NUMERICAL EXPERIMENT OF MEDIUM-RANGE CHANGE OF THE SUBTROPICAL HIGH Ⅰ. THE INFLUENCE OF THE HEATING SOURCE OVER TIBET PLATEAU

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ABSTRACT

The medium-range change of the subtropical high of June 1979 and its influences of the heating sources over Tibet Plateau are studied by using a global circulation spectrum-model. The analyses of the simulation results show that the heating sources over Tibet Plateau play an important role in the process of frontogenesis, the intensity of frontal zone and the upper-tropospheric westerly jet associated with it. When there are heating sources over Tibet Plateau, both the frontal zone and westerly jet are stronger. There are very important mutual relations between the sensible heating and latent heating. After the sensible heating and latent heating are isolated, it departs much from reality that the significance of them are studied

Key words: numerical experiment, subtropical high, sensible heating, latent heating, Tibet Plateau

Ⅰ. INTRODUCTION

It is well known that the Tibet Plateau as a powerful source of heating exerts important effects on the general circulation and the weather and climate in East Asia. Early in the 1950's, in his study of the thermal and dynamic action of the Tibet Plateau on East Asia circulation, Gu (1951) pointed out the inappropriateness of singly stressing the monsoon nature of the East Asia circulation. With summaries of chief research achievements from various aspects on meteorology for the plateau at home and abroad, Ye and Gao (1979) give large amount of facts of weather and climate there and their effects on the general circulation and mechanism of action. On the basis of these studies, clearer knowledge is acquired of the thermodynamics and the formation of the general circulation for the Plateau and their role in seasonal transition (Zhang, Zhu and Zhu, 1988). Many numerical experiments were made in the 1980's to address the role and mechanism of thermal and dynamic conditions of the Tibet Plateau and its adjacent areas (Qian, Yan and Luo et al., 1978; Kuo and Qian, 1981; Ji, Shen and Chen, 1982; Wang, Gu and Wand et al., 1984; He, Chen and Li, 1984; Zhu and Luo, 1985; Qian, Yan and Wang, 1988). The conditions are studied from different angles in terms of the effect on the general circulation across the globe and formation and evolution of East Asia Monsoon.

What is the role of thermodynamics and dynamics of the plateau in medium-range synoptic processes? The question seems more natural to put forward, as China and the region of South Asia are just adjacent to the plateau, leading to assertion that variations of overlaying synoptic regimes at medium terms have certain effects on the area. In order to provide theoretic and practical foundation for medium-term weather forecasting and related predictive models, a synoptic process at medium temporal scale, in which the West Pacific subtropical high advances northward to the south of China and "Mei-yu" (sustaining rainy weather) becomes active in the Basin of Huaihe and Changjiang Rivers, is selected to study numerically the Tibet Plateau as a heating source.

There has been much study on the activity and forecast of the West Pacific subtropical high as its intensity and location poses great influence on the rainy season, alternation of dry and wet spells and the track of typhoons in China. On the other hand, less work has been done on the mechanism of medium-term variations and further less work on numerical experiment with them. In the conventional viewpoint, the subtropical high is mainly resulted from the downdraft of the Hadley cell, i.e. the thermal circulating circle arisen from thermal action over the plateau in northern summer is a possible mechanism for the generation of downdraft in the cell, so that the high is strengthened and moved northward. The consideration explains why the plateau is selected as a heating source in our experiment.

II. SYNOPTIC PROCESS AND BRIEF ACCOUNT OF MODEL

With what is the ending stage of transition from winter to summer pattern of the general circulation in early June, 1979, the Southwest Monsoon starts on 12 June in India, followed by the beginning of Mei-yu in Shanghai, China. Evolutions of weather systems over East Asia and the West Pacific in mid-June are diagnosed with FGGE data.

1. *Evolution of 500 hPa circulation*

On 11 June 1979, the bulk of the subtropical high at 500 hPa was over waters around 150°E, south of 30°N, accompanied by weak and restricted circulation near the Philippines. The high did not start to grow northward and westward until 12 June. By 14 June, the high became much stronger with the main cell shifted to waters north of 30°N at the same longitude; the western tongue laying over the South China Sea with the ridge line at 120°E extending to around 18°N. In addition, there appeared a monsoon trough on the Arabian Sea, the Indian Subcontinent and the Bay of Bengal. Afterwards on 15-17 June, the subtropical high on West Pacific kept moving to the north, accompanied by the genesis of a monsoon depression on the Arabian Sea. On 18 June (as shown in Fig.1), the high shifted as far as the south of China and the ridge line at 120°E jumped to 23°N and the depression deepened on the Arabian Sea, forming a typical pattern of Mei-yu over East Asia. On 19 June, the Mei-yu season began in the Huaihe and Changjiang Rivers Basin.

2. *Evolution of extratropical frontal zone and westerly jet*

In their study of abrupt changes in atmospheric circulation for June and October, Ye, Tao and Li (1954) point out that one of the dominant features of the establishment of summer circulation is the sudden northward shift of the westerly in association with similar advancement of the subtropical high and ITCZ. In the middle decade of June, 1979, the westward and northward extension of the high over the East Asia coast at 120°E was also repeated in the westerly jet and extratropical frontal zone.

As is shown in the vertical profile of zonal winds and geopotential temperature at 120°E (a mean over 115 -125°E, same below) on 11 June 1979, a subtropical westerly jet was found at 200 hPa on 30°N and corresponding to it was a frontal zone in the troposphere between 30°N

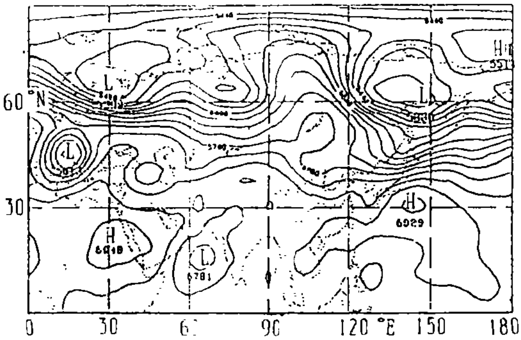

Fig. 1. Geopotential field at 500 hPa based on FGGE data on 18 June, 1979.

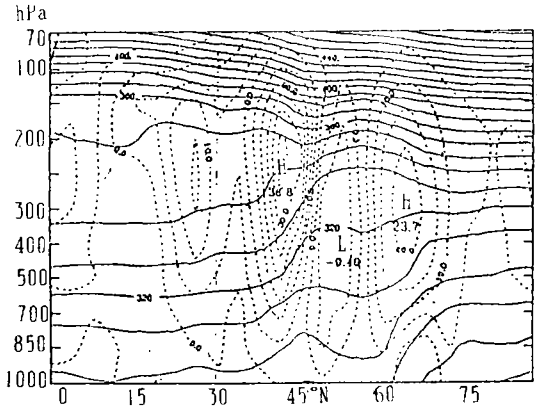

Fig.2. Latitude-geopotential height cross-section of zonal winds and potential temperature at 120°E (based on FGGE data) on 17 June 1979.

and 35°N. The westerly jet over the tropics was maintained where it had been on 12 and 13 June, though in decreasing intensity. On 14 June, another center of westerly jet was suddenly formed at 250 hPa on 40°N and a weak frontal zone followed in a location corresponding to it, when the subtropical high extended to 120°E. On 14-18 June, the westerly jet intensified at 120°E, 40°N and the frontal zone got steadier and stronger on 40-45 °N, both acquiring the utmost intensity on 17 June (Fig.2). In the course of the change, a frontal zone and westerly jet were also being moved northward and established on mid-and high-latitudes (55-65°N).

3.Brief account of the model and schemes of numerical experiment

The model used in the experiment is a global spectral model containing massive topography and non-adiabatic heating (Ji, Chen and Zhang, 1990). It is split vertically into 5 layers in the σ-coordinates. The model physics observes the radiative transfer equation in the concept of broadband radiation (Zhao and Wang, 1988; Zhao, Rockel and Raschke, 1987) and follows the turbulent diffusion, ground surface processes and large-scale condensation and improved KUO74 scheme of convective parameterization, from the ECMWF.

The relevant initial field uses the FGGE data at 1200 UTC on 11 June 1979, with that for the ground surface being the climatological mean for June; the integration is completed in 7 days (till 18 June) and gives output every 24 h. To compare the effects exerted by the Tibet Plateau in terms of the thermal action, including sensible and latent heating), 4 modeling experiments were performed. They are, specifically, Exp.1, in which all non-adiabatic physics are included, Exp.2, in which the sensible and latent heating for the plateau (75-105°E, 20-40°N) are removed, Exp.3, in which relevant sensible heating is removed to see its effects on plateau thermodynamics, and Exp.4, in which relevant latent heating is removed to study its effects on plateau thermodynamics.

Ⅲ. RESULTS OF MODEL EXPERIMENTS

1.Experiments containing all non-adiabatic physics

A modeling experiment is first done without changing any of the non-adiabatic factors in the model to illustrate its capability to simulate. The result shows good reproduction by the model of the westward and northward extension of the West Pacific subtropical high and evolution of mid- and high-latitude circulation. When the integration enters Day 3 in Exp.1 (14 June, figure omitted), the subtropical high extends westward to cover the South China Sea west of 120°E, as shown clearly in the chart of geopotential height; the westerly jet and corresponding frontal zone at 200 hPa weaken dramatically on 30°N while a new center of westerly jet and corresponding

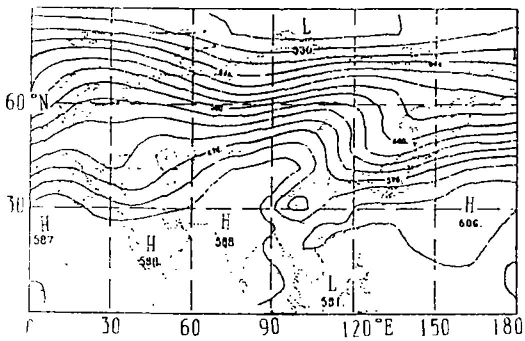

Fig.3. Geopotential height field at 500 hPa on Day 6 in Exp.1.

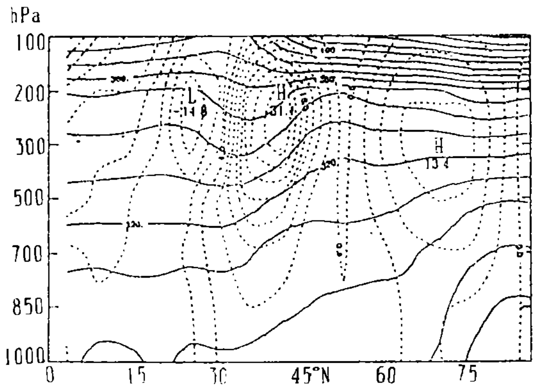

Fig.4. Same as Fig.3 except for longitudinal vertical profile of zonal winds and potential temperature.

frontal zone generate, as indicated in the relevant vertical profile of the zonal winds and potential temperature. By Day 6 (17 June, as in Figs.3 and 4), the high takes resemblance of that of Fig.1 as far as the shape and location are concerned and the systems over the continent evolve in much the same way as the observation. The westerly jet forming on Day 3 becomes the strongest and so does the frontal zone corresponding to it at 40-45°N; in the meantime the westerly jet and frontal zone at 65-70°N reestablish in much the same way the observation do.

Besides, study is done on the distribution of mean sensible and latent heat on Days 4-7 in model output during the integration. Some characteristics are found that are similar to the observation: the sensible heating is the strongest south of the plateau, the maximum center locating in its western part with another sensible heating center in the western section of the Great Bend of the Yellow River (as shown in Fig.5); latent heating is concentrated in the east of the plateau (figure omitted).

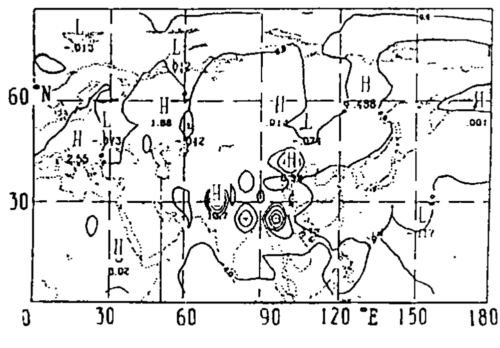

Fig.5. Same as Fig.3 except for mean sensible heating rate (°C/day) on Days 4-7.

Nevertheless, difference is evident between the result of Exp.1 and observation, such as faster northward advancement of the subtropical high, weaker intensity of trough and ridge ac-

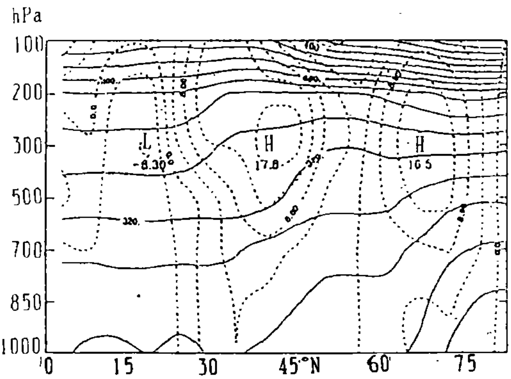

Fig.6. Longitudinal vertical profile of zonal winds and potential temperature at 120°E on Day 6 of the integration in Exp.2.

tivity in mid-and high-latitudes and stronger vortex east of the plateau, relative to the observation. The principal systems interested in this work – the West Pacific subtropical high, westerly jet over the East Asia coast and the frontal zone are well modeled in the aspect of evolution.

2. *Influence of thermodynamics over the plateau on the subtropical high and westerly*

To investigate the thermal role of the plateau in this weather process, Exp.2 is conducted by removing the sensible and latent heating at 75-105°E, 25-40°N on the basis of Exp.1. Comparing the two experiments, little difference is found between them for the first 3 days; the western subtropical high at 500 hPa also moves over the south of China in Exp.2 while the eastern bulk becomes much narrowed, resulting in a large deviation from the observation (Figure omitted). On the other hand, the westerly jet and frontal zone newly born at 120°E, 40-45°N are much weaker than what is observed. Fig.6 shows the longitudinal vertical profile of the zonal winds and potential temperature at 120°E in Exp.2. It is known from the figure that the central intensity is only 17.8 m/s for the westerly jet on 40-45°N in contrast to 31.1 m/s in Exp.1 (Fig.4) and 36.8 m/s in reality (Fig.2). In other words, the jet is only half as strong as in Exp.1 and observation. The frontal zone corresponding to it is also much weaker in Exp.2.

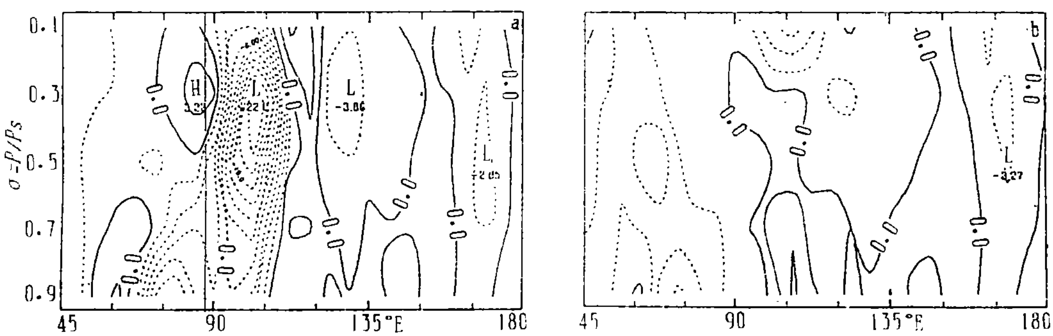

Fig.7. Zonal profile of mean vertical velocity between 25° N and 30° N on Day 7 in the model integration. (Unit: 10^{-4}hPa • s^{-1}; a. Exp.1; b. Exp.2)

To further illustrate the difference of the subtropical high between Exp.1 and Exp.2, latitudinal vertical profile of mean vertical velocity at 25-30°N (as shown in Fig.7) and longitudinal profile of the vertical velocity at 120°E (Figure omitted) are studied. It is seen from Fig.7 that the thermal action over the plateau is accompanied by marked zonal circulation in the subtropics between the plateau and West Pacific, i.e. there are areas of strong updraft over the plateau and the continent east of it and of downdraft over oceanic waters. With the removal of the plateau as the heating source, however, the zonal circulation becomes poorer defined. It is conclusive that the thermodynamics of the plateau is having important effects on the circulation of the subtropical high and the westerly during the synoptic process.

3. *Different roles of plateau sensible heat and latent heat in the process and interrelationship*

It is previously argued that the sensible heat is predominant in May and the latent heat plays an overwhelming role in June and July over the Tibet Plateau. To study the contribution by each of them in the medium-term weather processes, Exp.3 with the sensible heat removed and Exp.4 with the latent heat dropped are conducted.

Comparing Exp.3 and Exp.4 with Exp.2, we find little difference among the three results. Apart from mild difference in a trough in eastern plateau on 500 hPa, the circulation in mid-and high-latitudes has much in common. On Day 6 of the integration, just a small difference is found at 45°N for the zonal winds and meridional vertical profile: the intensity of the jet is 17.8 m/s in Exp.2, 18.5 m/s in Exp.3 and 17.2 m/s in Exp.4 and a small difference is also found in the intensity of the frontal zone (Figure omitted).

To investigate into the cause for the small difference among the three modeling experiments, the facts below should receive due attention. Firstly, the latent heat becomes much less in the eastern plateau with the removal of sensible heat in Exp.3 while the sensible heat is distributed differently if the latent heat is dropped in Exp.4. The changes are embodied as much weaker central intensity of sensible heat in the southeastern plateau east of 90°E and disappearance of a sensible heating center in the western Great Bend of the Yellow River. Secondly, similar patterns of vertical circulation exist in Exp.3 and Exp.4, regardless of whether or not the removal includes both the sensible and latent heat or just the sensible heat. They are shown as weak air currents going up in western plateau and weak air currents going down in eastern plateau through the ocean. In other words, removing the sensible heat results in weaker convection and decreased release of latent heat in eastern plateau; dropping the latent heat hardly changes the general pattern of large-scale circulation, though the lower troposphere is dominated by updraft and the coastal Eurasian region and subtropical region over the ocean by downdraft, under the condition of sensible heat over the plateau.

Through the study above, we know that the sensible and latent heat are indispensable each other for this medium-term weather process, which is also where the difference for this particular process lays between the roles by the heat and by the interannual variation of general circulation. Such dependence on each other is also deferred from their interactions in specific weather processes, much deviating from the previous viewpoint that the sensible and latent heat alternate its role in affecting the annual variation of general circulation. It should be revised on a seasonal basis, in which the dominant role is played by the sensible heat before the rainy season and by both the sensible and latent heat with the onset of the rainy season. It is, therefore, illogical to separate them in this particular discussion.

IV. CONCLUSIONS

a. Like all other seasonal variations in the general circulation, the thermodynamics over the Tibet Plateau also exerts strong effects on 3-7 day synoptic processes. For the process in question, its role is mainly manifested in the formation and intensity of the frontal zone north of the subtropical high, and the intensity of the middle and upper tropospheric westerly jet in correspondence to the frontal zone. With (without) the plateau thermodynamics, both the jet and zone are strong (weak): it is also reflected in the intensity and difference in the nature of vertical circulation of the subtropical high, though having little effect on its east-west advancement/retreat.

b. Depending each other in specific weather processes, the sensible and latent heat are such factors that it is not realistic to discuss them separately for their contribution. Concretely speaking, the sensible heat is possibly acting as a "source of disturbance" while the latent heat can change the general circulation and affect the weather through its feedback mechanisms.

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