer monsoon area, *J. Trop. Met.*, **9:** 90–96 (in Chinese).

Qian, Y. F. (1985), A five–layer primitive equation model with topography, *Plateau Meteorology*, **4(2):** (suppl.) 1–28.

Qian, Y. F. (1988), A scheme of calculation of heat balance temperature at ground surface, *Sci. Met. Sinica*, **4(4):** 14–27 (in Chinese).

Qian, Y. F. (1991), Numerical simulations of temperature and moisture changes in land–air coupled system, *Acta Met. Sinica*, **49:** 538–547 (in Chinese).

Qian, Y. F. (1992), Numerical simulations of the effects of sea surface temperature anomalies in the western Pacific on the summer monsoon climate, Climate Variability, Proceedings of IWCV, Beijing, 282– 293.

Schlesinger, M. E. and W. L. Gates (1980), The January and July performance of the OSU two–level atmospheric general circulation model, *J. Atmos. Sci.*, **37:** 1914–1943.

Stone, P. H., S. Chow and W. H. Quirk (1977), The July climate and a comparison of the January and July climates simulated by the GISS general circulation model, *Mon. Wea. Rev.*, **105:** 170–194.

Washington, W. M. and A. Kasahara (1970), A January simulation experiment with the two–layer version of the NCAR global circulation model, *Mon. Wea. Rev.*, **98:** 559–580.

Ye, D. Z., Q. C. Zeng and Y. F. Guo (1991), Current Research in Climate, Chapter 6, China Meteorological Press, Beijing, 1991, p. 353 (in Chinese).