NUMERICAL STUDY OF SHORT TERM EFFECT OF SST ANOMALIES

Gu Jianfeng (顾建峰)

Shanghai Institute of Meteorology, Shanghai, 200030

Wang Qianqian (王谦谦)

Nanjing Institute of Meteorology, Nanjing 210044

and Liu Jiangang (刘坚刚)

Shanghai Meteorological Bureau, Shanghai 200030

Received 28 July 1997, in revised form 26 March 1998*

ABSTRACT

Using a 5-layer P-σ mixed coordinates primitive equations model, a process of heavy rain is simulated that occurred over the middle-and lower-reaches of the Changjiang River on July 1 – 2, 1991 and numerical experiments are done of the effects of sea surface temperature (SST) anomalies over different waters on the precipitation. The result has shown that the appearance of SST anomaly is followed in a short term (2 or 3 days) by a change in the pattern of circulation as well as in precipitation to some extent.

Key words: SST, anomalies, short term effects, numerical research

Ⅰ. INTRODUCTION

As shown in many studies (Webster 1981; Keshavamurty, 1982; Shukla and Wallace, 1983; Tokioka, Yamazaki and Chiba, 1983; Huang and Lu, 1989; Sun, Zhang and Palmer, 1990; Ni, Qian and Lin, 1990; Chen, 1992 and Luo, Jin and Chen, 1985), anomalies of SST taking place in some of the waters are causing anomalous conditions of the general circulation in the tropics as well as the globe, leading to anomalous changes in the monsoon and eventually in the precipitation. All the effects are true only in relation to climatological state. It is generally the case that in short term weather forecasting the effect of the diabatic process in the underlying surface is negligible from the viewpoint of numerical forecasting. With the development of mesoscale NWP, however, local physical processes such as heat, water vapor and momentum exchange in the planetary boundary layer (PBL) are receiving more and more attention over the recent years while tele-anomalies of SST are normally considered to have little, simultaneous effects on the weather. With the purpose of studying the short-term effects of tele-anomalies of SST on the weather situations and precipitation over the simultaneous period, a 5-layer mixed P-σ coordinates primitive equations model is used to have numerical experiments on SST anomalies over various waters on basis of simulations of heavy rains over the middle-and lower-reaches of the Changjiang River on July 1 – 2, 1991.

II. BRIEF ACCOUNT OF MODEL AND EXPERIMENT SCHEMES

1. *Brief account of the model*

For the model, five layers are divided in the vertical, two of them above 400 hPa in the P coordinates assumed on the surfaces of 100 hPa and 300 hPa, respectively. The other three layers are below 400 hPa in the σ coordinates. The horizontal model resolution is 2.5×2.5 long./lat. over a spherical domain between 30°S and 70°N for computation. The model includes land-sea distributions and massive terrain, the highest altitude being 5 km. Major physical processes include longwave and shortwave radiation, large-scale condensation and Kuo-type convection parameterization and exchanges of momentum, heat and water vapor in the PBL.

The vortex diffusion term in the model equation is expressed by

$$D_a = K_h \nabla_h^2 a - g \frac{\partial F_a}{\partial P} \tag{1}$$

$$F_a = \begin{cases} -\rho^2 g K_z \dfrac{\partial a}{\partial P} & \text{(free atmosphere)} \\ \rho_s C_D V(a_a - a_s) & \text{PBL} \end{cases} \tag{2}$$

where a stands for any physical quantity, the subscript a is the value on the lowest model layer and the superscript s is the value on the underlying surface, and naturally T_s becomes SST over the ocean.

The sensible heat flux and latent heat flux are expressed by

$$SH = \rho_a C_p C_D V(T_s - T_a) \tag{3}$$

$$LE = \rho_a L C_D V(q_s(T_s) - q_a) \tag{4}$$

Detailed description of the model is referred to Qian (1985). Data used in the model are adopted from the 2.5×2.5 long./lat. mesh of a global data assimilation system for a medium-term numerical prediction at the National Meteorological Center, China. It is initialized at 1200 UTC June 29, 1991 and the SST information is provided by the monthly mean field for July 1991[1].

2. *Scheme of experiment*

In a global diabatic heating field computed with the FGGE data (Figure omitted) by Ming, Johnson and Towsend (1983), one of the heating sources is recognized in an area bounded by 0 – 25°N and 110 – 150°E, with the center around the Philippines. On the basis of the analysis, we set up a positive anomaly field of SST in the waters of the Philippines (0 – 20°N, 110 – 140°E) following a scheme called PHP (it is Region I in Fig.1, with a central value of +3°C). A negative anomaly field of SST is set up in the same region by a PHN scheme (It is the same region in Fig.1, though with a negative anomaly). In addition, the SST is found to be about 2°C cooler in

[1] The SST data in the work are excerpted from the Climate Monitoring Bulletin.

1992 than in 1991 over the central and northern Pacific regions (25 – 50°N and 165°E – 165°W), as indicated in a comparison of the monthly mean field of July between the two years. A similar negative SST anomalous field is then set up here following a so-called NPN scheme (region II in Fig.1). The preceding anomalous SST fields are superimposed onto the monthly mean SST field for July 1991.

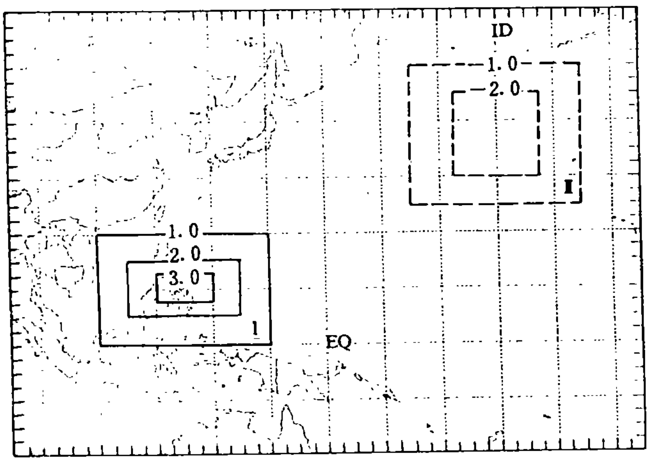

Fig.1. Distribution of SST anomalies in the experimental areas in unit of °C.

III. NUMERICAL SIMULATION

Initialized with the output for 1200 UTC June 29, 1991 from the mesh in the global data assimilation system of medium-term numerical prediction at the National Meteorological Center (and with the mean SST field for July 1991 for the part of sea surface temperature), the model is integrated for 72 hours with simulations available at an interval of 12 hours. The location and moving speed of the synoptic regimes reproduced are in good agreement with the observation as well as the distribution of precipitation, but the intensity of the regimes and precipitation are weaker than what is observed.

Studying the day-to-day 500 hPa geopotential and low-level wind fields (Figure omitted) as they are simulated, the ridge is found to stay between 22.5°N and 25°N for the subtropical high of the west Pacific; the blocking high of the Ural Mountains is near 55°E at 1200 UTC on June 29, retreats to around 45°E at the same time on July 1 and further moves to 40°E 24 hours later on July 2. During the movement of the Ural high, the cold air keeps flowing southeastward from its front portion while another blocking high over the Sea of Okhotsk stays stable to maintain to its southwest a cut-off cold vortex in northeast China, causing from behind a steady migration of cold air towards the south. In the meantime, the eastward-shifting westerly trough shows more southward component so that the southwesterly flow in front of the trough is superposed over a warm and humid current on the western edge of the subtropical high, meeting the two displaced flows of cold air over the middle-and lower-reaches of the Changjiang River; there is a marked monsoon circulation cell on the vertical profile of the meridional circulation along 120°E together with a major region of updraft near 30°N and of downdraft in areas south of 25°N. The circulation as presented above is causing a heavy rain over the middle-and lower-reaches of the

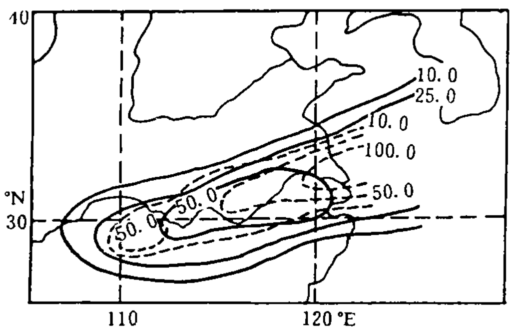

Fig.2. Distribution of precipitation as in observation (dashed line) and numerical simulation (solid line). The unit is mm.

Changjiang River. The agreement is good with the observation as far as the simulated pattern of circulation, location of various synoptic regimes and their movements are concerned. The simulation of the precipitation is seen in Fig.2. The dashed line in the figure depicts the real precipitation at 0000 UTC between July 1 and July 2 (using the same line in the text that follows) and the solid line is the distribution of simulated precipitation for the same duration and region. They agree quite well with each other, though with southward appearance, smaller rainfall intensity and deviated location of rainfall maxima in the latter. The numerical experiment as described above is denoted as control by the token of BAEX.

Ⅳ. NUMERICAL EXPERIMENT

Three numerical experiments are conducted for the SST anomalies corresponding to the three maritime areas in Fig.1 and the results are compared with that by BAEX. From Eqs.(1) – (4), it is known that the heat flux between the ocean and atmosphere in the planetary boundary layer (PBL) changes as there are anomalies taking place in SST. It is further found that the effects of heat flux in the PBL are shown gradually 36 hours after the onset of integration in the circulation patterns and precipitation and separate discussions are made relative to the three numerical experiments.

1. *The PHP experiment*

The circulation pattern changes 36 hours into the integration due to increased exchanges of heat flux in the PBL caused by positive SST anomalies in the waters of the Philippines. By the 48^{th} h in the integration, there is a difference of horizontal wind vector between the PHP scheme and BAEX in the lower model layers and it is shown as a large center of convergence of differential wind vector over the Philippines waters (Fig.3). The circulation of the subtropical high is also weakened over the west Pacific so that a consistent differential northerly flow is displayed for regions south of the Yellow River in east China through the Bay of Bengal and the South China Sea. It converges with the positive SST anomaly area over the ocean. On the chart that depicts the differential vertical circulation between the PHP and BAEX averaged over the 115 – 120°E section at the 48^{th} h of the integration (See Fig.4, with the vertical velocity enlarged by 1000 times). A differential anti-monsoon circulation appears in 10°N – 35°N, which strengthens the updraft (5°N – 15°N) but weakens the downdraft (near 30°N), both being formerly present in the area of positive SST anomalies. The characteristics suggest that it is the increase of the PBL heat flux due to positive SST anomaly in the sea areas of the Philippines that not only produces strong maxima of differential convergence and updrafts for the local region but also inhibits the transfer of water vapor from the ocean to the continent and the updraft near 30°N. The amount of precipitation is, as a consequence, reduced by 3 mm for the lower reaches of the Changjiang River (Fig.5).

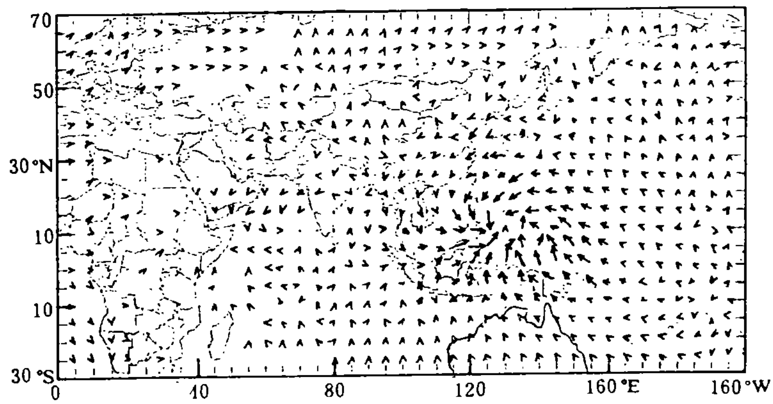

Fig.3. Difference of wind vectors by the 48th hour in the integration in PHP and BAEX.

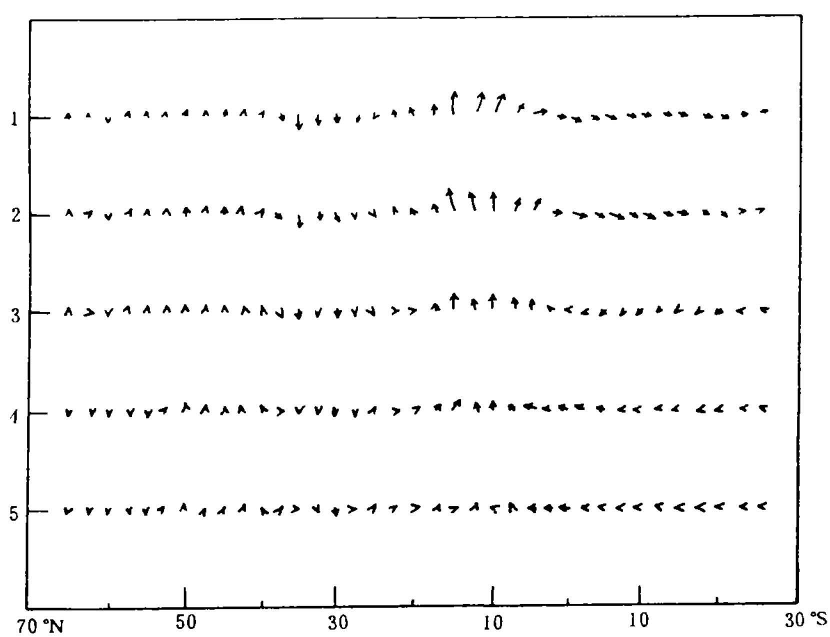

Fig.4. Differential vertical circulation between the PHP and BAEX averaged over the 115 – 120°E section at the 48th h of the integration

2. *The PHN experiment*

With results opposite to that in the PHP experiment, decreased exchanges of the PBL heat flux caused by negative SST anomalies in the Philippines waters are strengthening the circulation of the subtropical high for the west Pacific by the 48th hour in the integration as well as the transfer of water vapor towards mainland China from the ocean (Figure omitted). At the 48th hour of the integration, a negative SST anomaly region shows up in the meridional circulation on the 120°E section, weakening the original updraft near 10°N but strengthening the one near 30°N (Figure omitted), and the change results in an increase in rainfall for the lower reaches of the Changjiang River.

3. *The NPN experiment*

Being far away from the continent, the central and northern Pacific Ocean has less exchange of heat flux between the atmosphere and ocean in a 72-h lagging response to a SST decrease there. In the lower-level wind field for the difference between NPN and BAEX 72 hours into the integration, the negative SST area is shown as a differential anticyclonic circulation that weakens the subtropical high to the southwest, resulting in a weak differential divergence over the lower reaches of the Changjiang River (Figure omitted). In the meantime, a chart (not shown) for zonal vertical circulation on the 30°N section shows that the updraft that is previously near 120°E is now checked in growth. All of the features have shown that the effects of decreased SST in the central and northern Pacific Ocean is reflected in about 3 days, which is specifically displayed as weakened circulation of the subtropical high over the west Pacific and checked activity of the moisture convergence and updrafts for the lower reaches of the Changjiang River, with a consequential reduction of precipitation by about 1.5 mm (Fig.6). Although in a moderate coverage and extent, the reduction for this reason tends to be consistent with the fact that precipitation appears to be less in 1992 than in 1991 for the lower reaches of the Changjiang River.

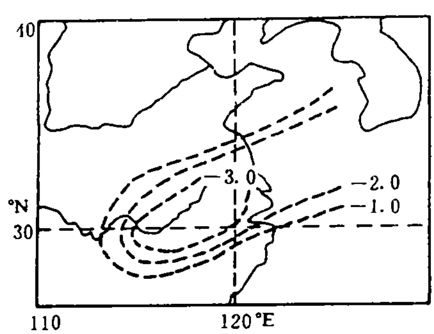

Fig.5. Difference in precipitation between PHP and BAEX. (unit: mm)

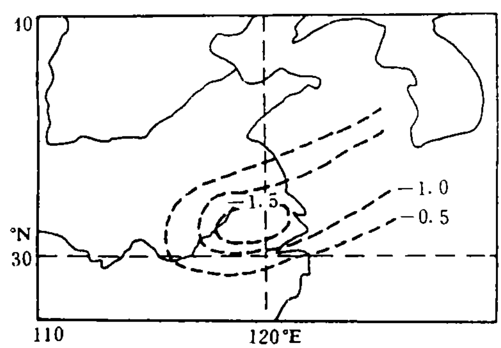

Fig.6. Difference in precipitation between NPA and BAEX. (unit: mm)

V. CONCLUDING REMARKS

a. The effects of tele-anomalies of SST are more or less reflected on synoptic patterns and associated precipitation in short term (2 – 3 days).

b. The positive (negative) SST anomalies in the sea areas of the Philippines are causing more (less) precipitation over the lower reaches of the Changjiang River; the negative SST in the central and northern Pacific are reducing it.

c. By our interpretation, the effects of anomalous SST distribution is such that the changes in the exchange of heat flux between the atmosphere and ocean in the PBL will affect the circulation in the horizontal as well as vertical and the transfer of water vapor and cause the precipitation to change in consequence.

d. By a very small extent as far as its short-term effect is concerned, the tele-anomalies of SST are in consistence with the climatic effect. It is then quite reasonable to expect that the short-term numerical prediction can be improved somewhat if the simultaneous effects of SST anomalies are also considered.

REFERENCES

Chen Yue'e, 1992. Numerical experiment with summer monsoon and precipitation in China in relation with SST over adjacent oceanic areas (in Chinese). *In*: A study on issues of climatic change. Beijing: Science Press. 157-167.

Huang Ronghui, Lu Li, 1989. Numerical simulation of the relationship between the anomaly of subtropical high over East Asia and the convective activities in the western tropical Pacific. *Adv. Atmos. Sci.*, **6**: 202-214.

Keshavamurty R N, 1982. Response of the atmosphere to sea surface temperature anomalies over the equatorial Pacific and the teleconnections of the southern oscillation. *J. Atmos. Sci.*, **39**: 1241-1259.

Luo Shanhua, Jin Zuhui, Chen Lieting, 1985. Analysis of the correlation between SST in the Indian Ocean and the South China Sea and summer precipitation over the middle and lower reaches of the Changjiang River (in Chinese). *Sci. Atmos. Sin.*, **9**: 314-320.

Ming Yingwei, Johnson D R, Towsend R D, 1983. Seasonal distributions of diabatic heating during the First GARP Global Experiment, *Tellus*, **35A**: 241-255.

Ni Yunqi, Qian Yongfu, Lin Yuanbi, 1990. Influence of SST anomalies in the equatorial west Pacific and Indian Ocean on the summer monsoon in Asia (in Chinese). *Sci. Meteor. Sin.*, **48**: 336-343.

Qian Yongfu, 1985. A five-layer primitive equation model with topography (in Chinese). *Plateau Meteor.*, **4**: 1-28.

Shukla J, Wallace J M, 1983. Numerical simulation of the atmospheric response to equatorial Pacific sea surface temperature anomalies. *J. Atmos. Sci.*, **40**: 1613-1630.

Sun Zhaobo, Zhang Jijia, Palmer T N, 1990. Numerical experiment of the effects of SSTA in the South China Sea on the summer monsoon and precipitation in China (in Chinese). *Sci. Meteor. Sin.*, **48**: 113-116.

Tokioka, Yamazaki T K, Chiba M, 1985. Atmospheric response to the sea surface temperature anomalies observed in early summer of 1983; A numerical experiment. *J. Meteor. Soc. Japan*, **63**: 565-588.

Webster P J, 1981. Mechanisms determining the atmospheric response to sea surface temperature anomalies. *J. Atmos. Sci.*, **38**: 1179-1196.

---

* The paper was translated into English by Mr. Cao Chaoxiong. (mylescao@grmc.gov.cn)