A COMPARATIVE STUDY OF THE HEATING EFFECTS OF THE TIBETAN PLATEAU AND THE WESTERN PACIFIC*

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Received October 11, 1995; revised January 29, 1996

ABSTRACT

A zonal domain primitive equation modeling system (ZDMS) is used to study the effects of the initial heating anomalies over the Tibetan Plateau and the western Pacific on the East Asian and the Chinese summer climate, the relative importance and the mechanisms are discussed. Results show that in spite of the different locations of the heating anomalies the influences of the two anomaly areas are much similar to each other when the scaling of the two areas is the same. The two areas of heating anomalies have their own affecting domains in which one is more important than the other. In the western Pacific the heating anomaly over the western Pacific is more evident and in the Tibetan Plateau area the heating anomaly over the Tibetan Plateau is more obvious. For the east part of China the effects of the two heating anomalies both exist and almost have the equal importance. The initial anomaly of the sea surface temperature (SST) over the western Pacific can be kept during the entire time integration while in the Tibetan Plateau it can not be maintained.

Key words: numerical experiments, summer climate, heating effects

I. INTRODUCTION

The heating effects of the Tibetan Plateau and the western Pacific on the East Asian and the global general circulations are the well-known fact. There are quite a lot of studies on the effects of the Tibetan Plateau at home and abroad; either observational or theoretical studies have already pointed out the important influences of the Tibetan Plateau on the weather and climate (e.g. Ye and Gao 1979; Qian et al. 1988; Hahn et al. 1975; Kuo and Qian 1981; 1982; Qian and Wang 1984). As to the influences of the sea surface temperature anomalies (SSTA) there have also been many observational and theoretical studies showing the important effects on the abnormal climate formation (see Ye et al. 1991). However, most previous studies usually separately investigate the heating effects of the Tibetan Plateau and the western Pacific, and concentrate their attentions on the single effects of them. In fact, the heating effects of the Tibetan Plateau and the western Pacific simultaneously influence the weather and climate. Therefore, it is necessary to make comparative studies in order to clarify the relative importance of their heating effects. In the comparative studies, it needs to pay special attentions to the scaling problem of the heating anomaly areas. The spatial area of the western Pacific is much larger than that of the

* Supported by the National Key Project of Fundamental Research: The Land-Air Physical Processes over the Tibetan Plateau (TIPEX).

Tibetan Plateau; if the areas of the heating anomalies over the two regions are given differently, the relative importance is hard to be studied.

The heating anomalies can be represented in various forms. The abnormally high or low initial soil temperature or SST is one of the heating anomaly forms. In this paper, in order to compare the relative importances of the heat anomalies over the Tibetan Plateau and the western Pacific, two anomaly areas of the soil temperature and the SST at the initial time are specified. One is over the Tibetan Plateau and the other over the western Pacific; the spatial scales and the distributions of the anomaly values of the two areas are the same. A zonal domain numerical modeling system (ZDMS) is used in this paper to study the summer climatic properties under the single and the combined effects of the two heating anomaly areas. The relative importance and the mechanisms are also discussed.

In order to investigate the relative importances of the two heating anomaly areas, it needs to integrate the ZDMS up to a relatively long time such as one month. Can the ZDMS be used for such studies? It needs to check. The best method of checking is, of course, to compare the model results with the corresponding observations. Many papers we have published have already proved the capability of the ZDMS (see Qian et al. 1994; Qian and Qian 1995; Qian and Dong 1995). Another method is to compare the results of the ZDMS with the results from a global domain modeling system (GDMS) which has the same dynamic frame and model physics as the ZDMS. In this paper such a method of checking is also used.

II. MODEL SYSTEM AND EXPERIMENTAL SCHEMES

The model system includes three models as follows:

The atmospheric model: the p-σ incorporated coordinate system in vertical is used; there are 5 layers with 2 in the p-system and 3 in the σ-system; various physical processes are included such as the solar and the longwave radiations, the large scale and the convective scale condensations and so on. The grid size is 5° lat. × 5° lon. and the model domain is changeable. The usually used domain is a zonal one from 60°S to 60°N.

The soil model: there are 2 soil layers, the first model layer representing diurnal changes and the second the annual changes of the soil temperatures and moistures which are predicted; the temperatures and moistures at the ground surface are diagnosed. The layer thicknesses are computed according to the physical properties of soil. Five types of the underlying surface are included, i. e. the clay pasture, the tropical rainforest, the desert, the muddy water or swamp and the Plateau snow cover; if the model domain is global, then the ice covers in the polar areas are also included.

The oceanic temperature model: there are also 2 layers, the layer thicknesses are 50 m and 250 m, respectively, and the effect of the oceanic current is not taken into account yet in this study.

The details of the above three models can be found in the author' s previous papers (see Qian 1985; 1988; 1993).

Five experiments are made. Table 1 shows the experimental schemes. In Table 1, the

Table 1. Experimental Schemes

Scheme	Integrated days	Initial time	Initial fields	Heating anomaly	Peak value	Anomaly area
GLB	35	Jun. 26	Zonal	No	/	0
CNL	35	Jun. 26	Zonal	No	/	0
PH	30	Jul. 1	CNL 5 day	Yes	2°C	9×7
SH	30	Jul. 1	CNL 5 day	Yes	2°C	9×7
SHPH	30	Jul. 1	CNL 5 day	Yes	2°C	2(9×7)

GLB is a normal experiment with a global model domain in which neither in the Tibetan Plateau nor in the western Pacific there are heating anomalies. The time integration is made up to 35 model days starting from June 26 with zonal mean fields as the initial values. The last 30-day mean fields are taken as the July mean climate state. The second one (CNL) is the same as GLB but with a zonal domain from 60°S to 60°N and taken as the control run. The third one is the plateau heating (PH) experiment in which the initial soil temperatures in the plateau and its vicinity are abnormal. The centre of the anomaly area is located at 90°E and 30°N with a domain of 9×7 grid points in the longitudinal and the meridional directions, respectively. The value of the initial temperature anomaly is 2°C at the centre point and becomes zero at the area boundary. The fourth one is the sea surface heating (SH) experiment which is the same as PH but the centre point of the initial temperature anomaly area locates at 140°E and 10°N in the western Pacific. The last one is a composite experiment (SHPH) in which there are both the initial soil temperature anomalies in the Plateau area as in PH and the initial SSTA in the western Pacific as in SH.

It is well known that the area around 140°E and 10°N over the western Pacific is a key area because this area is located just in the "Warm pool" and the SSTA in this area has evident and important effects on the climate in China especially in the East China.

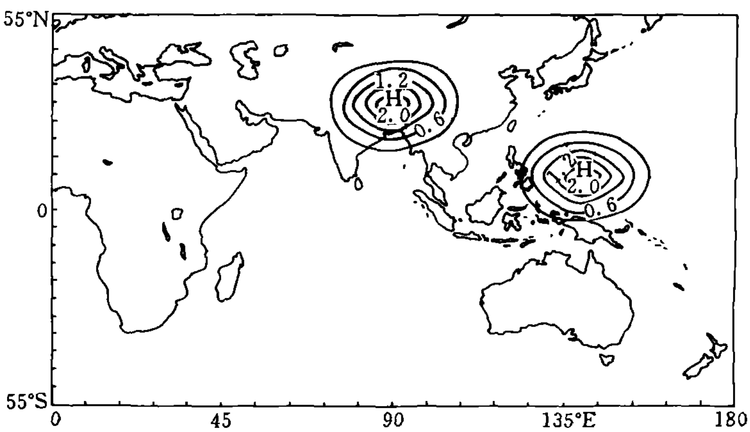

Fig. 1. Initial soil or water temperature anomaly areas in the Tibetan Plateau and the western Pacific used in SHPH.

Meanwhile, the SSTA in this area is usually closely related to that over the eastern Pacific and even to that over the Indian Ocean. Therefore, this area is selected as a representative area in our experiments.

Figure 1 shows the heating anomaly areas over the Tibetan Plateau and the western Pacific, respectively. As shown in Table 1, only the area over the Tibetan Plateau exists in PH and only the area over the western Pacific is kept in SH, while in SHPH both areas are included.

III. DISCUSSIONS OF THE RESULTS

1. *Similarities between GLB and CNL and the Main Results of CNL*

Figures 2a and 2b are the simulated 100 hPa geopotential heights (dm) and the sea level pressures (hPa) in CNL. The basic properties of them are quite close to the

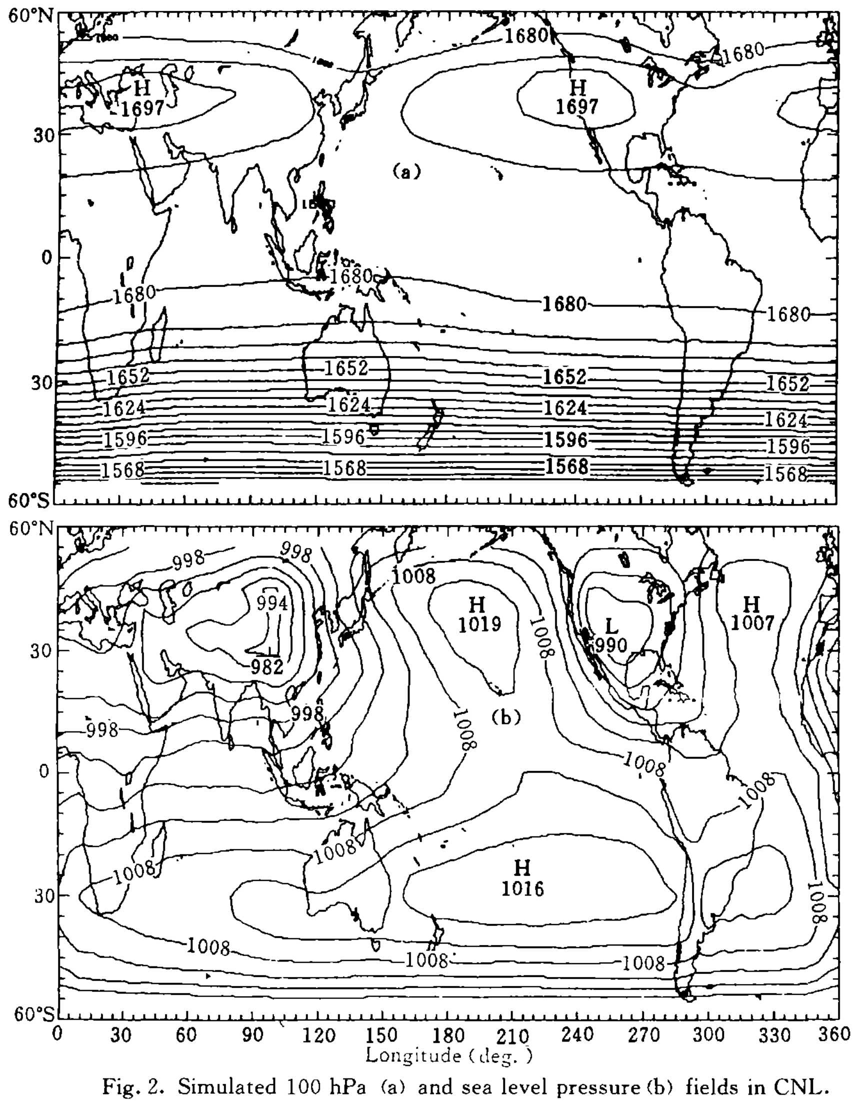

Fig. 2. Simulated 100 hPa (a) and sea level pressure (b) fields in CNL.

observations. For example, the large and strong highs at the 100 hPa level and the heat lows at the surface over the Tibetan Plateau and the North America are all well simulated. The zonal two wave structures of the simulated pressure systems are clearly seen.

The same fields from GLB are also analysed. It is found that the pressure patterns in GLB are very similar to those in Figs. 1a and 1b. The mean linear correlation coefficients between the results of GLB and CNL are shown in Table 2 for various model variables.

Table 2. Linear Correlation Coefficients between GLB and CNL in the Zonal Area from 60°S to 60°N (%)

Z	*T*	*W*	*U*	*V*	*R*
91.1	95.7	88.4	92.3	91.8	74.8

In Table 2, *Z*, *T*, *W*, *U* and *V* have conventional meanings and *R* is the total rainfall amount. From Table 2 it is seen that the simulated fields in GLB and CNL are quite similar.

Therefore, from the comparisons of the two experimental results and the correlation coefficients it is clearly seen that ZDMS can be used in spite of the non-global model domain.

Some results of the CNL are given next in order to further prove the capability of the

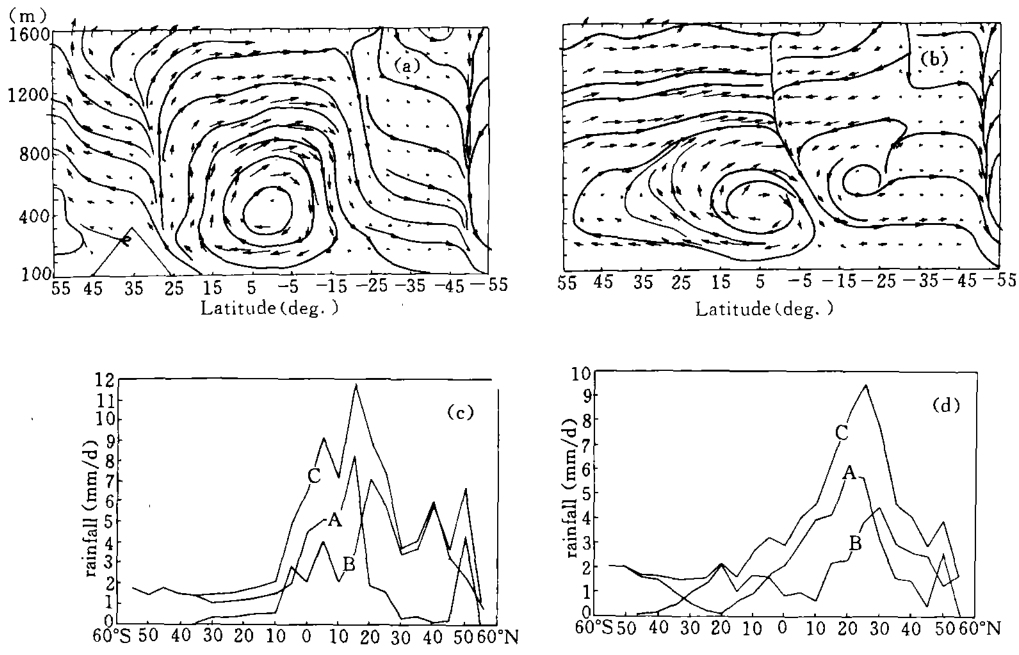

Fig. 3. Simulated mean meridional circulations along 70—110°E (a) and 120—160°E (b), mean rainfall profiles (mm/d) along 70—110°E (c) and 120—160E° (d) in CNL (Capital letters A, B and C in Figs. 3c and 3d indicate large scale, cumulative scale and total rainfall, respectively).

ZDMS.

Figures 3a and 3b are the mean meridional circulations along 70—110°E and along 120—160°E in CNL. Figures 3c and 3d are the same but for rainfall. From Figs. 3a and 3b it is found that the summer monsoon circulations over the Plateau area and its vicinities and over the East Asia are all well simulated and close to the observations. From Figs. 3c and 3d it seems that the peak values of the total rainfall and their locations are different in the two regions. In the Plateau area the peak value is about 12 mm/d which is larger than that in the East Asia and the location is more south. It is also seen that the cumulative precipitation is much more important than that due to large scale condensation, north of 20°N, in the Plateau area, while they are almost of equal importance in the East Asia.

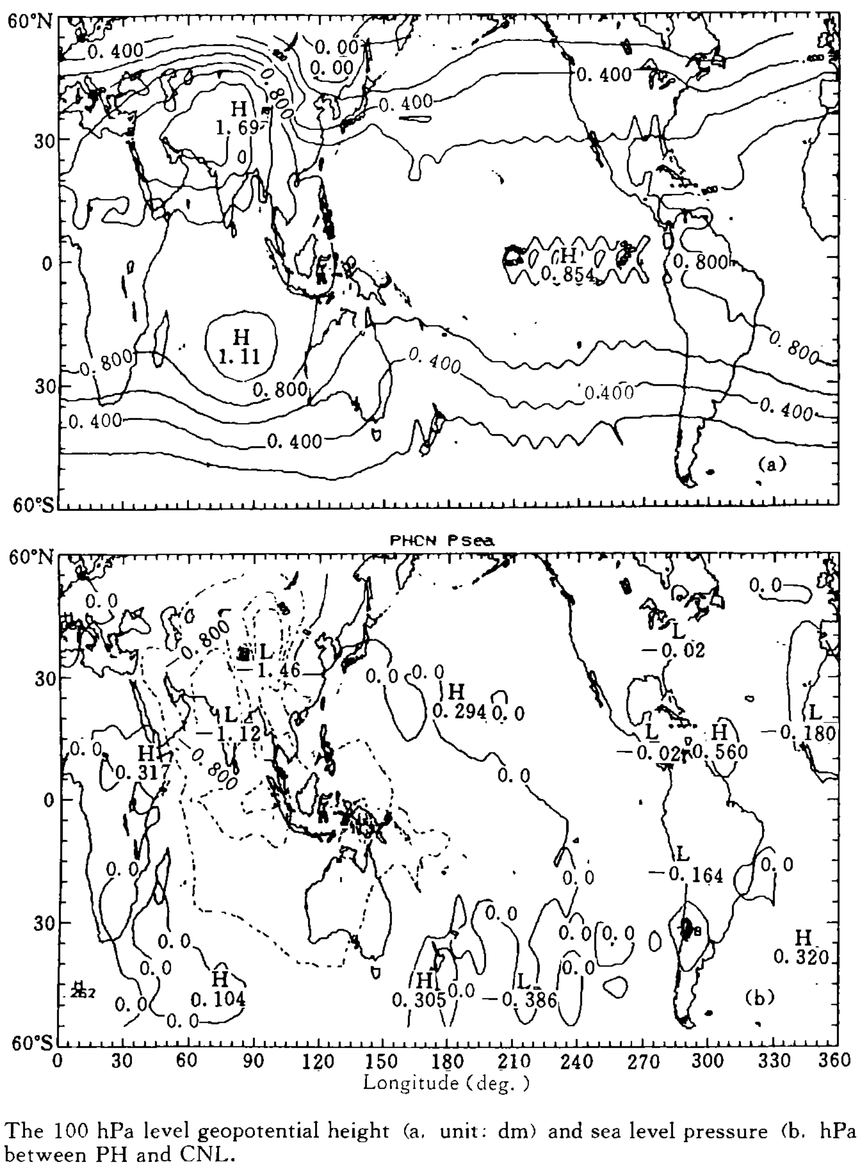

Fig. 4. The 100 hPa level geopotential height (a, unit: dm) and sea level pressure (b, hPa) differences between PH and CNL.

2. *Similarities between PH and SH and Their Differences from CNL*

Comparative analyses of PH and SH experimental results show that the influences of the plateau heating (PH) and the sea surface heating (SH) anomalies on the climate state are quite similar. The correlation coefficients between PH and SH are very high for various fields (see Table 3).

The differences of PH and SH from CNL also show the similarities between PH and SH. Figures 4a and 4b are the differences between PH and CNL for the 100 hPa geopotential height and the sea level pressure fields. Analyses of Figs. 4a and 4b and the corresponding differences between SH and CNL (not shown) point out that:

(1) Both abnormal heatings in the Plateau and in the western Pacific increase the 100 hPa level heights, especially over the Eurasian continent and the South Indian Ocean.

(2) In the sea surface level pressure fields of both experiments, there is a very wide area with decreasing pressure from the Eurasian continent to Australia through the western Pacific and the distributive patterns of the area are similar in the two experiments.

Comparisons also show that at the 850 hPa level the temperature difference patterns (figures omitted) are still close to each other but with some discrepancies. In spite of the high similarities in the temperature and the height fields, the precipitation fields of the two experiments are of more differences (figures omitted). The details of the differences between PH and SH will be discussed later.

Table 3. Linear Correlation Coefficients between PH and SH in the Zonal Area from 60°S to 60°N (%)

Z	*T*	*W*	*U*	*V*	*R*
99.88	99.90	98.46	99.68	99.41	89.37

Next we are going to analyse the effects of the two heating anomaly areas on the meridional circulations along the longitudinal belts where the two anomaly areas locate.

Figures 5a and 5b are the differential circulations between PH and CNL averaged along 70—110°E and 120—160°E, respectively. From Fig. 5a it is seen that the positive heating anomaly in the Tibetan Plateau increases significantly the upward motions over that anomaly area and consequently intensifies the summer monsoon circulations in the

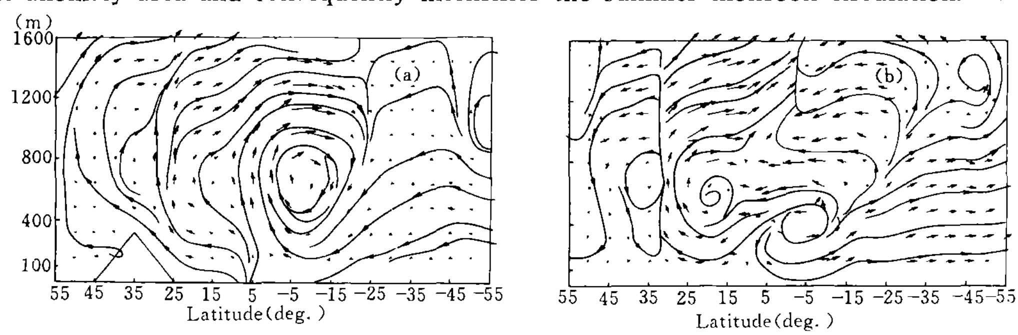

Fig. 5. Differential circulations between PH and CNL averaged along 70—110°E (a) and 120—160°E (b).

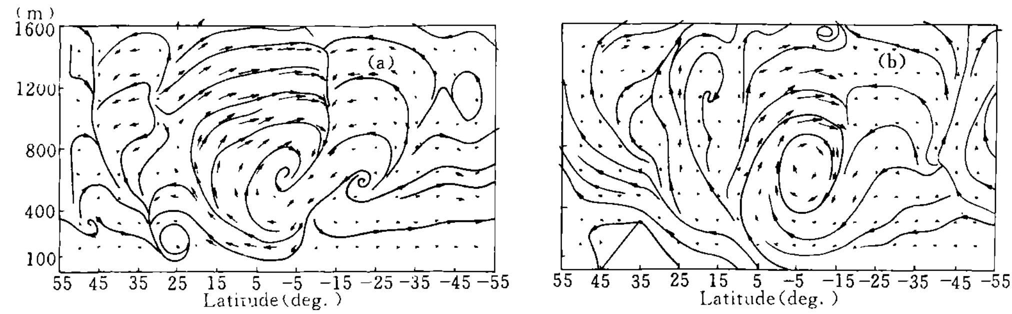

Fig. 6. Differential circulations between SH and CNL averaged along 120—160°E (a) and 70—110°E (b).

plateau and its vicinities. The ascent motions near 25°N in Fig. 5b strengthen as well.

Figures 6a and 6b are the same as Figs. 5a and 5b but between SH and CNL. From Fig. 6a it is found that the positive SSTA in the western Pacific increases the ascent motions right over the SSTA area just as the case in Fig. 5a. The upward motions over the plateau and its vicinities also increase by average (Fig. 6b). However, for 90°E the ascent motions near 25°N, right south of the plateau, somewhat decrease (not shown).

From above discussions we can see that although the locations of the heating anomalies in PH and SH experiments are different, their effects are basically the same. It is also found that the Asian continent and the South Asian subcontinent are the most sensitive regions to the heating anomalies over the world. There are still some differences between PH and SH and the details of the differences will be discussed later.

In order to judge which one of PH and SH is more different from CNL, we computed the linear correlation coefficients as shown in Table 4. From Table 4 it is seen that the differences between SH and CNL are larger than those between PH and CNL, which means that the heating effect of SSTA in the western Pacific is a little larger than that of the soil temperature anomalies in the Tibetan Plateau for the whole model domain, even though the spatial scales and the values of the two temperature anomaly areas are exactly the same.

Table 4. Linear Correlation Coefficients of PH and SH to CNL in the Zonal Area from 60°S to 60°N (%)

	Z	T	W	U	V	R
PH—CNL	99.782	99.832	98.630	99.666	99.517	92.114
SH—CNL	99.643	99.696	98.156	99.400	99.216	89.970

3. *Comparisons of SHPH with CNL*

The results of SHPH experiment are also analysed. It is found that the effects of both heating anomaly areas over the Tibetan Plateau and the western Pacific are nonlinear, because the results of SHPH are not the simple sum of results of PH and SH.

Figures 7a, 7b, 7c and 7d are differences between SHPH and CNL for the 100 hPa geopotential height, the sea level pressure, the 850 hPa level temperature and the total

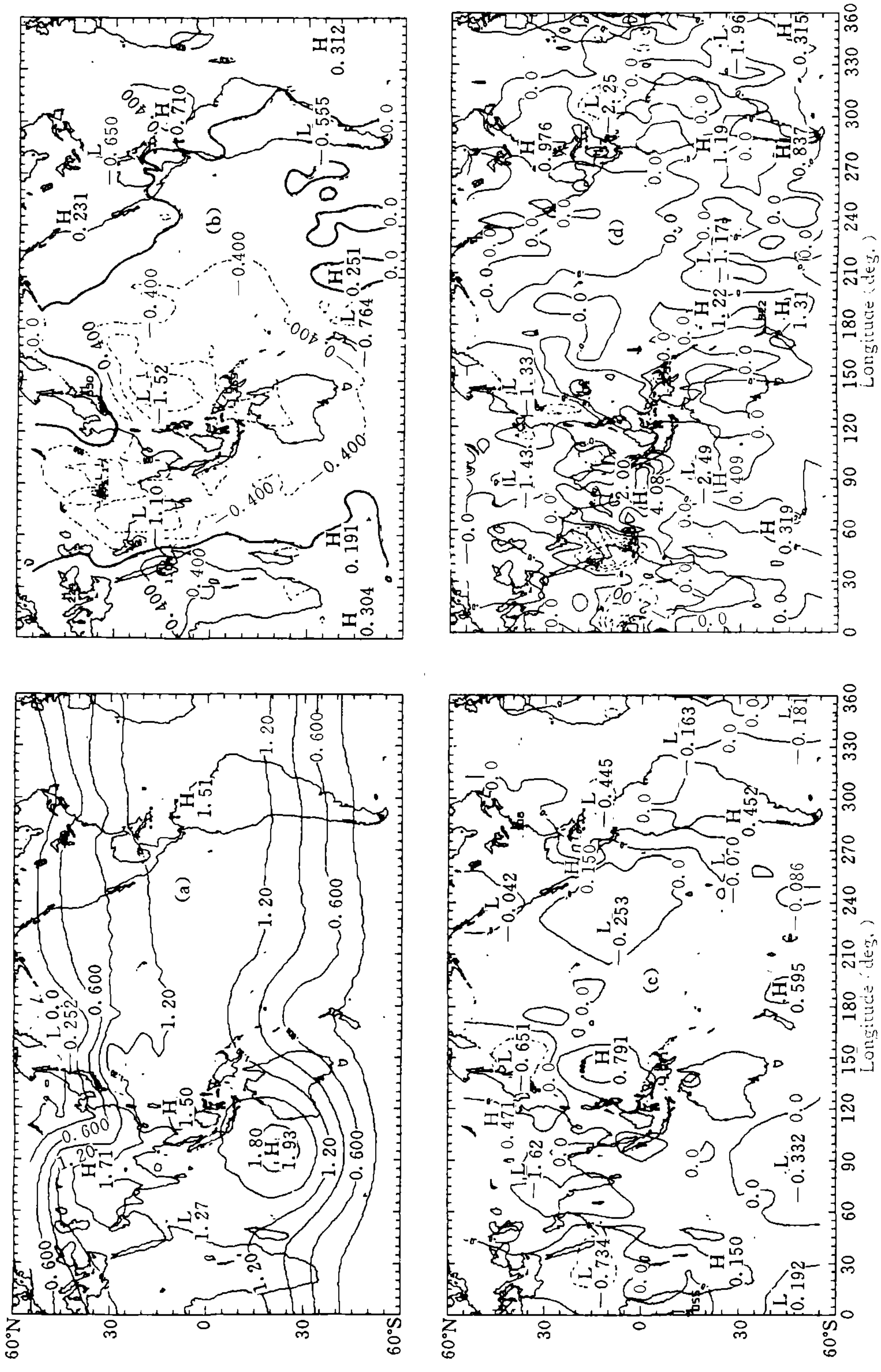

Fig. 7. The 100 hPa level geopotential height (a, dm), the sea level pressure (b, hPa), the 850 hPa level temperature (c, °C) and the total rainfall (d, mm/d) differences between SHPH and CNL.

rainfall fields, respectively. We can see that the distributive patterns in Figs. 7a, 7b are quite similar to those shown in Figs. 4a, 4b. However, because of the similar effects of PH and SH, the changes of SHPH compared with CNL are larger than those of both PH and SH.

From Fig. 7c it is seen that over the western Pacific heating anomaly area there are positive temperature differences with a centre value of about 0.8℃ which is evidently due to the initial SSTA, while over the Tibetan Plateau no apparent temperature differences can be seen at the 850 hPa level. Figure 7d shows that owing to the combined effects of the two heating anomaly areas the east part of China becomes a region with decreasing precipitation while most parts of China have increasing precipitation.

From the correlation coefficients of PH and SH to SHPH as shown in Table 5, it seems that the coefficients are larger between SH and SHPH in Z, T and U fields while the case is reversed in W, V and R fields. It seems that for some variables the results of SHPH are more similar to those of SH while for other variables they are more similar to those of PH. The mechanisms of the plateau heating anomalies and the western Pacific heating anomalies may be different.

Further analysis finds out a more interesting phenomenon, that is, the heating anomalies over the Tibetan Plateau and the western Pacific both have their own affecting domains matched to them. In the domain surrounding the plateau the plateau heating effect is dominant while in the western Pacific the Pacific heating effect is more evident. The area correlation coefficients between SHPH and PH are larger than those between SHPH and SH in the plateau area while smaller in the western Pacific area. As to the relative importance of the effects of the plateau and the Pacific heating anomalies on the precipitation over the East China, it is found that they have almost the equal importance.

Table 5. Linear Correlation Coefficients of PH and SH to SHPH in the Zonal Area from 60°S to 60°N (%)

	Z	T	W	U	V	R
PH−SHPH	99.800	99.776	98.702	99.616	99.276	90.638
SH−SHPH	99.846	99.837	98.203	99.618	99.225	89.700

4. *Comparisons between the Results of PH and SH*

Figures 8a, 8b, 8c and 8d are the same as Figs. 7a, 7b, 7c and 7d, respectively, but for the differences between SH and PH. In order to see the differences more clearly the maps are drawn only for the Eastern Hemisphere. From those figures we can find that there are indeed some differences between the two experiments, and from those differences we can judge their relative importances of PH and SH in different areas.

From Fig. 8a it is seen that the 100 hPa level heights are decreased in SH compared with that in PH, north of 25°N, while in all other regions the case is opposite. A comparison of Fig. 8a with Fig. 7a shows that the heating effect of the plateau is greater than that of the western Pacific at latitudes north of 25°N and smaller in other regions.

Figure 8b shows that in most areas of the Eastern Hemisphere the pressures at the

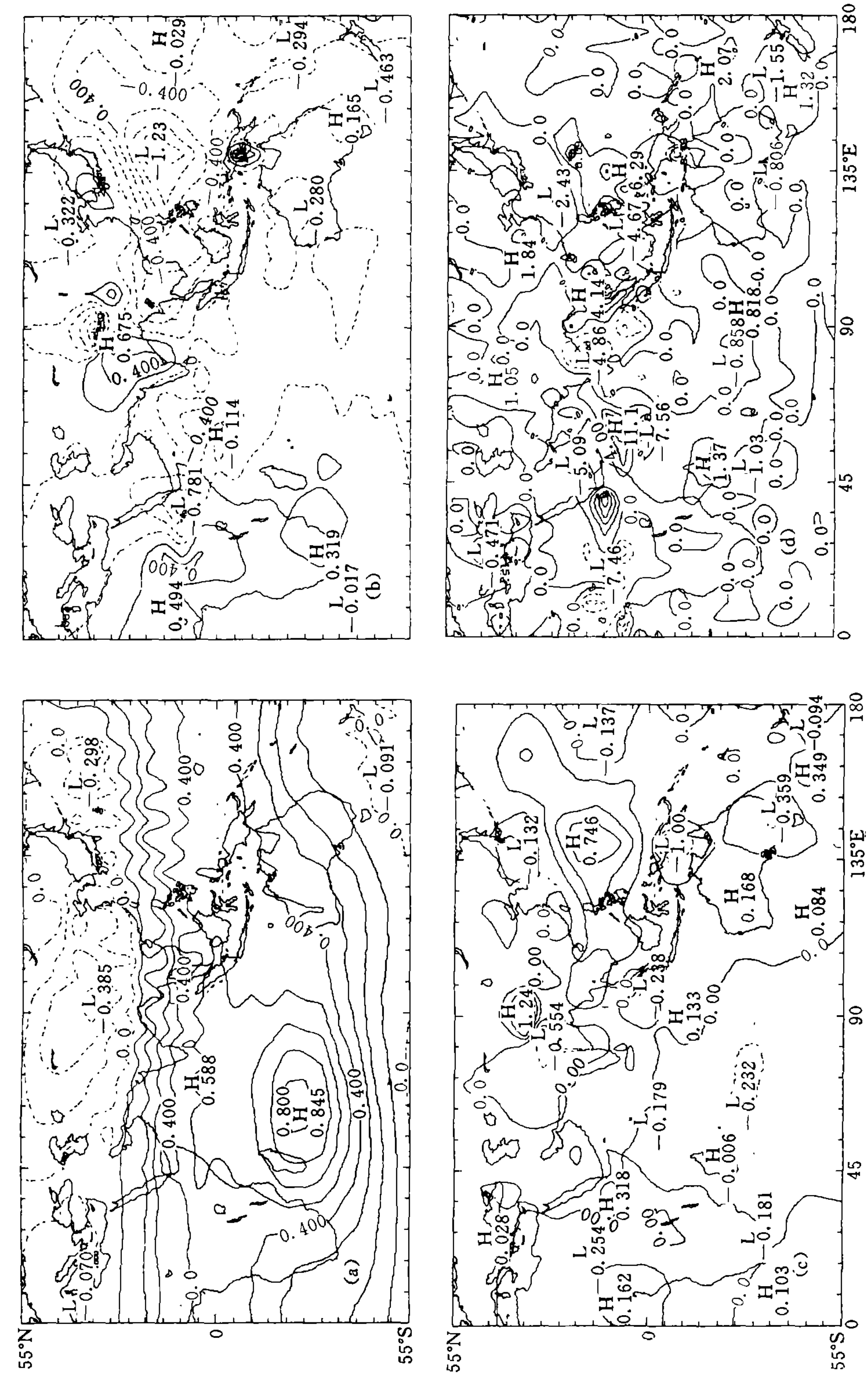

Fig. 8. The 100 hPa level geopotential height (a, dm), the sea level pressure (b, hPa), the 850 hPa level temperature (c, °C) and the total rainfall (d, mm/d) differences between SH and PH.

sea level are lower in SH than in PH, but while with some exceptions in the tropical west Africa, the west plateau area and the East India. Figure 8b is quite similar to Fig. 7b in the western Pacific where the pressure drops by more than 1 hPa in both figures. However, in the plateau area they are different. Therefore, it is further proved that the temperature anomalies in different areas have their own correspondent affecting domains.

Differences of the 850 hPa temperatures (Fig. 8c) show that in the western Pacific heating anomaly area the temperature is higher in SH than in PH by 0.748°C. In Fig. 7c, the temperature increase in that area is 0.791°C. Therefore, the heating effect of the western Pacific is more important there. However, in the plateau area the temperature change is mainly due to the plateau heating, because in that area SH induces a positive temperature difference near 35°N and 90°E where there is a negative difference in Fig. 7c.

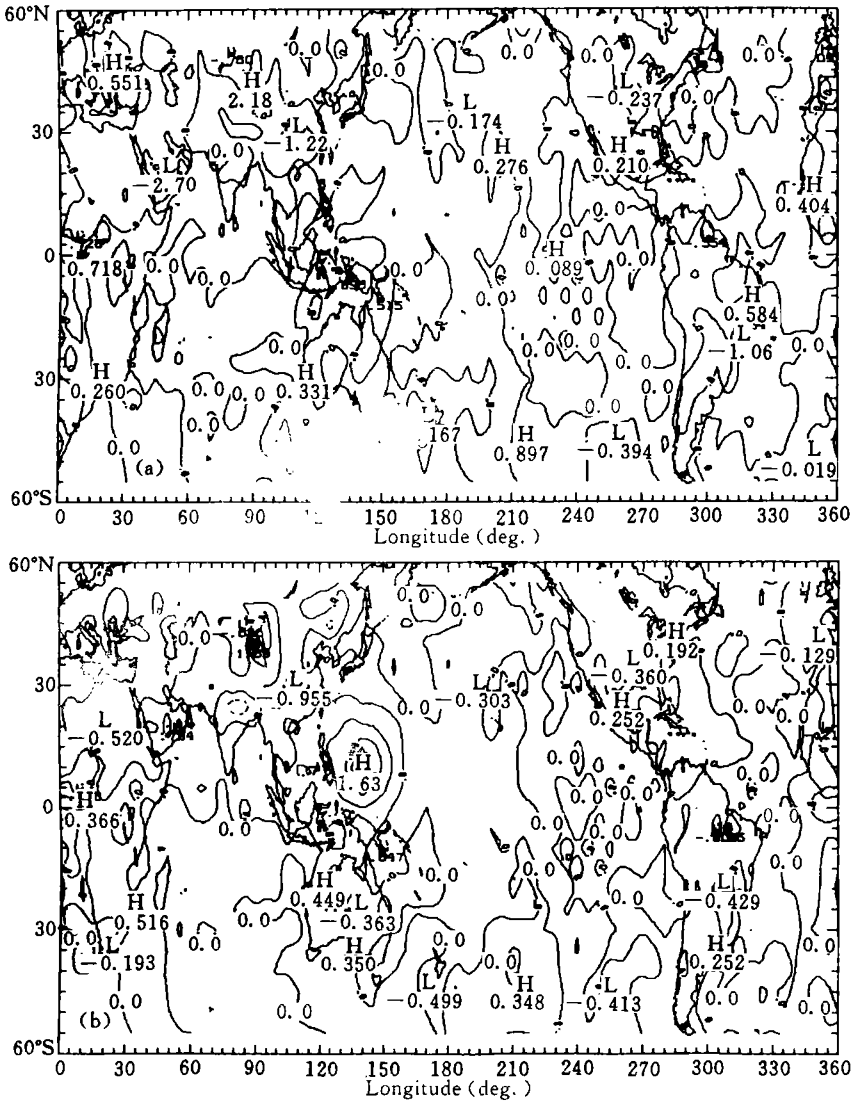

Fig. 9. Differences of surface temperatures (c, °C) between PH and CNL (a) and between SH and CNL (b).

As for the precipitation, Fig. 8d shows that there are quite a lot of differences between PH and SH, especially in the tropical belt. In China the difference is also evident. We can see that in the southeast part of China the precipitation amount is reduced in SH and it increases in the north and the northeast China. Over the western Pacific heating anomaly area the precipitation evidently increases by 6 mm/d.

From the above discussion, it may be concluded that there are still some important differences between PH and SH due to their different locations and different properties of the underlying surfaces in spite of a lot of similarities between them.

5. *A Brief Discussion of Mechanisms*

In order to briefly discuss the mechanisms of heating anomalies over the Tibetan Plateau and the western Pacific, we analysed the simulated heating fields (figures omitted) and found that the changes of the heating fields induced by PH and SH have the same order of magnitude. The temperature differences of the first soil or water layer between PH and CNL and between SH and CNL are also analysed (see Figs. 9a and 9b). It is found that there is always an area with obvious positive temperature differences in the western Pacific in SH while no such kinds of temperature differences in the plateau area in PH. Therefore, the western Pacific heating anomalies exert their effects perhaps mainly through the continuously higher SST, while the initial anomalies of the soil temperatures in the plateau area exert their effects perhaps through the changes of the vertical motion and the precipitation fields. The initial anomaly of the soil temperature is only a trigger which might be different from the former.

IV. BRIEF CONCLUSIONS

The effects of the plateau and the western Pacific heating anomalies are studied and discussed. The brief conclusions are gotten as follows:

(1) The effects of both the plateau and the western Pacific heating anomalies are evident.

(2) The effects of PH and SH are quite similar, although there are still some obvious differences between them.

(3) The relative importances of the two heating anomaly areas depend upon the geographic locations of regions in question. As a whole, the effect of the Pacific heating is a little more important than that of the plateau heating, but on the vertical motion, the v-component and the precipitation fields, the latter seems more important than the former. It is also found that each heating anomaly area has its own affecting domain centred at the heating area. The farther a region is, the less the heating effect and vice versa.

(4) With equal area and value, the plateau and the Pacific heating anomalies are of equal importance for the east part of China. In the plateau area the former is more important than the latter and in the Pacific area the case is opposite.

(5) The affecting mechanisms of PH and SH are perhaps not the same. The Pacific heating comes to affect through a continuously existing positive SSTA in the western Pacific area, while the plateau heating does not produce such a positive temperature anomalies both in the soil and in the lower atmosphere. Therefore, the initial temperature

anomalies in the soil or in the atmosphere in the plateau area are only taken as a trigger which drives changes in the atmosphere and keeps the initial information in the changes of the vertical motion, the v-component and the precipitation fields.

Of course, the above conclusions are preliminary and also depend on the geographical locations of the temperature anomaly areas. If the SSTA area over the western Pacific was not at 140°E and 10°N, the results would be different.

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