Effects of Land–Sea Distribution, Topography and Diurnal Change on Summer Monsoon Modeling[①]

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ABSTRACT

The effects of the land–sea distribution, the topography and the diurnal change of the solar radiation on the summer monsoon modelings are studied by use of a coupled modeling system with a 5–layer primitive equation model of the atmosphere and a 2–layer soil or ocean thermodynamic model which are all solved in a zonal model domain between 60°S and 60°N. The results of numerical simulations show that the quasi–stationary patterns of the mean monsoon circulations are mainly affected by the land–sea distribution and the topography, the effect of the diurnal change is the secondary. However, the inclusion of the diurnal change into the model system may improve the intensity of the simulated monsoon circulation, it can influence the distributive pattern of precipitation to a larger extent, without the diurnal change precipitation in the interior of land would decrease and in the coastal regions it would increase.

Key words: Effects of land–sea distribution, Topography and diurnal change, Numerical simulations, Summer monsoon

I. MODEL SYSTEM AND EXPERIMENTAL SCHEMES

As it is well known that the solar energy directly absorbed by the atmosphere itself is very limited. The main energy source of atmospheric motions comes from the energy exchange between the atmosphere and the underlying surfaces, that is, the underlying surfaces transfer their absorbed solar radiation to the atmosphere in the forms of the sensible heat, the latent heat and the long wave radiation. So that the nonuniformity of the underlying surfaces, especially the different land–sea distribution and topography, can alter the zonally uniform solar radiative energy to the non–zonally–uniform one to heat the atmosphere and result in many important weather phenomena. Because of the earth rotation, the distribution of the solar energy is not zonally uniform strictly, either. Such zonally nonuniformity of the solar energy induced by the diurnal change has similar effects as the underlying surfaces, the relative importance of the two is clearly seen, however, it still needs to study.

In this paper, an improved, zonal domain numerical modeling system with $p-\sigma$ incorporated coordinate is used. The atmospheric model is a 5–layer model which has been used for many years by authors (see Qian, 1985), some improvements have been made for inclusion of a soil and a mixing layer ocean models which are coupled with the atmospheric model. The details of the underlying surface models can refer to Qian's papers (1991, 1993). The diurnal

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change of the solar radiation is expressed by the time variation of the zenith angle. The heating fields are calculated by every hour, therefore, the zenith angle changes once an hour. In the experimental schemes without diurnal change the cosine of the zenith angle is daily averaged. The solar declination changes once a day no matter with or without the diurnal change, therefore, the seasonal change of the solar radiation is always included.

Two experimental schemes are designed, one with and the other without the diurnal change. They are designated by CNL and NDL sequentially. The initialization scheme of the two experiments can refer to Qian (1985). The initial sea surface temperature (SST) field is a multiyearly averaged July observed SST field. The initial time of integration is set at 12:00 GMT June 26th. Total time integration is 35 days. As it is known (see Qian et al., 1994) that a quasi–stationary state can be reached by a time integration of 20 days, therefore, the mean fields of every hour results during day 6 to day 20 are taken as the model climate state and the results until day 5 are excluded as the transition state from the zonal mean initial fields to the nonuniform ones.

II. DISCUSSIONS OF THE RESULTS

As it is well known that the main components of the summer monsoon include the low level cross–equatorial air currents, the easterly jet near 20°N south of the Plateau at high levels and the meridional monsoon circulation near the Plateau. Next we are going to mainly discuss the modelled properties of the three components.

1. *Results of the CNL Experiment*

Figs. 1a and 1b demonstrate the wind vectors of summer monsoon for the July observation and the CNL experiment, respectively. Compared with the observation, it is seen that the CNL reproduced the main properties of the summer monsoon region. From Fig. 1b it is seen that at the equator there are all the southerly or deflective southerly winds pointing out the air mass transfer from the Southern Hemisphere to the Northern Hemisphere. In the interior regions of the land the wind speeds are all small, while at the intersections of the land and the sea there are strong air currents which move cyclonically round the land. Due to the high and large Tibetan Plateau the air currents are more complicated in the Eurasian and the African Continent. The air currents are parallel to the coast lines at the east coast of Asia, but those in the South Asia are basically perpendicular to the coast lines. Therefore, the flow patterns of the low level air currents mainly depend on the land–sea distribution and the topography changes their directions to a certain extent.

Further analysis points out that the wind speeds are not uniform in the cross–equatorial air currents. Fig.2a shows the cross–equatorial currents at 45°E, 80°–105°E, 90°W and 65°W, of which the Somalian low level jet at 45°E is the strongest with a maximum v–component of 7 m / s. The cross–equatorial current near Australia is also simulated well. From Fig. 2a it is also seen that the low level southerly winds can extend to a maximum altitude of 5 km and above them there are three centres of northerly winds correspondently, they together form three monsoon circulations, two of them over the Eurasian and African Continent and another over America. We find that the most evident monsoon circulation is located at 90°E and second evident one at 45°E. At the above two longitudes, the ascent motions over the Northern Hemispheric land are very strong and so do the descent motions over the Southern Hemispheric oceans and land. The 90°E circulation is much larger than the 45°E one. At 65°W, the upward motion over the land of the Northern Hemisphere is not apparent, the upward branch is mainly located in the ITCZ near 10°N, to the contrary, the downward motions

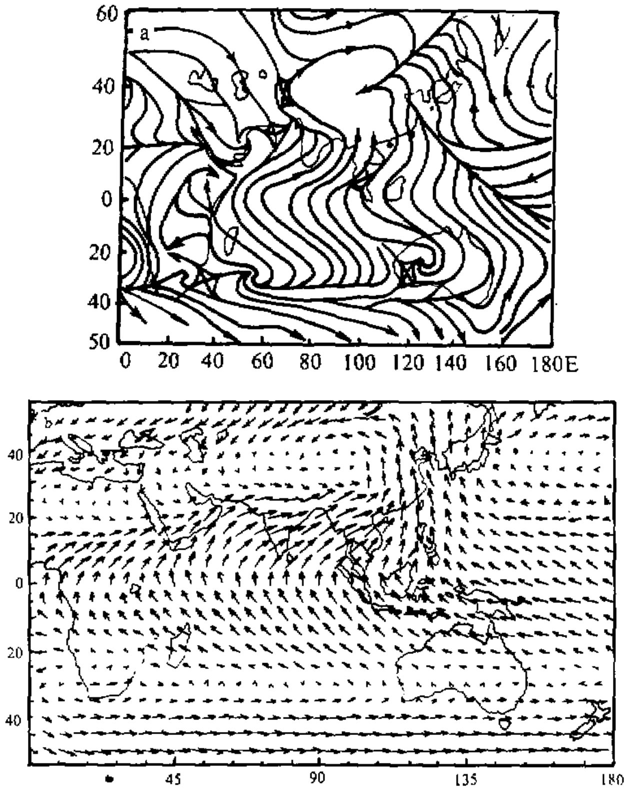

Fig.1. The July low level wind vectors. (a) observed, (b) the CNL simulated.

over the land of the Southern Hemisphere are very strong which are in fact the Hadley Cell in the Southern Hemisphere. From above analysis it is seen that although the 90°E cross–equatorial current is not the strongest, the total monsoon circulation is the strongest due to the fact that there are the Tibetan Plateau over the land in the north and oceans in the south, the contrast of land–sea is very obvious. At 45°E the underlying surfaces on both sides of the equator are similar, the contrast of land–sea is small, the monsoon circulation is also weak. At 65°W, the ocean is in the north and the land in the south, the land–sea contrast is opposite to that at 90°E, the monsoon circulation is therefore much weaker.

As similar to the structures of the temperature and the pressure fields (see Wang et al., 1992), the structure of the u–components both at the upper and the lower levels is a zonal two–wave structure at 20°N as shown in Fig. 3a. Such a structure coincides with the land–sea distribution at the same latitude which is also a zonal two–wave structure. The easterly jet over the Eurasian and African Continent at the 200 hPa level can reach a speed of 11 m / s, while that over the Mexican High of America is relatively weaker. Below 5 km, the patterns are in the opposite phase. All these are well in agreement with observations. Fig. 3b shows the vertical distribution of the u–component along 90°E. From Fig. 3b it is seen that the easterly

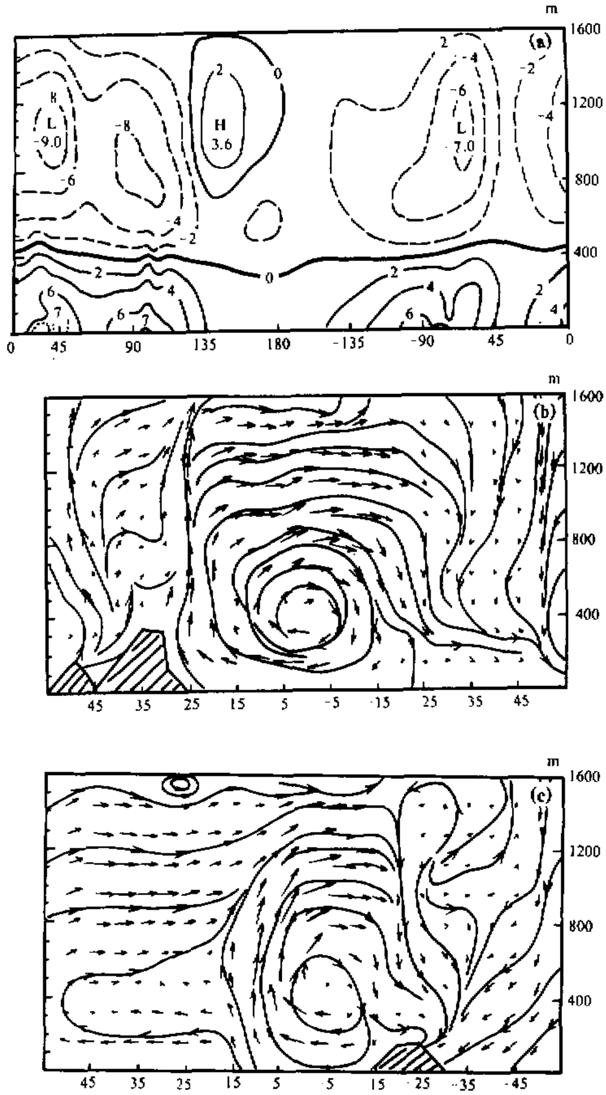

Fig.2. The vertical profile of v—component along the equator (a), the meridional monsoon circulations along 90°E (b) and 65°W (c), simulated in the CNL experiment. In (a) the solid line is the southerly wind and the dotted line the northerly wind.

wind belt, which is an important component of the summer monsoon at the upper troposphere, can reach 27.5°N, the zero speed line on the north side of the easterly jet somewhat shifts to the north from low to high levels. The south boundary of the jet can reach the equator. The maximum wind speed of the jet is 13.4 m / s, the centre of the speed is located at the altitude of 11 km near 15°N and below it there is a zone with southwesterly winds.

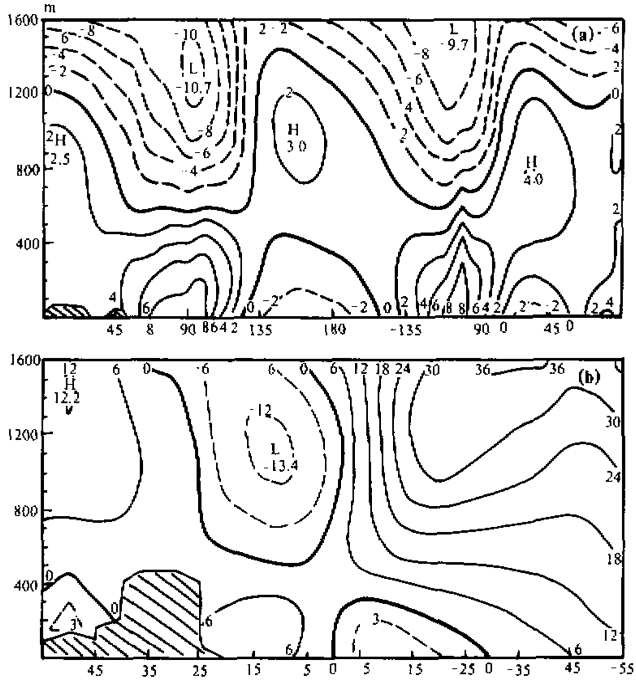

Fig. 3. The vertical profiles of u–components along 20°N (a) and 90°E (b) of the CNL experiment (The solid line is westerly wind and the dashed line the easterly wind).

From above discussion it is seen that the land–sea distribution is the main cause of the summer monsoon system, while the topography intensifies the contrast between the land and the sea to an evident extent and makes the summer monsoon phenomena over the Eurasian and African Continent specially apparent.

2. *Differences between the NDL and CNL Experiments*

The results of the two experiments are generally very similar. However, there are still some notable differences in the details.

For simplicity, we only analyze the cross–equatorial currents and the easterly jets. Fig. 4a shows that below 4 km there are the negative differences in the v–components along the equator partly in the whole globe, but with smaller values. That means that if the diurnal changes of the solar radiation is omitted in the experiment, then the low level cross–equatorial current would be weakened to some extent. It is also found that there are positive difference centres at the mid and the high altitudes at 0°–45°E, 100°E and 65°W which happen to form dipoles with the low level negative centres of differences. This again proves the weakening of the monsoon circulations in those areas. It is not difficult to find out by comparison of Fig. 4b with Fig. 3b that the high level easterly and the low level westerly south of the Plateau are both weakened. From the differences of precipitation between the two experiments it is found that in the interior land such as the Eurasian continent, the north parts of both the North and the South America, precipitation decreases, while over the Arabian Peninsula, the Indian Peninsula and the coastal regions of East Africa and East Asia, precipitation increases. The

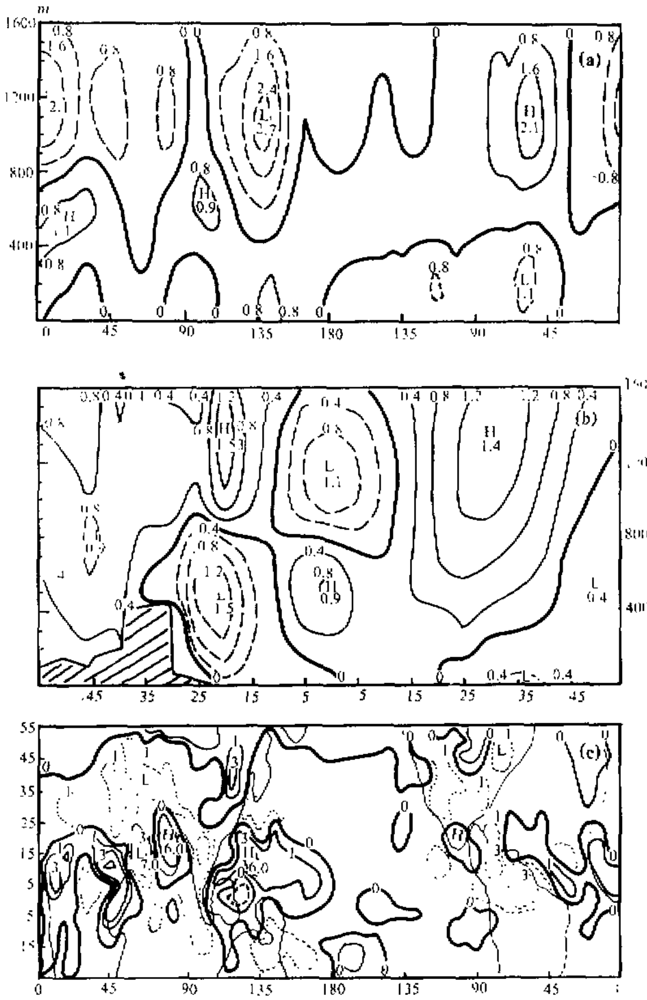

Fig.4 The vertical profiles of the differences (m / s) for v—components along the Equator (a), for u—components along 90°E (b) and the differences (mm / d) of precipitation (c) of NDL minus CNL (the solid line is positive and dotted line negative).

amounts of the differences of precipitation are larger and the centre values can reach 1—5 mm / d. From the differences of the soil temperature and moisture between the two experiments we find that in the areas with decreasing precipitation the soil temperature rises up and the soil moisture drops down, and vice versa.

III. CONCLUSIONS

From above analyses it is known that the effects on the mean summer monsoon patterns come mainly from the land—sea distribution and the topography. The diurnal change of the solar radiation has effect on the strengths of the important monsoon systems at the upper and the lower atmosphere, however, relatively speaking, it has more influence on the amount of precipitation. Without the diurnal change of the solar radiation the precipitation over the land would decrease and it would increase over the coastal regions.

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