IMPACT OF UPLIFT OF TIBETAN PLATEAU AND CHANGE OF LAND-OCEAN DISTRIBUTION ON CLIMATE OVER ASIA*

CHEN Longxun (陈隆勋), *LIU Jiping* (刘骥平), *ZHOU Xiuji* (周秀骥)

Chinese Academy of Meteorological Sciences, Beijing 100081

and *WANG Pinxian* (汪品先)

Chinese Tongji University, Shanghai 200092

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ABSTRACT

Using an improved CCM1/NCAR climate dynamic model and a combination distribution of land-ocean-vegetation during 40 — 50 MaBP, a series of numerical experiments representing different stages of the Tibetan Plateau uplifting and different land-ocean distributions are designed to discuss the influence of the Plateau uplifting and land-ocean distribution variation on Asian climate change. It is shown that Tibetan Plateau uplifting can firstly increase the precipitation in China during the period from initial uplift to half height of modern Tibetan Plateau and then decrease the rainfall during the time from the half height to the present plateau. At the same time, the uplifting can reduce surface air temperature over China. Besides, the effects of the uplift and land-ocean distribution change on the variation of winter and summer Asian monsoon circulation are also discussed.

Key words: climate dynamic model, Tibetan Plateau uplifting, different land-ocean distributions

I. INTRODUCTION

The Tibetan Plateau (hereafter TP), the highest and largest plateau in the world, stretches 30° in longitude from west to east and 15° in latitude from south to north and lies in the southwest of China with an area of 2.4×10^6 km^2, having great effects on the global climate. As such, studies on influence of modern TP (hereafter MTP) and its uplifting process on the climate are one of the subjects of continuing concern to meteorologists and geologists in China and abroad.

As far back as 1950s many authors (Staff members 1957a; 1957b; 1957c; Tao and Chen 1957; Wu and Chen 1957) have discussed the MTP effects on the atmospheric circulations over Asia, discovering that in winter MTP helps to stabilize the existed upper-air two westerly jets and to let them merge in the lower reach and form the strongest jet on the earth. In summer, MTP favours to maintain a subtropical upper anticyclone over this region with an easterly jet to its south. Additionally, MTP has important effect not only

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on the formation of winter NW monsoon and the stretch of summer SW monsoon into Asian Continent but also on the mutation in monsoon seasonal variation.

The Chinese geologists and geographers have carried out a lot of research about impacts of TP uplifting upon the climate change over China. For example, Liu (1985), Sun (1996), Shi et al. (1998), and Li and Fang (1998) have obtained many significant results. In summary, during the middle of the 40—50 MaBP Eocene Epoch, the first crucial period in the uplifting course of the plateau, the TP region was controlled by Paleo-Tethy Sea, and the Asian and European Continents and Indian Subcontinent were still separated with spread of the subtropical forests in the north of 40°N. At this time China is dry and hot. After about 40 MaBP, chiefly at 25 MaBP, the second important period, Paleo-Tethy Sea disappeared as the north part of TP started to uplift in the process of the above three continents merging. It follows that the TP region changed to a mass of mainland and observed is colder climate than in previous period in China. Some researches (Li et al. 1979; Sun 1996; Shi et al. 1998; Li and Fang 1998) revealed that TP experienced three upliftings and two levelings. Of the uplift, the first two only made TP to enhance less than 2000 m, but the last one, beginning at 3. 4 MaBP, permited TP higher than 2000 m at about 2. 5 MaBP with colder climate and the rainfall increased in mainland of China. As TP continued to upgrade, the climate became colder, but the precipitation decreased instead of the earlier increase, accompanying to come the great glacial epoch of Quaternary period and to form the desert north of TP. The Chinese loess also started to develop at about 2. 6 MaBP (Liu 1985), which suggests that TP uplifting to 2000—2500 m (equivalent to half of present TP height, hereafter 1/2 MTP) has much influence on the climatic change. The third period is the present time when TP is far above 4000 m on the average and is uplifting continuously.

Hahn and Manabe (1975) initiatively investigated the impact of topography uplift on climate, addressing that without global topography it is difficult for summer monsoon to shift into the Asian Continent and no seasonal mutation is in occurrence. Afterwards, Kutzbach (1989) and Broccoli and Manabe (1992) further documented the effects of global topographic change. On the other hand, Chinese scientists also discussed the effect of Plateau on the Asian monsoon, by using of the global model (Wu and Ni 1997). Following achievement of Chinese geologists and geographers, this paper will simulate the influence of TP uplift and the transformation of land-ocean distribution on climate over Asia (in particular the mainland of China) by means of dynamic climatic model. In the context of the findings of Chinese geologists and geographers, we will explore four stages:

(1) Before TP uplift (GPSSTP): 40—50 MaBP.

In this stage land-ocean and sea surface temperature (SST) patterns took on ancient characteristics.

(2) TP beginning to uplift (NTP): about 25—40 MaBP.

TP is assumed to be as high as 500 m with present land-ocean and SST distribution.

(3) TP uplifting to half height of MTP (1/2 MTP):

It is a key period and is crucial to impact of TP on the climatic change in China (Kutzbach et al. 1993).

(4) Modern TP (MTP): a control test.

Results of this case are used to compare with the observation data and assess the ability of climate model.

In addition, the numerical simulation with ancient land-ocean distribution (GP) and modern SST distribution (SSTM) is carried out in an effort to examine the function of SST.

II. SIMULATION SCHEME

Employing CCM1 dynamic climatic model of NCAR of USA, we conduct five numerical experiments as follows:

(1) *MTP case*

It is a control test with modern distribution of land-ocean vegetation and the global topography, aiming to adjust the model into the best state based on modern observations.

(2) 1/2 *MTP case*

Only the height of TP is assumed to be half of MTP height and the vegetation of TP region is consistent with that at same altitudes on the east and west sides of TP. The other is the same as MTP case.

(3) *NTP case*

TP is as high as 500 m with the modern distribution of land-ocean and SST and the topography which exceeds 500 m between 40°E and 120°E is also reduced to 500 m. Smoothing method along the boundary of this area is used in such a way as to keep topographic continuity. Selected vegetation type is analoguous to 1/2 MTP case.

(4) *GPSSTP case*

We have collected the results of paleo distribution of land-ocean, SST and vegetation published in China and abroad and have conbined to a figure to show the pattern during the period of 40—50 MaBP (Fig. 1). In the figure, it indicated that the European and Asian land masses and Indian Subcontinent were still seperated and based on the vegetation pattern, it may be inferred that the north edge of subtropical forests might reach 60°N. Compared to the present, surface temperature is approximately 15°C warmer and SST in temperate zone of Northern Hemisphere is also warmer but in tropics colder, being responsible for little SST difference in the north-south direction. With the aim of analyzing seasonal change during 40—50 MaBP, the seasonal variation values of SST on the monthly average derived from the present records are added to ancient yearly mean SST so that the ancient monthly SST is of seasonal change.

(5) *GPSSTM case*

The case with GP and SSTM is designed in attempt to deal with the impact of SST upon antique climate and the role of TP.

In numerical experiments, the model of NCAR is improved in following fields: (1) the smoothing TP topography with 4000 m in CCM1 is replaced by realistic TP topography

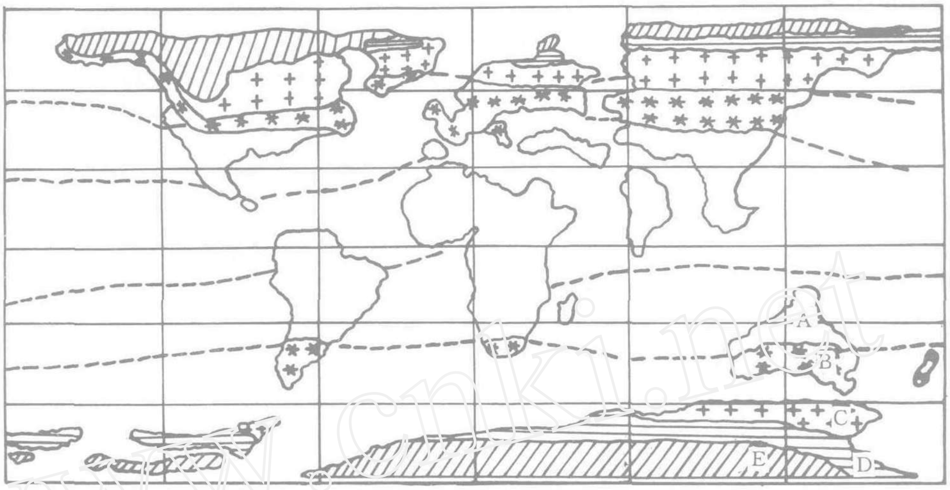

Fig. 1. The patterns of land-ocean and vegetation and SST during the period of 40—50 MaBP. A: tropical rainforest; B: subtropical rainforest; C: evergreen broad-leaved forest; D: coniferous and broad-leaved mingled forest; E: mixed coniferous forest.

with 4600 m and the vegetation pattern in the mainland is adjusted by Chinese observational data; (2) some parameters in the schemes of computing convective and stable precipitation of CCM1 are changed so that the simulated rainfall pattern in the control test approaches to the climatic observations on the average of three decades from 1961 to 1990 (Chen and Zhu et al. 1998); (3) surface turbulent exchange coefficients (C_D, C_H) are adjusted to the value of $4-5\times10^{-3}$. This value is derived from the computation results using the data of the observation stations which are built in the Tibet area since 1991 for studying heat balance and are much less than those in CCM1 so that the computed surface air temperature is closer to the climatic observational value in TP and its neighborhood.

In the experiments it is found that the global integral energy keeps stable from the third integral year for cases (1)—(3), but from the fifth year for cases (4) and (5), so that we integrate the model to six years for each case and analyse the mean values of the last two years.

III. EFFECT OF LAND-OCEAN DISTRIBUTION AND TP UPLIFT ON THE YEARLY PRECIPITATION

Figure 2 indicates the simulated yearly precipitation distribution for MTP and GPSSTP cases and the differences among the cases of GPSSTP, NTP, 1/2 MTP and MTP.

From the rainfall distribution of MTP case (Fig. 2a) it is seen that a strong rainfall center is located in the northeast of Indian and Bay of Bengal and spreads to the mainland of China, causing the precipitation of the mainland to decrease in the direction from SE to NW. This is coincidence with observational pattern. The simulated rainfall amount in China to the south of 30°N is around 2190 mm, close to the realistic value of 1500—2000

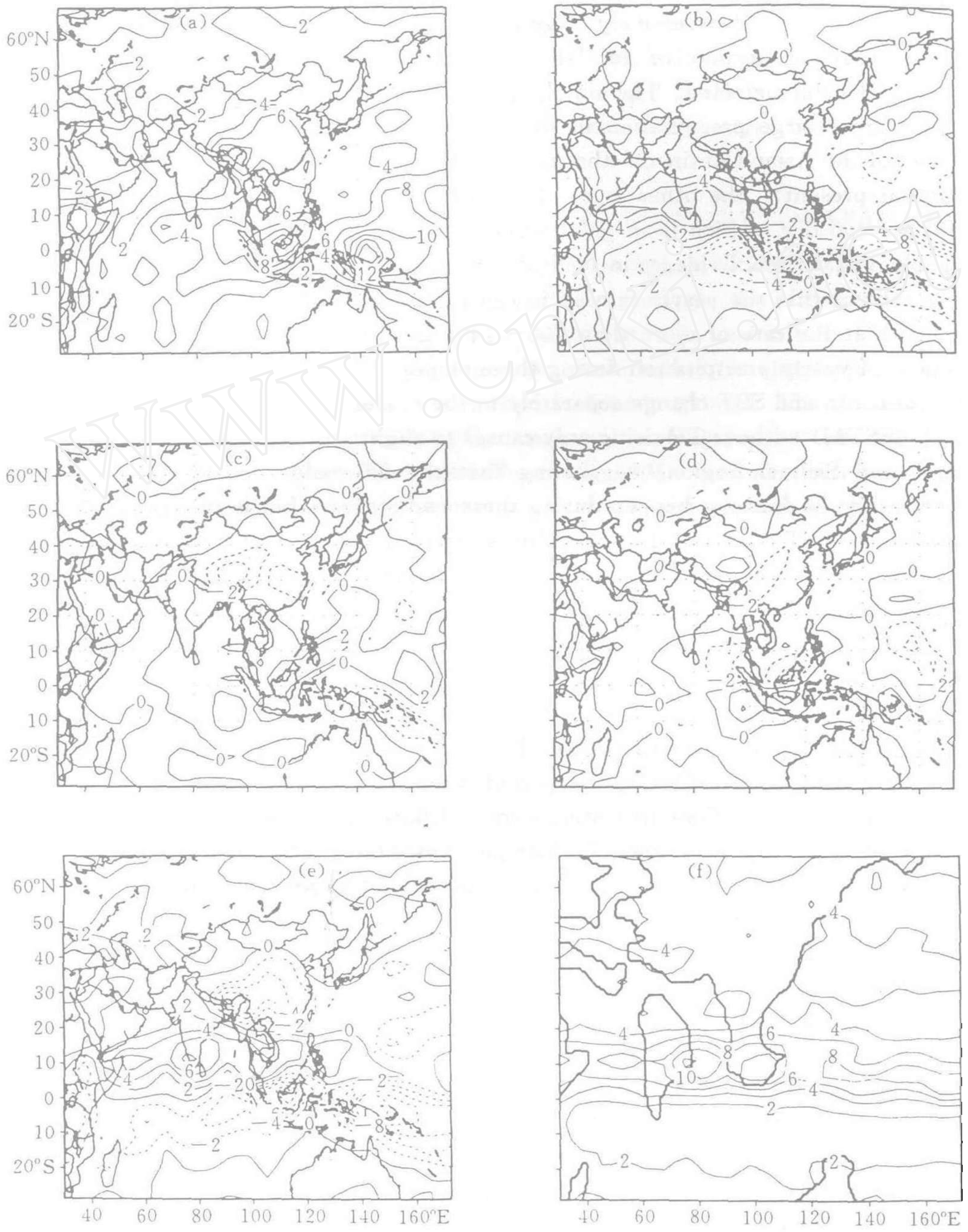

Fig. 2. Effect of TP uplift and land-ocean pattern change on Asian yearly precipitation (mm d^{-1}). (a) MTP case; (b) difference between GPSSTP case and NTP case; (c) difference between NTP case and 1/2 MTP case; (d) difference between 1/2 MTP case and MTP case; (e) difference between GPSSTP case and MTP case; (f) GPSSTP case.

mm. In addition, the other two rainfall areas centered respectively in the South China Sea and the west of the equatorial western Pacific with maximum of about 3500 mm are also simulated out in spite of excessively large rainfall amounts being simulated. This implies that the simulated results of rainfall for MTP case agree well qualitatively with observations in the mainland. The simulation of GPSSTP case (Fig. 2f) indicates the fact that apart from large precipitation in the equator and the rainfall of 4 mm d^{-1} in the southwest of the Asian Continent (that means the region from the central Asia to the west of China at present), the other areas of the landmass where the rainfall is less than 2 mm d^{-1} are too dry, which is in good agreement with the climatic distribution inferred from geological period. Evidence in the difference between the cases of GPSSTP and MTP (Fig. 2e) shows that the yearly rainfall in central and East (Northwest) China increases (decreases) at the rate of more than 700—1400 mm (700 mm). Further analyzing the differences of yearly precipitation during three stages (Figs. 2b, 2c and 2d) indicates that paleo land-ocean and SST change separately to the modern pattern of land-ocean (LSPM) and SST (SSTM) without TP rising only causes to slightly increase of rainfall in the south of China and Sichuan region, suggesting that the noticeable increase of precipitation depicted in Fig. 2e does not happen during these two stages, that is to say, the change of land-ocean and SST does not make the Chinese rainfall too much change. Figure 2c shows the difference between the cases of NTP and 1/2 MTP. It is seen that except the north part of Northwest China in which the precipitation slightly reduces from beginning of the uplift to 1/2 MTP, in the other region of China including the east of Northwest China (such as Gansu, Qinghai, Ningxia and the west of Inner Mongolia) and present Gobi Desert region the rainfall increases a great lot with its centers mainly locating from the Tibet east of 80°E, including the West China, the central China, East China and south part of the central China. During the period from 1/2 MTP to MTP, the precipitation remarkably decreases in the entire west part of China (including TP area) and does the same in most of East China except the Yunnan, Guizhou and Sichuan Provinces.

It turns out that during the course from the ancient to present, ancient land-sea and SST transforming to LSPM and SSTM does not give rise to the increase of Chinese rainfall but TP uplifting does. Moreover, the precipitation increases all the way until TP reaches to 1/2 MTP and then the rainfall decreases. Therefore, for the precipitation change of China, from beginning of the uplift to 1/2 MTP is a crucial period in which relevant height of TP is called "critical height" by Kutzbach et al. (1993). About the reason of the great change in rainfall, it is held in the past that the dynamic function of TP helps air to climb the south slope of TP, monsoon will be to cross over TP and arrive to West China, leading to the formation of precipitation. Except for the above explanation, we believe that thermal factor is also important. The obvious thermal contrast between TP and its neighborhood does not emerge before TP rising to 1/2 MTP. However, as TP continues to uplift afterwards, the noticeable thermal contrast overcomes the dynamic function that produces ascent over TP and descent in its vicinity in summer and then over TP it observes a special TP monsoon circulation that hinders summer Indian monsoon to move into the TP area and leads to take place strong convection of tropical monsoon in Indian monsoon trough around 23°N. Only when the trough weakens and shifts northward from its normal location to the foothill of TP and converges into the TP monsoon system, may the summer monsoon in the south of TP move into the TP, being responsible for the rainfall in this region. In the same time, Indian monsoon breaks out (Chen et al. 1991).

From the above results, it may be inferred that West China was not short of rainfall before uplifting of TP to 1/2 MTP and the present drought of the Northwest China (such as Taklimagan Desert) and the accumulation of Chinese loess might be formed after TP exceeds 1/2 MTP.

IV. EFFECT OF LAND-OCEAN CHANGE AND TP UPLIFT ON YEARLY TEMPERATURE

Similar to Fig. 2, we also analyze the simulated yearly surface air temperature and its difference during different periods (Fig. 3) so as to investigate the effects of land-ocean change and TP uplift on the change of air temperature in Asia, specially in China.

From the simulation of MTP case (Fig. 3 a) it is seen that the simulated temperature distribution on the annual average is in accord with climatic records. The simulated yearly surface air temperature of China is 7. 94℃, much approaching to 8. 4℃ on the basis of observation during 1961—1990 (Chen and Zhu et al. 1998), and the difference between them is 0. 46℃. This indicates that the simulated value of temperature of the control test is believable.

Figure 3f shows the result of GPSSTP case. As shown in Fig. 3f, the isotherm in the Asian Continent goes in the zonal direction. The difference between GPSSTP and MTP (Fig. 3e) exhibits that in comparison with ancient state, the present temperature is 15—25℃ less in the TP area, 10—15℃ lower in the mainland to the east of TP and 5℃ colder in Northwest China (Figs. 3b, 3c and 3d), which is close to the results estimated from geology (Li and Fang 1998). When the ancient land-ocean and SST change to LSPM and SSTM, the TP does not uplift alongside temperature reducing only about 5—10℃ in East China and about 5℃ in the west, implying that the simulated temperature variation from GPSSTP to MTP chiefly occurred after the TP uplift in West China and at least 70% of cooling in East China occurred after the period of NTP. From the difference between NTP and 1/2 MTP (Fig. 3c), we discover that under the conditions of LSPM and SSTM, the temperature in the TP area decreases 5—10℃ and 0—5℃ in East China and 5℃ in the northwest when the TP uplifts from the beginning to 1/2 MTP and the similarity takes place when TP rises form 1/2 MTP to MTP.

Based on the foregoing discussion, it can be concluded that from GPSSTP to MTP the temperature reduces 15—25℃ in the TP region, 10℃ in East China and 15℃ in West China. The variation in the TP area is mainly influenced by the TP uplift, but the changes of 10℃ and 5—10℃, i.e., about 70% of the cooling occurring after the uplift of Tibet, separately in Northwest and East China are owing to the TP rising, the other 30% are attributed to the variation of land-sea and SST distributions from the ancient to present without the TP uplift. Beyond that, the air temperature in the mainland of China linearly responds to the TP uplift, that means, no critical height for temperature variation.

It deserves attention that the foregoing discussion is only the simulated results related to the uplift of TP. During the period from GPSSTP to MTP, the global atmosphere experienced a wavelike process of temperature decrease. It is seen from the data of

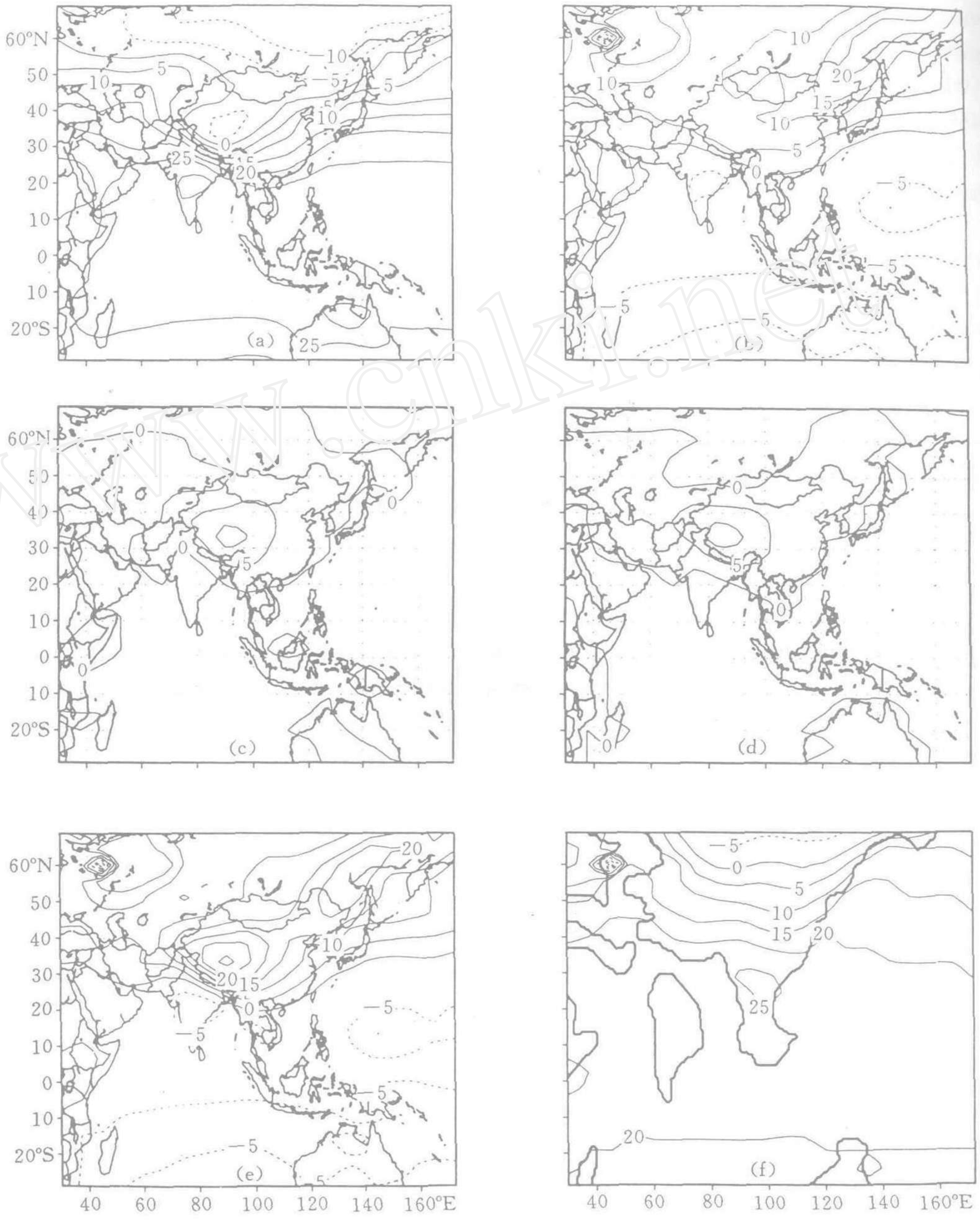

Fig. 3. As in Fig. 2 but for yearly temperature ℃(C).

foraminifer $\delta^{18}O$ at the seabed that since 50 MaBP the temperature at the high latitudes decreased about 15°C and experienced warming and glacial epoch repeatedly. Therefore, the uplift of TP probably is one of important factors which are responsible for the decrease of temperature. Our results only show that the uplift of TP might make the climate of China become cooling.

V. EFFECT OF LAND-OCEAN VARIATION AND TP UPLIFT ON LOW-LEVEL MONSOON CHANGE

Figure 4 shows the simulated January 850 hPa windfields for MTP, 1/2 MTP, NTP and GPSSTP cases. In MTP case (Fig. 4a), the mainland of China is controlled by NW winter monsoon which arrives in the Yellow (Huanghai) Sea and progresses southward and then changes its direction to NE winter monsoon at 22°N, observationally the flow turning direction at 25°N at 850 hPa and at 27°N over sea, and finally reaches the Southern Hemisphere through the equatorial region of the South China Sea. Compared to 850 hPa, the simulated area of NW monsoon at 1000 hPa is more inland (that is to say, more westward). The NW monsoon follows behind an East Asian trough at 850 hPa, which is extremely similar to the present records (Chen et al., 1991). But as depicted in GPSSTP case (Fig. 4d), over the Asian Continent and the east of continent does not exist NW winter monsoon except for WNW wind with the much weaker trough and over the tropics there is no NE monsoon but SW wind. In the difference between GPSSTP and MTP, in the place where NW monsoon happens at present there appears the SE difference in the winds and in the South China Sea there is a strong SW difference in the flows. It is easy to see that the zonal westerly wind prevails in the midlatitude (30—50°N) in GPSSTM case similar to GPSSTP case, but to the south of 20°N emerges tropical NE winter monsoon. For the reason, the modern low-level NE winter monsoon in the tropical area is mainly under the influence of the thermal contrast between the present SST and the landmass pattern and can not contribute to the TP uplift.

In the result of NTP case (Fig. 4c), the zonal westerly controls the mid-latitude similar to GPSSTP and GPSSTM cases and WNW wind takes place in the coast of East Asia without modern NW monsoon. In the case, the NE monsoon already occurs in the tropics. However, this is different from GPSSTP case but similar to GPSSTM, indicating the fact that the ancient SST distribution can not produce the tropical NE winter monsoon only in the situation that the SST distribution changes to modern pattern and along with the thermal pattern of the mainland, the NE monsoon can be formed. From the results of 1/2 MTP case (Fig. 4b), the NW winter monsoon occurs obviously in the East Asian coast and connects with the tropical NE monsoon that is more feeble than the present. Altenatively, in Fig. 4b the flow originated in the Arabian Sea turns the direction and forms SW wind in West China. The phenomenon is not seen in NTP case and MTP case, which indicates that before the TP uplifts to 1/2 MTP, the NE monsoon is in the east and the SW monsoon in the west. This monsoon pattern is favorite to the formation of winter rainfall. This phenomenon coincides with precipitation maximum in the west (Fig. 2c) in this stage. When the TP continues to rise, the SW winter monsoon in West China at 850 hPa disappears quickly.

From the foregoing analysis, it can be seen that the NW winter monsoon in the mainland of China is closely related to the TP uplift and reinforced with the TP rising and the tropical NE monsoon is mainly affected by the SST pattern. On the other hand, the northern component of the NE monsoon increases as TP uplifts, showing that the uplift has some effect on the NE monsoon strength. Additionally, the winter SW wind at 850

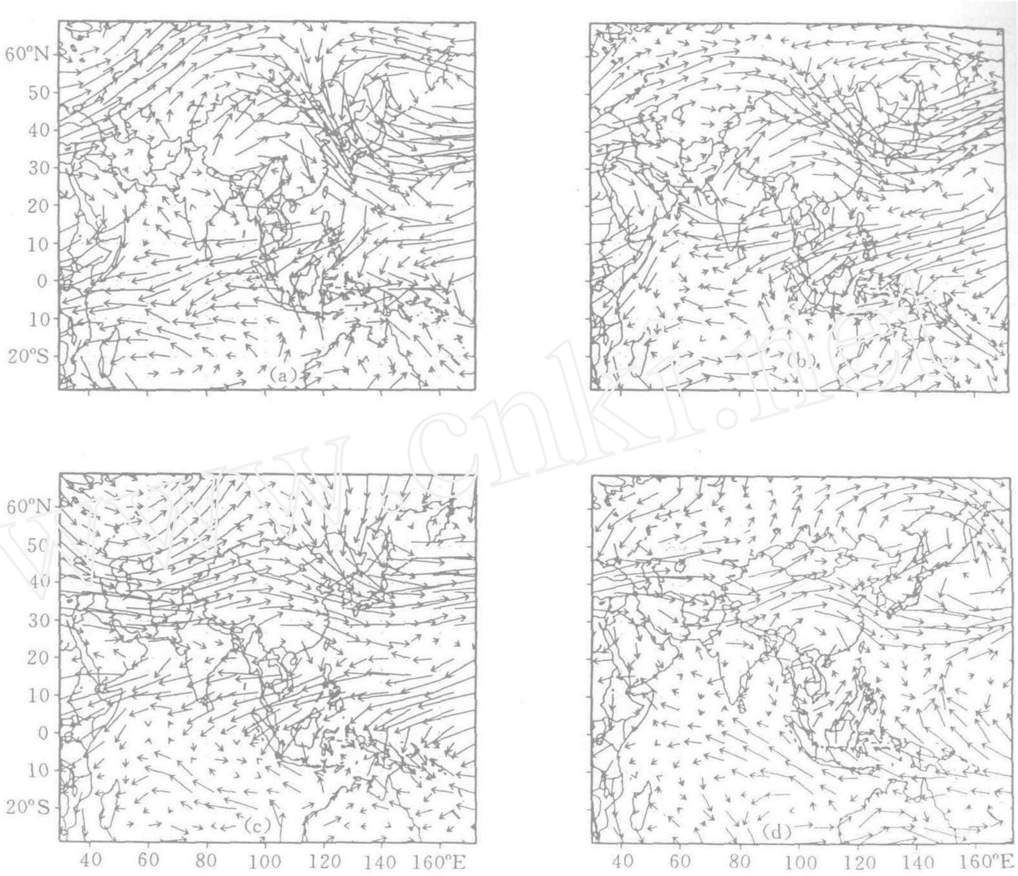

Fig. 4. Effect of TP uplift and land-ocean pattern change on January 850 hPa flowfield. (a) for MTP case; (b) for 1/2 MTP case; (c) for NTP case; (d) for GPSSTP case.

hPa happens in West China and stretches into the west part of the mainland of China when the TP rises to 1/2 MTP, which helps the increase of rainfall, and the SW wind vanishes with the TP continuing to uplift.

Now we discuss the simulated summer (July) windfields at 850 hPa (Fig. 5). In MTP case (Fig. 5a), over the tropics there exists a modern system of integrated SW monsoon which obviously possesses two branches of flow crossing the equator. One crosses the equator from the eastern coast of Africa (called Somalia low-level cross-equator flow) and another crosses at around 105°E into the South China Sea. The two flows at 1000 hPa remarkably make the system of the eastern Asian monsoon circulations distinct from that of Indian monsoon circulations. This characteristic is extremely close to the observations (Chen et al. 1991). In addition, in MTP case the summer SW monsoon may migrate into the middle of the mainland of China and arrive to the Northeast China. In QPSSTP case (Fig. 5d), however, in summer over the Asian Continent is NW-WNW wind that forms the drought in the mainland of China. West of 100°E the NW wind expands to 10—15°N and then changes into SW wind. In the east of 100°E the flow with north wind component is prevalent over the East Asian Continent and SW wind migrates

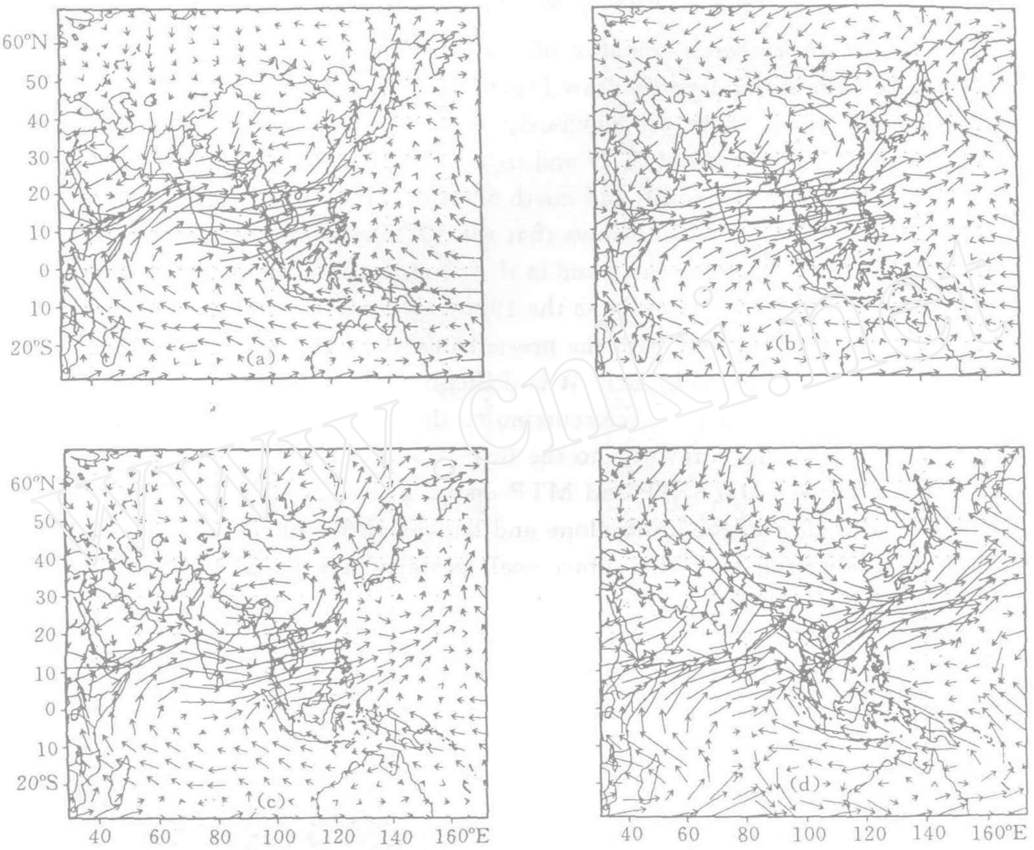

Fig. 5. As in Fig. 4, but for 850 hPa July.

to the western Pacific from the South China Sea. The modern summer SW monsoon can not enter into the continent under the ancient SST and land-ocean patterns. Evidence in the results of NTP case (Fig. 5c) displays that the southern component of SW monsoon is weaker. And the stronger SW monsoon only appears in the regions of the Arabian Sea and the east part of the South China Sea and may move into the mainland of China only over the eastern coast of the eastern Asian landmass. In 1/2 MTP case (Fig. 5b), the tropical SW monsoon is stronger and the SW monsoon to the east of 100°E may reach the mainland of China to 35°N and then turn direction so as to travel to the east of Northwest China.

From the above analysis, it is seen that the summer tropical SW monsoon only takes place to the south of 15°N under the paleo period (GPSSTP) and the SW monsoon with weaker south wind component only expands to 20 — 25°N under the LSPM and SST conditions (NTP). However, the SW monsoon quickly strengthens and stretches toward the west into the mainland of China when TP begins to rise and the monsoon reaches farthest westward when TP uplifts to 1/2 MTP (1/2 MTP). The SW monsoon is difficult to move westward into the west part of China although the monsoon is stronger as the TP continues to uplift after 1/2 MTP period. Similar to the winter NE monsoon, the intensity of summer monsoon strengthens continuously with increasing TP height.

VI. EFFECT OF LAND-OCEAN CHANGE AND TP UPLIFT ON UPPER-LEVEL CIRCULATION

In an effort to research impacts of the TP uplift and land-sea change on the circulation at 200 hPa in January we draw Fig. 6. In 200 hPa fields of MTP case (Fig. 6a), over Eurasian Continent there are obviously two branches of westerly jets. They are separately located to the south of 35°N and to the north of 40°N. Over Europe also exist two jets which stretch to the south and north sides of TP and combine into one strongest jet in the world over Japan, which shows that the TP is less important in the formation of these two jets than in stabilizing them and in their combination that leads to the occurrence of the eastern Asian trough. As early as the 1950s. Wu and Chen (1957) have noticed the phenomenon. This is consistent with the present observations (Chen et al. 1991). In the simulation of GPSSTP case (Fig. 6c), it is difficult to distinguish these two upper-level westerly jets over the continent only occurring to the east of 120°E and do not merge but separate each other, being unfavorite to the formation of eastern Asian trough. Evidence in the difference between GPSSTP and MTP displays that over the region of the trough there exists a difference in the anticyclone and between 20—40°N exists difference in the easterly wind, indicating that the subtropical westerly jets in GPSSTP case are much weaker than those in MTP case.

When TP begins to uplift (Fig. 6c), the two jets over the mainland also start to be

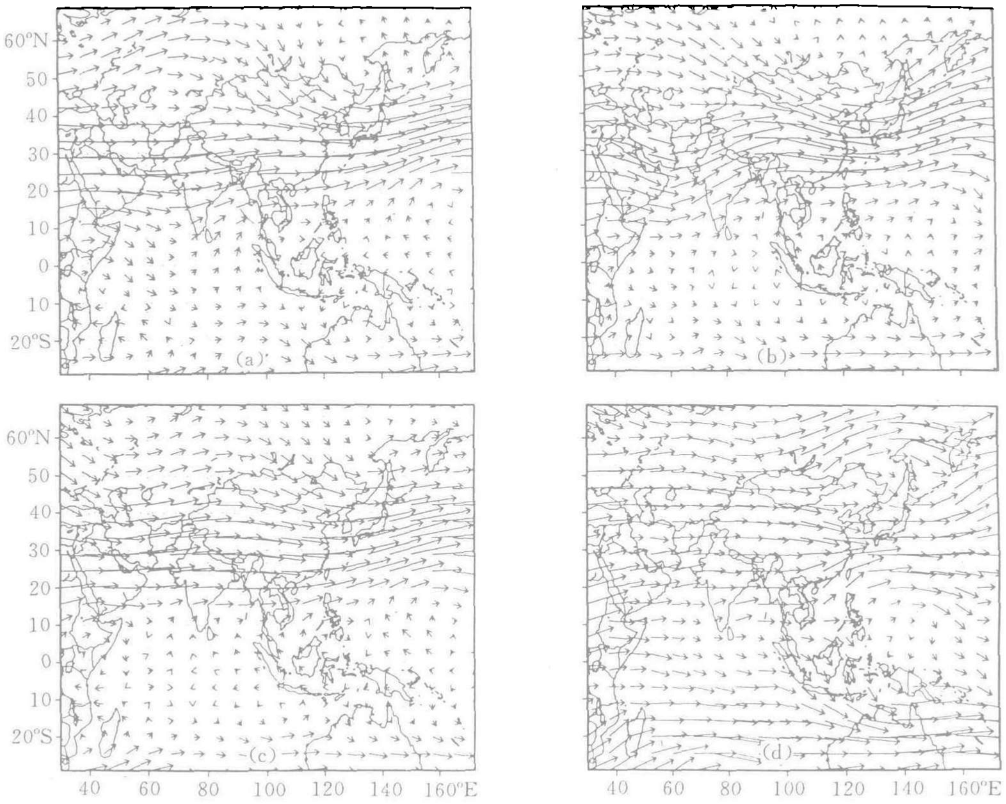

Fig. 6. As in Fig. 4 but for 200 hPa.

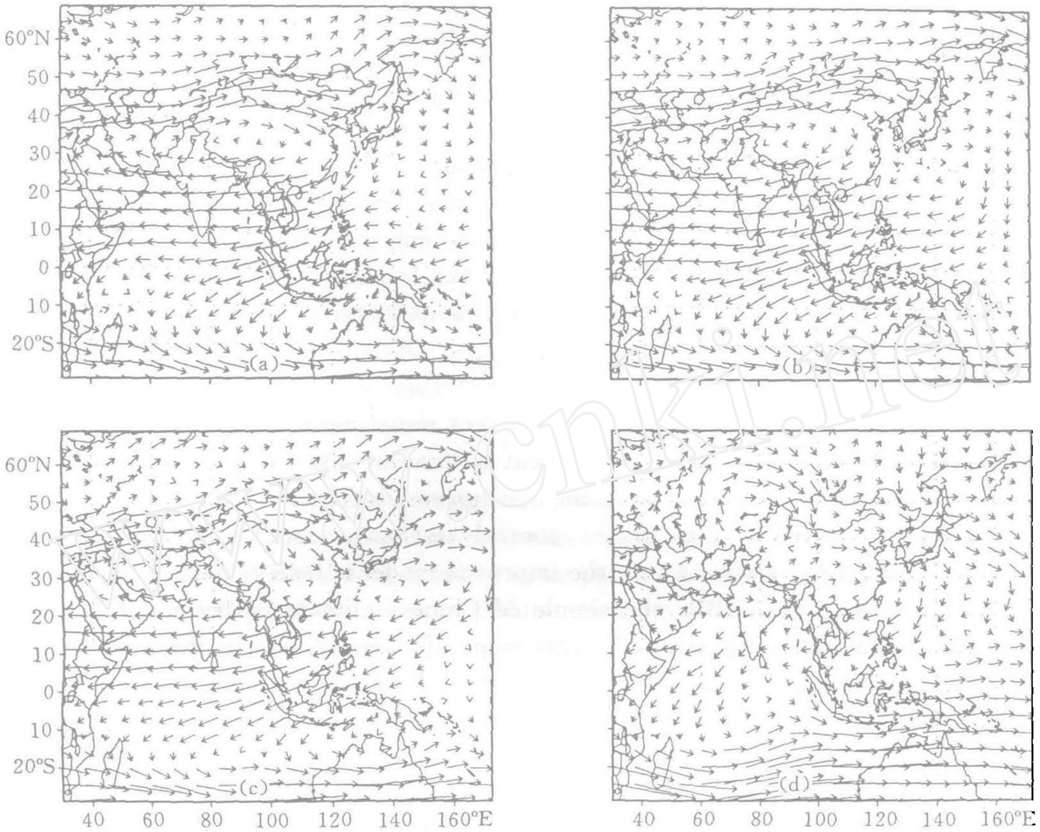

Fig. 7. As in Fig. 5 but for 200 hPa.

noticeable and a faint trough forms in the eastern Asian coast as the thermal contrast between land and ocean forms. Compared to the result of MTP case, the jets are easy to be seen in 1/2 MTP case except that the two jets merge and the trough forms more westward. Additionally, the flow with south wind component in front of the jet trough of southern branch over the Arabian Sea expands all the way to the West China, which implies that even if in the winter rich water vapour can also be transported to the west so as to satisfy the demand of precipitation. With the TP rising continuously, the flow disappears. Therefore, the winter upper-level two jets emerging in the early stage of the TP uplift strengthen and maintain on the south and north sides of the plateau alongside mergence of the jets into a stronger jet downstream of TP when TP rises further, giving rise to the formation of the eastern Asian trough.

Figuer 7 depicts the simulated 200 hPa flowfields in summer (July). It is seen therefrom that the circulation system located over the TP in MTP case is an upper-level anticyclone with its axis around 35°N, and to its south there are two branches of easterly jets which cross the equator separately in Africa and the South China Sea. This is also close to the climatic observational data (Chen et al. 1991). Adversely, the upper-level high pressure belt is much weak and is located in the vicinity of 20°N in GPSSTP case (Fig. 7d) alongwith two weak centers respectively over South China and Arabic Sea. In general, the subtropical anticyclone is inconspicuous. After the plateau begins to uplift

(Fig. 7c), the anticyclone becomes successively noticeable with two centers separately over the western Pacific (about 32°N) and TP (90°E). Thus, both of the TP uplift and LSPM and SSTM have effect upon the formation of the anticyclone belt and the anticyclone over the TP.

When the plateau reaches 1/2 MTP (Fig. 7b), the flowfields agree well with the results of MTP case. At the same time, an anticyclone in high pressure belt vanishes over the western Pacific and only another anticyclone center maintains over the TP, which indicates that TP uplifting has little impact on the formation of upper-level subtropical high belt but on reinforcement of the belt and its center stable over the TP.

VII. CONCLUSIONS AND DISCUSSION

From the results of five cases which represent the climatic features of different land-ocean and SST distributions from the ancient to present and the different stages in the process of TP uplifting, we can obtain the conclusions as follows:

(1) The simulated results of the control test are close to the present Chinese climatical observations, showing that the improved model is believable.

(2) During 40—50 MaBP, the simulated Chinese climate is dry and hot alongside little rainfall in the most regions aside from some of West China. In the course from the ancient state to the initial stage of the TP uplift, the simulated rainfall in China does not obviously increase, but from initial uplift to half height of modern TP the simulated yearly precipitation amplifies in China. However, the rainfall, particularly in the west part of China, decreases except for Yunnan, Guizhou and Sichuan as the TP continues to rise, which suggests that in so far as rainfall is concerned, there possibly exists a "critical height" that is as high as half of the present TP. Beyond that, we hold that during this period except that the TP dynamic effect makes the rainfall decrease in West China, the thermal contrast between TP and its neighborhood in the later stage of the uplift is also important to precipitation quickly decreasing in West China. And the drought and desert areas of West China mainly form after TP rises to half height.

(3) From 40—50 MaBP to modern time, the temperature of China obviously becomes cold. The simulated temperature reduces 20—25°C in the TP region and 10—15°C in East China and 15°C in the northwest. From the ancient period to the early stage of the TP rise, the temperature in the west part of China decreases 5°C and in the east part decreases 5—10°C. From the initial stage of the TP uplift to the present time, the uplift makes temperature of the plateau (the east part of China) reduce about 15—20°C (10°C). Hence, as for impact of land-ocean change and plateau uplifting on the cooling in China, the cooling chiefly takes place during the process of the TP uplift and is more remarkable versus the rising, that means, the rising leads to colder climate of China and as far as temperature is concerned there does not exist a "critical height".

(4) As we know, the facts causing the temperature decreasing (cooling) are complex, the Tibetan uplifting only is one of the important facts. So we need to study more for other facts. Under the ancient condition, in the eastern Asia there are not modern low-level winter NW monsoon in mid-latitudes and NE monsoon in tropics and two upper-level strong westerly jets and the mergence of the two jets downstream of TP. Low-level

summer SW monsoon is only seen to the south of 15°N with a weak upper-level subtropical high pressure belt. In the stage from the ancient time to the early period of TP uplifting, in the winter the land-ocean distribution and the thermal contrast between land and ocean are responsible for weak NE wind at mid-latitudes and strong tropical NE monsoon and high-level two weak westerly jets and weak trough over the eastern Asian coast. In the summer, the land-ocean effect causes a weak low-level SW monsoon which enters into the mainland in the coast of China and a weak upper-level anticyclone with several centers. Before the TP reaches half height of MTP, summer low-level SW monsoon is noticeable and stretches to the mainland of China and then turns into SE wind which further arrives in West China. At the same time, the center of upper-level subtropical high belt stabilizes over the plateau and winter low-level NW and NE monsoon in East Asia is extremely remarkable alongwith upper-level two westerly jets and a trough in East Asia. It is also seen that only during this stage, in winter there exists a flow with southern component originating in the Arabian Sea and entering into West China. In summer the SW monsoon enters into the mainland and changes direction and then reaches West China , resulting in the circulation condition which is helpful to more precipitation.

On the whole, effect of the plateau uplift on the Chinese climate predominantly makes the place colder and from the early stage to the half height the rainfall in China remarkably amplifies (specially in the west part of China). However, with the continuing uplift the rainfall quickly decreases, particularly in the northwest of China.

Although we obtain some interesting results, the model is not a ocean-atmosphere coupling model with high resolution and many conditions (such as SST) are artificially set, responsible for the coarse results. We expect to simulate further the effects of TP uplifting on climate by using a high resolution ocean-atmosphere-land coupling model which embeds with a fine-mesh regional climatic model. Moreover, the variation of astronomical factors is also not considered in our simulation, therefore, it is difficult to simulate the glacial period and so on. All of these are under improvement. Finally, we hope the geologists, geographers and meteorologists to cooperate in applying the tool of numerical simulation in the field and expect an integrated theory explaining the climatic states during different geoglogical stages in China.

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