Interannual Fluctuations of Surface Air Temperature over North America and Its Relationship to the North Pacific SST Anomaly①

Wu Renguang (吴仁广) and *Chen Lieting* (陈烈庭)
Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100080
Received May 18, 1994; revised July 16, 1994

ABSTRACT

The characteristics of interannual fluctuations of the surface air temperature over North America are investigated by using the surface air temperature data of 130 stations during 1941 through 1980. It is found that the surface air temperature bears about ten–year time scale oscillation over the southeastern and northwestern North America and along the west coast of the United States, and it has the characteristics of quasibiennial oscillation over the eastern North America. The ten–year scale oscillation of the surface air temperature is related to that of the sea surface temperature (SST) of North Pacific through the PNA pattern atmospheric circulation anomaly over North Pacific through North America. It is shown that the North Pacific SST has a closer association with the surface air temperature over North America than the central and eastern equatorial Pacific SST. The characteristics of the seasonal variations of the relationship between the North Pacific SST and the surface air temperature over North America are also analyzed.

Key Words: Surface air temperature, North America, North Pacific, Sea Surface Temperature (SST), Ten–year scale oscillation

I. INTRODUCTION

Investigations (Horel and Wallace, 1981, etc.) has shown that the interannual fluctuations of the surface air temperature (SAT) over North America are associated with the El Nino / Southern Oscillation (ENSO). When large extent anomalous warming of sea water occurs in the central and eastern equatorial Pacific, the atmospheric circulation anomaly of PNA pattern will appear over the North Pacific through North America in response of atmospheric circulation over middle latitude to the SST anomaly and lead to anomalously low winter air temperature over the southeastern United States (US) and anomalously high air temperature over the western North America. On the other hand, large scale east–west SST anomaly gradient over North Pacific can also cause atmospheric circulation anomaly by zonally different heat flux and lead to atmospheric circulation and climate anomaly downstream over North America through Rossby wave dispersion (Namias, 1969; 1978). Walsh and Richman (1981) also showed that the SAT variation over the southeastern and far western United States has good relations to the North Pacific SST. These investigations demonstrate the SST anomaly over North Pacific having significant impacts on the weather and climate of North America. This is verified by model simulation results of Pitcher et al. (1988).

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① * PRC / CAS—US / DOE Joint Research Program on CO_2—Induced Climate Change

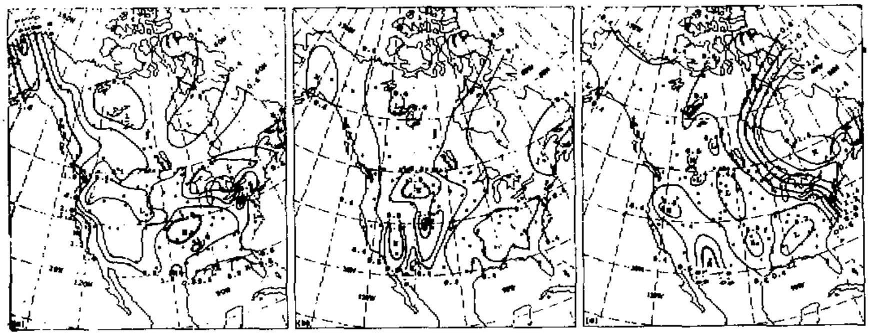

Fig. 1. Distribution of ratio of power spectrum of ten–year (a), 40–month (b) and 26.7–month (c) to that at 95% significance level. Contour interval is 0.2.

Pacific SST (EEPSST) anomaly both have obvious influence on the atmospheric circulation over North Pacific through North America. Our recent studies (Chen and Wu, 1991; Wu and Chen, 1991a, b) show that the North Pacific SST (NPSST) has closer association with the PNA flow pattern than the EEPSST anomaly and the PNA flow pattern has two obvious interannual oscillations: i. e. the scale of about ten–year and 3～5–year. The former is out of phase with the ten–year scale oscillation of NPSST, while the latter is in phase with the EEPSST. The impact of NPSST on the PNA flow pattern is mainly in the ten–year scale and the impact of EEPSST on the PNA flow pattern is in the 3–5 year scale. Since the PNA pattern is closely related to the North America SAT variation, is there ten year scale oscillation in the SAT over North America? Since the NPSST has closer association with the PNA pattern than the EEPSST, does it have closer relation to the SAT over North America than the EEPSST? These problems are to be analysed in this paper.

Monthly mean SAT (covering the period 1941–1980) over North America at 130 stations is provided by Carbon Dioxide Information Center (CDIC) of the Department of Energy of US.

II. INTERANNUAL FLUCTUATIONS OF SAT OVER NORTH AMERICA

Power spectrum of SAT over North America during 1941 through 1980 is analysed. It is demonstrated that there are obviously three different interannual fluctuations: ten–year, 40–month and 26.7–month. The distributions of the ratio of power spectrum of SAT at these three different time scales to that at 95% significance level are shown in Fig. 1, where the ratio above 1.0 is over 95% significant level.

It can be seen from Fig. 1 that the ten–year scale oscillation is over 95% significance level over the southeastern US, west coast of US and the northwestern North America. The 40–month scale oscillation reaches 95% significance level over part of the central–western US and the significant 26.7–month oscillation is over the eastern North America. This demonstrates the SAT over North America being of obvious ten–year scale oscillation over the southeastern US, west coast of US and the northwestern North America, and it has obvious 40–month oscillation over part of the central–western US and quasibiennial oscillation over the eastern North America.

In order to get a more direct impression, time series of SAT anomalies subjected to 13–month running means at three stations in relation to these three different time scales are given in Fig. 2. Corresponding power spectra are shown in Fig. 3.

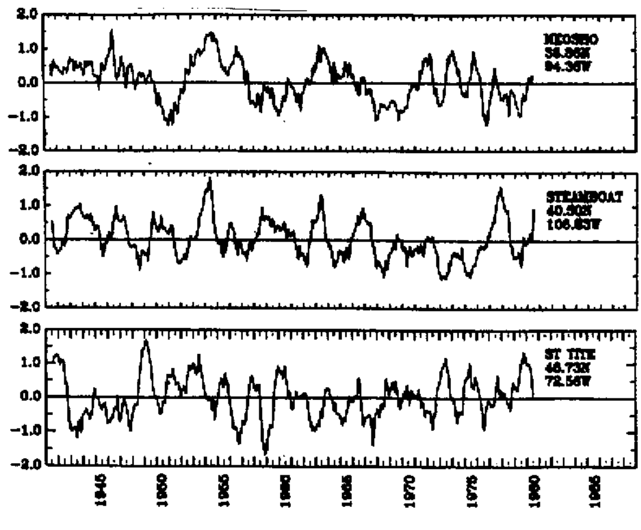

Fig. 2. Time series of SAT anomalies (relative to 1951–1980) subjected to 13–month running means.

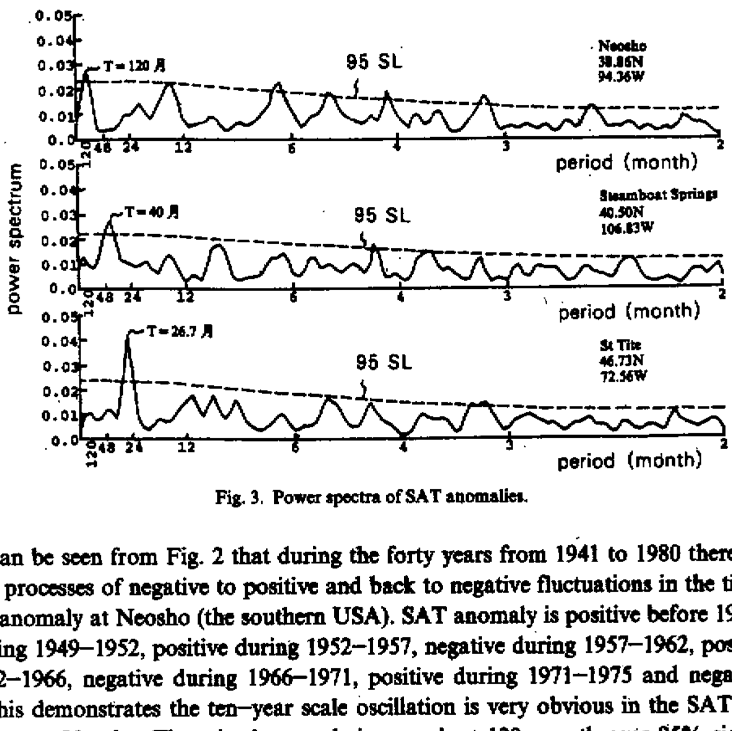

Fig. 3. Power spectra of SAT anomalies.

It can be seen from Fig. 2 that during the forty years from 1941 to 1980 there are four obvious processes of negative to positive and back to negative fluctuations in the time series of SAT anomaly at Neosho (the southern USA). SAT anomaly is positive before 1948, negative during 1949–1952, positive during 1952–1957, negative during 1957–1962, positive during 1962–1966, negative during 1966–1971, positive during 1971–1975 and negative after 1976. This demonstrates the ten–year scale oscillation is very obvious in the SAT anomaly fluctuation at Neosho. There is also an obvious peak at 120–month over 95% significance level in the power spectrum of SAT at Neosho. In the fluctuation of SAT anomaly at Steamboat Springs (the central–western US), there are 12–13 times of peak to valley and back to peak fluctuations, which means there exists 40–month oscillation. The power spectrum at 40–month is over 95% significance level as well. In the fluctuation of SAT anomaly at St Tite (eastern North America), there are 15–17 times of peak to valley and back to peak fluctuations with power spectrum at 26.7–month over 95% significance level, showing clear 24–26 month oscillation at St Tite.

III. RELATIONSHIP BETWEEN SAT OVER NORTH AMERICA AND NPSST

Investigations by Horel and Wallace (1981) and Namias (1978) demonstrated that when atmospheric circulation anomaly of PNA pattern appears over North Pacific through North America, high ridge develops over the west coast of North America, and the trough over the east coast of North America is deepened. Under such circumstances, SAT over the western North America is above–normal because of warm air advection, while SAT over the southeastern US is below–normal because of cold air advection from higher latitude. The contemporary correlation distribution between PNA pattern index (see Wu and Chen, 1991b) and SAT over North America is shown in Fig. 4. It is clear that negative correlation over the southeastern North America and the positive correlation over the west coast through the northwestern North America are very high, far over 99.9% significance level (correlation coefficient 0.16). This clearly shows that the PNA pattern atmospheric circulation anomaly is closely associated with the SAT over North America.

On the other hand, it is demonstrated that the PNA pattern is closly related to the NPSST (Chen and Wu, 1991; Wu and Chen, 1991a), especially the NPSST and PNA pattern both have ten–year scale oscillation (Wu and Chen, 1991b). Since the PNA pattern is closely associated with the SAT over North America and the latter also bears ten–year scale oscillation, then how about the relation between the NPSST and the SAT over North America in the ten–year scale oscillation?

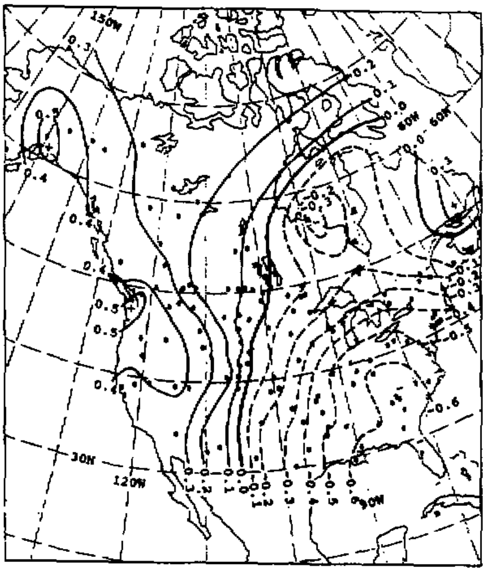

Fig. 4. Distribution of contemporary correlation between PNA pattern index and SAT over North America (1946–1980). Contour interval is 0.1.

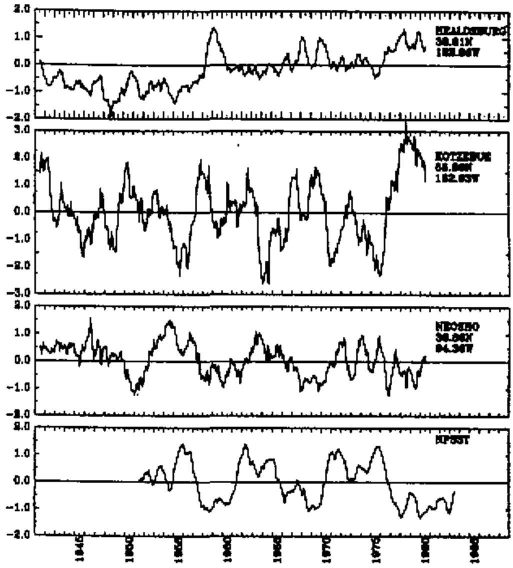

Fig. 5. Time series of SAT anomalies (relative to 1951–1980) and NPSST anomaly subjected to 13–month running means.

Firstly, we select a representative station from the southeastern US, west coast of US and northwestern North America respectively. Their time series of SAT anomalies subjected to 13–month running means are given in Fig. 5, together with similar time series of NPSSST anomaly. The NPSST anomaly is the area–averaged SST anomaly difference between Namias region (35°N: 170°W, 165°W, 160°W) and California current region (15°N: 145°W, 140°W, 135°W). It can be seen from Fig. 5 that not only the SAT anomalies have about ten–year scale oscillation but also such oscillation has a good correspondence with that of NPSST anomaly. During periods of lower SST over the central North Pacific and higher SST over the eastern North Pacific, the SAT is generally lower at Neosho, while it is generally higher at Healdsburg and Kotzebue. For example, during the late 1950′s, late 1960′s and late 1970′s through early 1980′s, the SST is lower over the central North Pacific and higher over the eastern North Pacific. Correspondingly, the SAT is lower at Neosho, obviously higher at Healdsburg and Kotzebue. On the contrary, during periods of higher SST over the central North Pacific and lower SST over the eastern North Pacific, the SAT is generally higher at Neosho, while it is generally lower at Healdsburg and Kotzebue. For example, during the middle 1950′s, early–middle 1960′s and early–middle 1970′s, the SST is higher over the central North Pacific and lower over the eastern North Pacific. Correspondingly, the SAT is higher at Neosho, relatively lower at Healdsburg and lower at Kotzebue except for 1952–53 and 1962–63. This demonstrates that the NPSST is in phase with the SAT over the southeastern US, while it is out of phase with the SAT over the northwestern North America and west coast of US.

In order to verify the above relationship further, the cross spectrum between NPSST and SAT over North America is calculated and shown in Fig.6. It can be seen clearly that there is an obvious peak (Neosho) or valley (Healdsburg and Kotzebue) at about ten–year in the coherence spectrum. Significance test of condensed spectrum shows that these peaks or valleys are over 95% significance level. This further demonstrates that NPSST and SAT have ten–year scale oscillation in common and the NPSST is in phase with the SAT at Neosho and out of phase with the SAT at Healdsburg and Kotzebue. From time–lag spectrum, the SAT lags behind the NPSST in this scale oscillation.

From above analyses it can be summarized that there is a good correspondence between the SAT over North America and NPSST in ten–year time scale oscillation and that they are in phase over the southeastern US and out of phase over the northwestern North America and west coast of US.

The contemporary correlation between SAT over North America and NPSST is given in Fig.7. It can be seen that the correlation is positive over the eastern and negative over the western North America with the highest positive correlation over the southeastern US and the large negative correlation along the west coast of US through Alaska. This further demonstrates the association between the NPSST and SAT over North America. Since the PNA pattern is associated with the SAT over North America on the one hand and it is affected by NPSST on the other hand, the association between the NPSST and SAT over North America is established by the atmospheric circulation anomaly over North Pacific through North America. When the SST anomaly is positive in the eastern and negative in the central North Pacific, through the differential heating of sea on the above air, warm ridge forms over the west coast of North America and low trough develops over the eastern North America, the PNA pattern atmospheric circulation anomaly forms over North Pacific through North America with developed meridional circulation. Under such circumstances, the SAT is higher over the western North America through warm air advection, while it is lower over the southwestern US because of cold air advection west to the trough. On the contrary, when the SST anomaly is negative in the eastern and positive in the central North Pacifc, anti–PNA pattern atmospheric circulation anomaly forms over North Pacific through North America with developed zonal circulation and weakened ridge and trough. In this case, meridional flow is weakened, warm and cold air advections are weaker, the SAT is lower over the western North America and higher over the southwestern US.

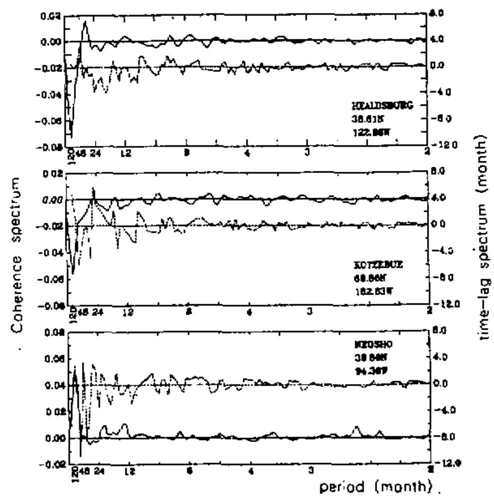

Fig. 6. Coherence spectrum (solid lines) and time–lag spectrum (dashed lines) between NPSST and SAT over North America.

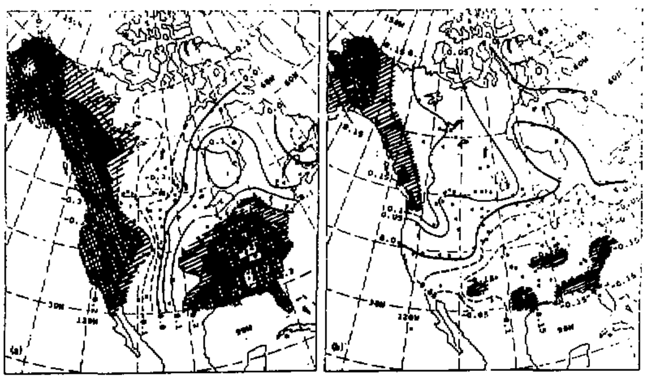

Fig. 7. Distribution of contemporary correlation between SAT over North America and NPSST (a), EEPSST (b). Contour interval is 0.05. Regions of 99% and 99.9% significance level are covered by hatched lines and cross–hatched lines respectively.

For comparison, the contemporary correlation between SAT over North America and EEPSST is also shown in Fig. 7. EEPSST is area–averaged SST anomaly over 180°–80°W, 5°N–5°S by 5° × 5° grids. It is obvious that the correlation is negative over the southeastern US and positive over the northwestern North America. The high negative correlation over the southeastern US extends toward the southwestern US and high positive correlation is over the west coast of Canada through Alaska. By careful detailed comparison of Fig. 7a with Fig. 7b, it can be identified:

(1) Correlation between NPSST and SAT over North America is obviously higher than that between EEPSST and SAT, especially over the southeastern US, the west coast of US and the northwestern North America.

(2) Over the western US, correlation is negative for NPSST, while it is of opposite sign over the southwestern to that over the northwestern for EEPSST.

(3) Over the central eastern Canada, the correlation is high for NPSST, while it is relatively weak for EEPSST.

Above correlation distribution demonstrates that though NPSST and EEPSST both have good relations to the SAT over North America, the NPSST has closer association with SAT whether over the southeastern US, the west coast of US or over the northwestern North America. This is may be due to the better relation of NPSST to PNA pattern than that of EEPSST (Chen and Wu, 1991; Wu and Chen, 1991a, b).

IV. SEASONAL VARIATION OF RELATIONSHIP BETWEEN NPSST AND SAT OVER NORTH AMERICA

In order to investigate the features of seasonal variation of relationship between NPSST and SAT over North America, the contemporary correlation between NPSST and SAT in different seasons is calculated (see Fig.8).

In winter, positive correlation is over the southeastern US with maximum positive correlation above 99.9% significance level (correlation coefficient 0.59) over east and south coast. Negative correlation is over the west coast of US and Alaska with correlation above 99% significance level (correlation coefficient 0.46). There is an obvious negative correlation center above 99.9% significance level over the central–western Canada. In spring, the positive correlation over the southeastern US shrinks in extent with much weaker correlation. Negative correlation over the central–western Canada vanishes, and positive correlation is over the northern Canada. There is not much variation in the negative correlation over the northwestern North America. The negative correlation over the west coast of US is strengthened somewhat.

In summer, there is still negative correlation over Alaska and the west coast of US, while negative correlation dominates over the east and south coast of US and the positive correlation shifts westward and northward with maximum positive correlation over the central–western Canada through the central North America. Such a seasonal variation in correlation between winter and summer may be related to that of PNA pattern since the PNA pattern shifts westward and northward obviously in summer (Wu and Chen, 1991a). In fall, positive correlation no longer exists over the central–western Canada, and the correlation is shifted southward and eastward. The negative correlation over the southwestern US is weaker than that in summer.

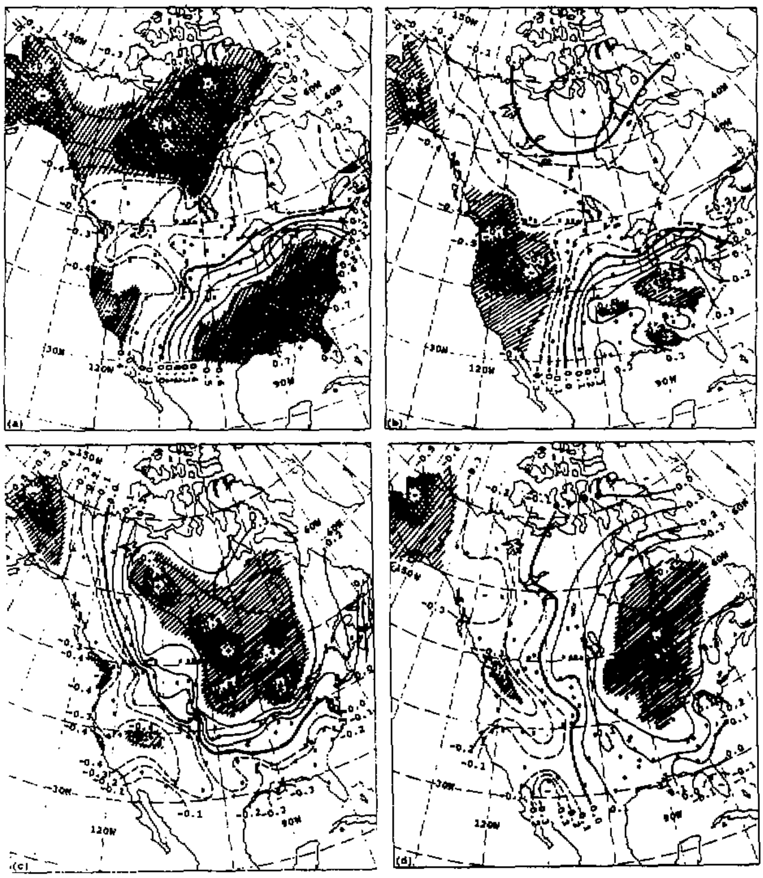

Fig. 8. Contemporary correlation between NPSST and SAT over North America in winter (a), spring (b), summer (c) and fall (d). Contour interval is 0.10. Regions of 99% and 99.9% significance level are covered by hatched lines and cross–hatched lines respectively.

It can be summarized from above analyses, the most stable relation between NPSST and SAT over North America with minimum seasonal variation is over the northwestern North America and the west coast of US. The next stable relation is over the southeastern US (not including the south and east coast). The most obvious seasonal variation of relationship is over the central–western Canada with obvious negative and positive correlation in winter and in summer respectively. In addition, the correlation distribution in spring is basically similar to that in winter and that in fall bears similarity to that in summer.

V. SUMMARY

The characteristics of interannual fluctuations of SAT over North America and its relation to NPSST are investigated by using the monthly mean SAT data of 130 stations during 1941 through 1980 provided by CDIC of the Department of Energy of US. The main results are as follows:

1. The SAT over the southeastern, northwestern North America and west coast of US bears ten–year scale oscillation, the SAT over the eastern North America has quasibiennial oscillation and 40–month scale oscillation is obvious only over part of the central–western US.

2. The ten–year scale oscillation of SAT over North America is related to that of NPSST through the atmospheric circulation anomaly of PNA pattern. They are in phase over the southeastern US and out of phase over the northwestern North America and the west coast of US in this scale oscillation.

3. The NPSST has closer relation to the SAT over North America than the EEPSST does.

4. The relationship between the NPSST and SAT over North America has seasonal variations.

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