NUMERICAL EXPERIMENT OF MEDIUM-RANGE CHANGE OF THE SUBTROPICAL HIGH Ⅱ. THE INFLUENCE OF THE HEATING SOURCE OVER WESTERN TROPICAL PACIFIC

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ABSTRACT

Numerical experiments are carried out using a global spectral model to study the role of an ideal heating source over the western tropical Pacific region in a medium-term weather process that marks the western advancement of the subtropical high in mid-June 1979. The result has indicated that the effect of the ideal heating source is evident in about 4 days after the inclusion in the high and the circulation at mid-and high-latitudes over the eastern part of China; the disturbance produced over the tropical ocean first transfers towards the northwest along the easterly flow on the southern edge of the subtropical high and then divides into two branches as it moves over the westerly over the mid-latitude area, one continuing the journey northwestward and the other turning to the northeast by east, resulting in changes in the subtropical high and the westerly through combined action.

Key words: numerical experiment, subtropical high, tropical western Pacific, ideal heating source, disturbance

Ⅰ. INTRODUCTION

It has been noted long ago that the changes in the general circulation is affected by anomalies in sea surface temperature (SST) and convection over the tropical ocean as a forced heating source on the part of the atmosphere. The examples include Bjerknes (1966) who discovers the correlation between the general circulation changes and the equatorial Pacific SST as early as in the 1960's, and Rowntree (1972 and 1976), Shukla (1975 and 1983), Keshavamurty (1982), Moura (1981) and Kershaw (1988), who conduct a series of numerical experiments with the effects of tropical SST anomalies on the general circulation using varied GCMs for individual seasons and geographic locations. In China, the relationship between interannual changes of the subtropical high over the western Pacific and SST anomalies (SSTA) and convective activities over waters in the South China Sea and east of the Philippine islands is studied by observed facts, theoretic analyses and numerical experiments (Huang, 1989). The results have shown that the thermally forced anomalies over the ocean in the tropics are causing changes in the whole general circulation due to transportation of disturbances over the subtropical zone and mid-and higher-latitudes through physical mechanisms like the planetary waves, as well as the atmospheric motion in the tropics.

Based on the recognition above, it is understood that the anomalous SST and convection over the oceanic surface in the tropics pose important influences on the interannual variation of the general circulation, with little work on the aspect of its role in the medium-term weather processes. The insufficiency is especially felt in the tropical northwest Pacific regions which are adjacent to China and South Asia where the anomalous development of convection is expected to have certain influence on the weather in China. A medium-term weather process is carefully chosen for the middle pentad of June 1979 so that the western Pacific subtropical high is depicted as it moves westward and northward into the southern part of China and brings about a rainy process (the Mei-yu) in the basins of the Changjiang and Huaihe Rivers. The heating source produced by convection over the tropical northwestern Pacific is numerically studied for its role in the weather process, in addition to a discussion on the transportation of disturbances generated by the heating source in the Northern Hemisphere.

II. OBSERVATIONAL FACTS

A major adjustment is undertaken in the pattern of the circulation over the Eurasian continent and western Pacific in the middle pentad of June 1979, when the subtropical high for the latter extends westward and northward to the southern part of China from waters south of 150°E and 30°N and a sustained rainy weather is established over the former (Gong and Ji, 1998). In the meantime, obvious changes are found in the study of the process with the cloud bands of the western Pacific – the northward jump of the subtropical high is followed by activation of convection in the ITCZ to the south, which is moving north with the high.

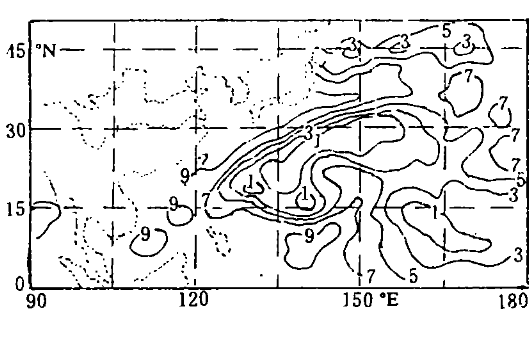

Fig.1. Average cloudage total over the western Pacific in June 10 to 14, 1979.

Fig.1 is the chart of contours of average cloudage total as shown in the monthly report of Japan Meteorological Satellite Center (M.S.C., 1979) for the third pentad (the 10th – 14th day) of June 1979 in northwestern Pacific. It is illustrated that the ridge of the subtropical high is located near 25 °N for the eastern half and near 20°N for the western half, with a cloud cover of more than 70% appearing over a large area from the South China Sea to 150 °E and from the Equator to 13 °N and a much larger one (90% to 100%) over the regions of the South China Sea and east of the Philippines (around the point of 140 °E and 8°N). It is an indication that there is active convection over the South China Sea and waters east of the Philippines. Earlier in the second pentad of June (the 5th – 9th day, figure omitted), less-cloud areas for the western Pacific subtropical high appear south of 30°N over waters east of the Philippines, with the ridge aligning south of 20°N in the direction of ENE-WSW, while more-cloud areas of the ITCZ locates between 8 °N and 10°N, with cloud amount usually from 70% to 80%. In the fourth pentad (the 15th – 19th day, figure omitted) of June, the subtropical high is much dislocated northward, with the ridge shifted to 30°N for the eastern part and 25°N for the western part.

From the preceding facts about the changes in cloudage, it is not hard to assume that changes in the subtropical high in the middle pentad of June 1979 is closely related with the evolution of convection within the ITCZ to its south.

III. SCHEMES OF EXPERIMENT

In a similar way as in Gong et al. (1998), a global spectral model is used to conduct four experiments initializing with the FGGE data at 1200 UTC on June 11, 1979 in order to study the role of the convection over the tropical western Pacific in the westward and northward extension of the subtropical high in the middle pentad of June 1979 and the response of synoptic systems in the mid-and higher-latitude areas to an anomalous heating source over the tropical ocean. Integrated for a duration of 7 days, the model gives output every 24 h. No alternation is made to the diabatic heating for Experiment 1 (hereafter simplified as expt.1), and an ideal heating source is added to the region of the tropical western Pacific (120 ~ 160 °E, 0 ~ 15 °N) for expts.2, 3 and 4, which is distributed as

$$Q(\lambda,\varphi,\sigma)=\begin{cases} Q_0\left[\sin\dfrac{\pi(\varphi-\varphi_1)}{\varphi_2-\varphi_1}\cdot\sin\dfrac{\pi(\lambda-\lambda_1)}{\lambda_2-\lambda_1}\right]\cdot\exp\left[-\left(\dfrac{\sigma-\bar{\sigma}}{d}\right)^2\right] \\ \quad\text{where } : \varphi_1\langle\varphi\langle\varphi_2,\ \lambda_1\langle\lambda\langle\lambda_2 \\ 0 \quad \text{other conditions} \end{cases}$$

where $\sigma = P - P_s$ is the height coordinate of the model, λ, φ are degrees of latitude and longitude, $\bar{\sigma} = 0.5, d = 0.4$, Q_0 is the maximum intensity of the ideal heating source. The centers of the sources are all located at 141 °E, 8°N for expts.2, 3 and 4, with the maximum central intensity Q_0/C_p being 3° K/day, 2° K/day and 5° K/day, respectively.

IV. RESULTS OF EXPERIMENT

1. *Experiments without inclusion of ideal heating sources*

Detailed descriptions are given in the first part of our work (Gong et al., 1998) relating to expt.1 in which no attempts are made to change any physical processes in the model, which is just the same experiment in this part that does not include any ideal heating sources for the tropical western Pacific. The result has indicated that the model is capable of simulating the westward and northward advancement of the subtropical high over the western Pacific and the evolution of frontal zone and westerly jet in the mid-and higher-latitude areas in the middle pentad of June 1979. Obvious disadvantages are with the result in that the vortex is stronger in the eastern plateau than in the observation, which is a low between two highs, and tropical systems are also poorly reproduced. It may be related to coarse model treatment of diabatic physical processes in the tropics and input and use of climatological mean ground surface temperature, humidity and SST and the resolution of the model.

2. *Experiments with inclusion of ideal heating sources*

In view of the disadvantages of the experiment above (and there is much difficulty in improving the model), another experiment (expt.2) is carried out by including an ideal heating source with the intensity of 3° K/day in the tropical western Pacific. Fig.2 gives the distribution of the ideal heating source in expt.2 at the layer of $\sigma = \bar{\sigma} = 0.5$. As a matter of fact, the convection over the tropical western Pacific is indeed significant during the early and middle pentads of June

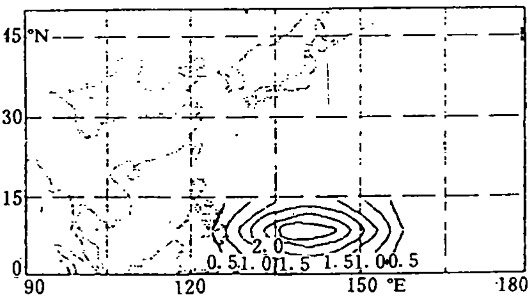

Fig.2. Distribution of the ideal heating source in expt.2 (° K/day).

1979, as revealed in the second section of the current paper – there is a large release of latent heat over the area.

The result has shown that only insignificant effects are present with the ideal heating source for the first three days of integration, leading to little difference in the 500-hPa-geopotential field as compared to expt.1. The source begins to be much evident on the fourth day of the integration. Fig.3a presents the simulation of Day 6 in expt.2. It gives a much stronger and more extensive subtropical high and the region of low pressure, much weaker than the vortex in expt.1, is successfully simulated between two highs

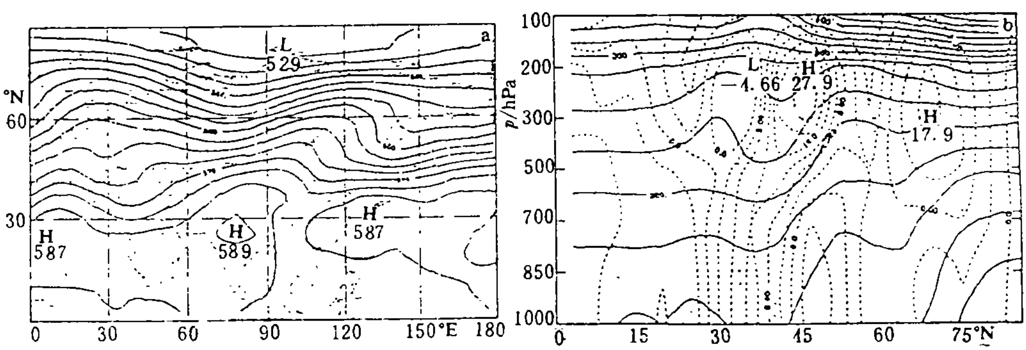

Fig.3. Simulation results on Day 6 of the integration in expt.2. a. 500 hPa geopotential field; b. Latitude-height profile of the zonal winds and geopotential temperature at 120°E.

east of the plateau, comparing with that in expt.1. Though in a better shape against the observation, the experiment has not been able to reproduce the monsoon low over the Arabian Sea, as in the preceding case. Fig.3b gives the latitude-height profile of zonal winds and geopotential temperature at 120°E on Day 6 in the integration. Comparing with expt.1, it is noted that the frontal zone is stronger corresponding to the jet, though with a weaker westerly jet at 200 hPa on the latitude of 45°N, as compared to expt.1. The chart also gives a stronger westerly jet north of 45°N and polar front near 70°N in association with it. It is not hard to find that results with expt.2 are closer to the observation as compared to expt.1.

To have a clearer understanding of the difference between experiments with and without the ideal heating source, a meridional-height profile (See Fig.4) is given for the vertical velocity at 120°E in expts.1 and 2 and the observation (FGGE data). As is shown, there is much similarity from high down to lower latitudes between expt.2 (Fig.4a) and the observation (Fig.4b) in terms of the distribution of latitudinal-vertical circulation, especially in good agreement with the observation in the location of the centers of updrafts and downdrafts for the frontal zone in middle latitudes, though with lower-than-real intensity. Having well determined latitudinal-vertical circulation, which is similar to the observation, expt.1 gives a much-deviated location of the centers of the updraft and downdraft.

Based on the comparison and analysis above, the following conclusion can be drawn that the heating source, produced by convection over the tropical western Pacific for the particular weather process in the middle pentad of June 1979, is having an important influence on the circulation in the adjacent regions of subtropical high and mid-and higher-latitudes as well as that in the tropics. A question arises then: how (or by what means) is the heating source affecting the changes in the subtropical high and mid-and higher-latitude weather systems? A number of channels through which the heating source over the western Pacific poses effects on the latter are suggested by investigating the following facts.

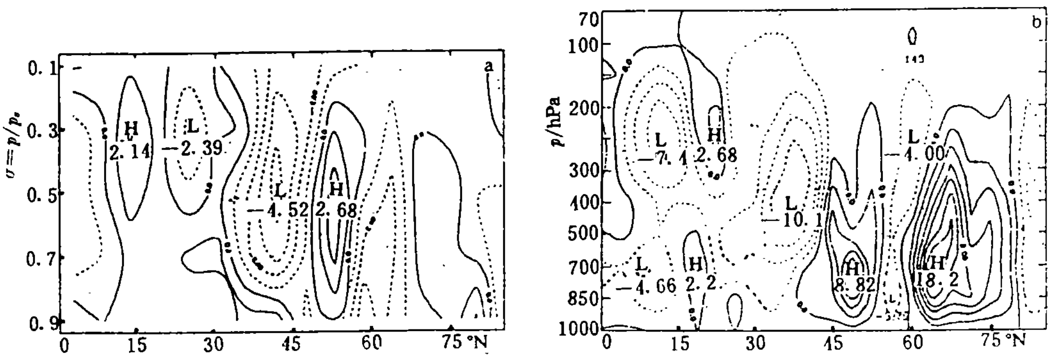

Fig.4. Latitude-height profile of the vertical velocity at 120°E. Unit: 10^{-4}hPa • s^{-1}; a. Mean velocity on Day 7 in the integration in expt.2; b. FGGE data on June 18, 1979.

3. *Influence of ideal heating source over tropical western Pacific on mid-and higher-latitude weather systems*

First of all, the difference in the vertical velocity for individual model layers during the integration is compared between expt.1 and expt.2. It is found that the heating source first results in the strengthening of updrafts right over where it is located before transporting the disturbance northwestward to increase the downdrafts over the northern islands of the Philippines through the South China Sea and downdrafts over the northern Indochina Peninsula and the southern part of China. The effect is also evident in areas further north in the Republic of Mongolia through northeastern China, which is having active updrafts. Such response is well-defined on Day 4 in the integration. A chart of difference in the mean vertical velocity is given in this work, which has been integrated for 7 days in expt.1 and expt.2 on the layer of $\sigma = 0.5$. As shown in Fig.5, it is well determined that there are changes in the vertical velocity. The figure also illustrates how the vertical velocity varies by the largest amplitude in the eastern plateau as there are relatively strong updrafts in correspondence to a stronger-than-reality vortex east of the plateau in expt.1. For expt.2, however, the same region is not favorable for the development of convection because of the downdrafts east of the plateau, a result due to the addition of an ideal heating source over the tropical western Pacific. The vertical velocity varies the most in an area of low pressure between two highs that used to be a strong vortex in the former experiment.

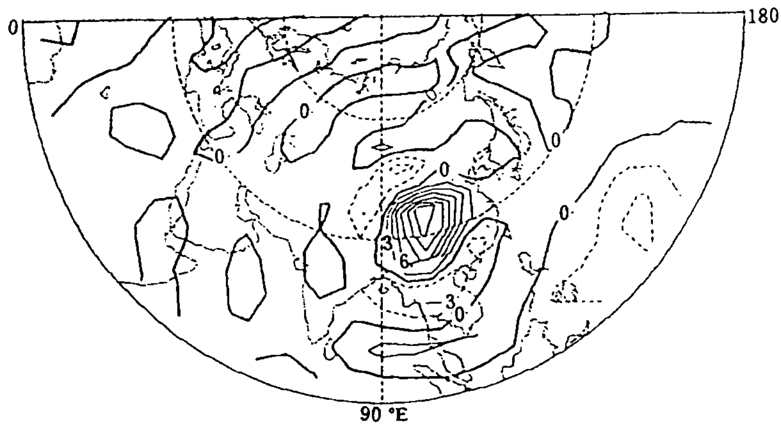

Fig.5. Difference in mean vertical velocity on Day 7 in the integration at the layer of $\sigma = 0.5$ in expt.1 and expt.2 (Intervals: 3×10^{-4}hPa • s^{-1})

Then, the difference in the 500-hPa-geopotential field is studied on a daily basis. Likewise, large changes in the field do not occur until the fourth day into the integration. As shown in Fig.6a, a zone of positive geopotential increases is well marked east of the plateau at 100°E, 30°N, which is accompanied by a zone of weakly decreasing geopotential height to the north. On Day 5, the intensity of both centers grows together and by Day 6 they have expanded the coverage, in addition to formation of another pair of geopotential change zones from the southern China through the Korean Pen. to waters east of Japan and Kamchatka Pen. for the northwestern Pacific (Figure omitted). By Day 7, the earlier-formed pair has reduced to some degree in intensity while the lately-formed pair has increased in both extent and intensity. Our analyses have suggested that disturbances in the tropical atmosphere resulted from an ideal heating source over the tropical western Pacific follow such a route that they are first transported towards the northwest in the easterly current south of the subtropical high and then divided into two branches in their advancement to the mid-and higher-latitude regions – one continuously heading for the northwest into the interior the Eurasian continent and the other turning to a northeast-by-east direction towards the Sea of Japan and mid-and higher-latitude regions over the northwestern Pacific. It is the combined effects of two branches of disturbance that the changes in the subtropical high and circulation in mid-and higher-latitude regions are resulted during this particular weather process.

It is on the observational facts about the tropical convective clouds that the preceding experiments are based for determination of the role of the heating source over the tropical western Pacific in the middle pentad of June 1979. Due to limitation of related data, it is not known beforehand how strong the heating source will be from convection. Three experiments are thus conducted that are applied with different intensity in the heating source and the one just presented is the experiment that has a central intensity of 3°K/day. Two more experiments (expt.3 and expt.4) have been carried out (Details of which not shown here) that have central intensity in the heating source of 2°K/day and 5°K/day. The results have indicated varied effects of the heating source in different intensity being exerted on the subtropical high and weather systems in mid-and higher-latitudes regions. When the source is weak, the effects are weak, too, incapable of bringing about significant changes in the high and the weather systems; when the source is too strong, a larger response is found with the high and the weather systems to the heating source, though destroying the circulation and evolution of weather in the real atmosphere.

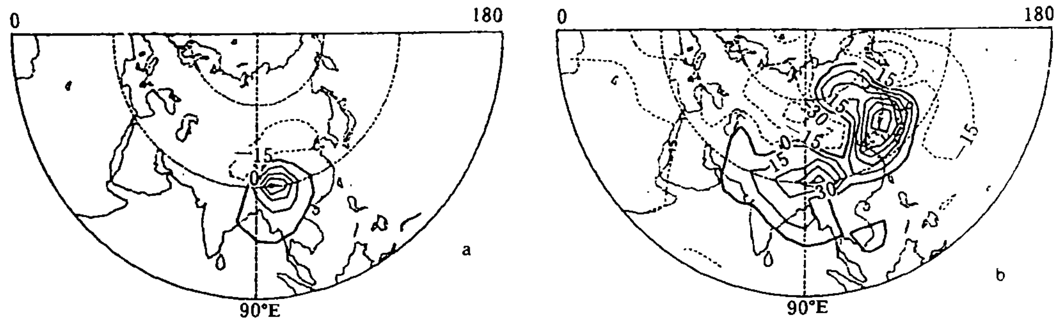

Fig.6. Difference of 500 hPa geopotential height in the integration of expt.1 and expt.2. a. Day 4; b. Day 7. The intervals are in 15 gpm. The dashed line designates the negative value and the solid line the positive.

V. CONCLUSIONS AND DISCUSSIONS

a. With an ideal heating source added to the model region of the tropical western Pacific, the inclusion shows its effects with a lapse of 4 days in the eastern part of China such that the subtropical high in the region east of the Tibetan Plateau and the downstream and mid-and higher-latitude circulation are modified in their evolution, improving the simulation to some extent.

b. It is in the easterly south of the subtropical high that the disturbance produced by the ideal heating source over the tropical western Pacific is moving towards the northwest. Upon arriving in the westerly east of the plateau, the disturbance breaks up into two branches, one continuing its northwestward transportation and the other traveling to the northeast by east. The subtropical high and mid-and higher-latitude circulation are subject to the combined action of the two branches of disturbance.

In addition, it should be pointed out that the simulating experiments are conducted with the assumption that the ideal heating sources are of the same scale and distribution. Difference in scale and distribution may lead to varied effects on the circulation and it remains to be addressed in studies to come. One more point about the weather process used in this work: it is well-known one, which witnesses the establishment of a monsoon depression over the Arabian Sea and the outbreak of the Southwest Monsoon in June 1979. Our experiments have done a less satisfactory job in the simulation of the system. In his experiment with the same case, Kershaw (1988) studies how the formation and the monsoon depression and the outbreak of the Southwest Monsoon are affected by inclusion in the model of anomalous SST for the Arabian Sea. He investigates into variation of low-level circulation over the Arabian Sea and the adjacent areas and mechanisms responsible for the anomaly of SST, but leaves the evolution of circulation for the whole Eurasian continent virtually untouched. It is our attempt, therefore, to address the problem by including in the model both sources of heating over the Arabian Sea and tropical western Pacific to examine how they would have combined influence on this particular weather process, what they would do to change the simulated results and in what manner the disturbance they produce would transport towards the subtropical latitudes and mid-and higher-latitude regions, etc. These are the issues to solve in future study.

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