Article ID: 1006-8775(2010) 02-0042-09

SEASONAL PERSISTENCE OF THE WEST PACIFIC SUBTROPICAL HIGH AND ITS RELATIONSHIP WITH THE SURFACE HEAT FLUX ANOMALY

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Abstract: This paper investigates the interannual variation of the West Pacific Subtropical High (WPSH) intensity based on the data compiled by the Chinese National Climate Center. Monthly reanalysis data from National Centers for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) are also used to study the lead-lag relationship between WPSH intensity and surface heat flux anomalies. The three major findings are as follows: First, WPSH intensity presents good seasonal persistence, especially from winter to the ensuing summer. Persistence is more significant after 1977, especially from spring to summer, and from summer to autumn; persistence of anticyclonic anomalies are significantly better than cyclonic anomalies. Second, surface heat flux tends to present opposite anomalous patterns between the strong and weak years of the WPSH intensity, which is especially valid at the latent heat flux over the ocean. Simultaneous correlations between surface heat flux and WPSH intensity in each of the seasons are marked by similar key areas. Finally, surface heat flux from the preceding winter of a strong summer WPSH is quite similar to strong spring WPSH, but the positive anomalies over the northwest Pacific and south of Japan are notably stronger. The situations in the weak years are similar except for those over the northwest Pacific: winter surface heat flux shows negative anomalies for a weak spring WPSH, but positive anomalies for a weak summer WPSH. It is suggested that surface heat flux in the previous winter plays an important role in maintaining the WPSH intensity in the ensuing spring and summer.

Key words: West Pacific Subtropical High; surface heat flux; seasonal persistence

CLC number: P422.4 **Document code:** A **doi:** 10.3969/j.issn.1006-8775.2010.01.006

1 INTRODUCTION

The West Pacific Subtropical High (WPSH) plays a very important role in weather and climate variations in China. The country's summer precipitation is closely related to the position of the WPSH. The onset and end of the Meiyu of the Yangtze River basin are determined by the seasonal variability of the WPSH, and the direction of the typhoon can be influenced by the movement of the WPSH. Therefore, the study of the WPSH has been carried out for years[1-5]. Tao and Chu[6] proposed a criterion for forecasting the movement of the West Pacific anticyclone during summer, while Cao et al.[7] studied physical mechanisms determining WPSH position.

Most of the literature focused on the summertime season because WPSH can influence the spatial-temporal distribution of precipitation in China from April to September[8]. At present, the question is whether WPSH in summer is related to WPSH in spring, and whether there is seasonal persistence in the WPSH. By identifying such relationships, we can forecast WPSH anomalies in summer using WPSH anomalies in winter and spring. Therefore, the seasonal persistence of anomalous WPSH is primarily discussed in this paper.

Many studies were conducted on the mechanism of WPSH formation and its variation in relation to time scales. Wen and He[5] found that the downdraft in the WPSH center is mainly caused by the latent heat release in its adjacent monsoon rainband. An interaction also exists between the westward extension

Received date: 2009-09-04; **revised date:** 2009-11-10
Foundation item: National Basic Research Program of China (2004CB418300 and 2010CB833404); National Natural Science Foundation of China (40675042, 40890054, 40871007 and 40672210)
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of WPSH and its surrounding rainbands. Lin and He[9] indicated that strong convection over the central plateau during summer leads to strengthened subsidence in the western Pacific, which is responsible for the enhancement and westward extension of the subtropical high ridge, as well as the maintenance of WPSH to the south of the Yangtze River, resulting in anomalously heavy rainfall in the lower-middle reaches of the Yangtze River. Gong and He[10] revealed that changes in the sea surface temperatures (SST) mainly result in the interdecadal variability of the WPSH.

WPSH formation and its seasonal, intraseasonal, interannual, and interdecadal variations have been popularly related to the anomalous thermal factors on the same time scale, mainly, condensation heating[11-12] and SST[13-16]. Surface sensible heating and latent heating associated with surface evaporation had received lesser attention. Water vapor evaporated from the surface supplies water vapor in the atmosphere, which then heats the air through condensation. As surface evaporation releases latent heat through condensation, its anomalies could affect WPSH. Therefore, a study on the relationship of surface latent heat flux (evaporation) and WPSH is deemed an interesting subject, and thus merits this present work.

The NCEP/NCAR monthly reanalysis data, including surface latent heat flux (SLHF) and surface sensible heat flux (SSHF) (for clarity, their sum is referred to as “surface heat flux” in this paper), and the wind field on each pressure level from January 1948 to December 2002 are used for this paper. WPSH intensity, as an index defined by the Climate Diagnostics and Prediction Division of the Chinese National Climate Center from January 1951 to December 2001, is also used. Intensity index is defined based on the geopotential height of the grids enclosed by the contour of 5880 gpm.

2 INTERANNUAL VARIATION OF THE SEASONAL WPSH INTENSITY INDEX AND ITS RELATIONSHIP WITH THE SURFACE HEAT FLUX

2.1 *The interannual variation of the WPSH intensity index in individual seasons*

Figure 1 indicates the normalized time series of the WPSH intensity index in individual seasons. It can be seen that the variation trend of the WPSH index in individual seasons is similar to one another. The values for amplitude and variance of the variation are small before the mid-1970s, but have significantly increased after the mid-1970s, and most especially in the 1990s. The normalized anomaly of the WPSH intensity index is mainly negative before 1978 but positive after 1979.

Using the years by which the normalized index values are equal to or have exceeded 2 as strong WPSH years, and those with values equal to or less than –2 for weak WPSH years, Fig. 1 shows that a strong WPSH in spring is associated with strong WPSH in summer and autumn, and even in winter. However, if springtime WPSH is weak, persistence is not so good. To judge quantitatively the seasonal persistence of WPSH intensity, the correlation coefficients of every two seasons are calculated for the entire period (1951 – 2001), the pre-1977 period (1951 – 1976), and the post-1977 period (1977 – 2001), as shown in Table 1.

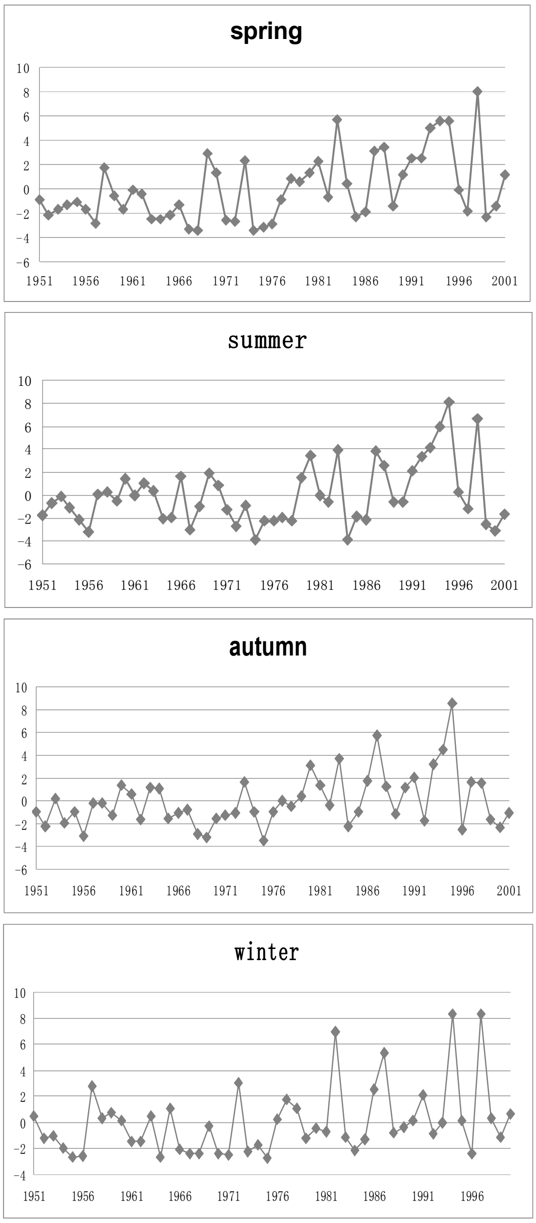


Fig.1 Normalized time series of the WPSH intensity index in individual seasons (1951-2001).

Table 1 shows the WPSH intensity persisting well throughout the entire period. The correlation coefficients between the listed pairs of seasons are remarkable except for those between the pre-winter and the subsequent winter. Clearly, when WPSH intensity for the previous winter is strong (or weak), the intensity in the ensuing spring and summer is expectedly strong (or weak) despite the decreasing coefficient. Such persistence is consistent with what was already mentioned by earlier reports, which analyzed the correlation coefficient of the WPSH area index between seasons[17]. Thus, WPSH intensity in winter has a seasonal persistence of about three seasons, but the correlation coefficient is insignificant between the intensity in the previous winter and the succeeding winter for the next year.

Table 1 Intraseasonal correlation coefficients of the WPSH intensity.

	Spring and summer	Summer and autumn	Autumn and winter	Pre-winter and spring	Pre-winter and summer	Pre-winter and autumn	Pre-winter and winter
Entire period	0. 81	0. 69	0. 43	0. 75	0. 67	0. 57	−0. 01
Pre-1977 period	0. 56	0. 18	0. 20	0. 55	0. 41	0. 52	−0. 13
Post-1977 period	0. 87	0. 76	0. 35	0. 75	0. 68	0. 47	−0. 20

Notes: The correlation coefficient above the 1% significance level is underlined. The entire period is from 1951 to 2001 ($r > 0.354$), the pre-1977 period is from 1951 to 1976 ($r > 0.48$), and the post-1977 period is from 1977 to 2001 ($r > 0.49$).

Seasonal persistence manifests interdecadal changes: persistence during the pre-1977 period is obviously weaker than in the post-1977 one.

Composite analysis is used to determine the relevance between WPSH intensity and surface heating in order to identify the key areas of the surface heat flux. Focus was given on surface heat flux in previous, contemporary, and subsequent seasons in terms of abnormal WPSH intensity in spring and summer.

2.2 *The surface heat flux distribution in relation to the spring WPSH intensity anomaly*

Strong and weak years of WPSH intensity during spring and summer are chosen based on the absolute value of the normalized index equal to or exceeding 2. Table 2 shows the identified abnormal years. Only two strong years are identified for spring in the period before 1977, and two weak years after 1977, which indicate a strengthening WPSH for spring after the mid-1970s. The strong years for summer are all presented at the post-1980 time, and the weak years have mainly appeared before 1980. Results suggest a prominent interdecadal variation, as shown in Table 1. Furthermore, a comparison of the abnormal years of intensity for spring and summer shows that the strong years in summer are almost continuations of spring; similarly, only half of the weak years in summer are extended from spring. This illustrates better persistence of strong intensity (anticyclonic anomalies) in spring compared to the weak intensity (cyclonic anomalies).

Table 2 Years of the WPSH intensity abnormality in spring and summer.

	spring	summer
strong WPSH years	1969, 1973, 1981, **1983, 1987, 1988, 1991, 1992, 1993, 1994, 1995, 1998**	1980, **1983, 1987, 1988, 1991, 1992, 1993, 1994, 1995, 1998**
weak WPSH years	1951, 1957, 1963, 1964, 1965, **1967,** 1968, 1971, **1972, 1974, 1975, 1976,** 1985, **1999**	1955, 1956, **1967, 1972, 1974, 1975, 1976,** 1978, 1984, 1986, **1999,** 2000

Notes: The years in bold fonts are the ones whose springs and summers are consistent in intensity.

Figure 2 shows surface heat flux anomalies from the preceding winters for spring WPSH intensity anomaly. Both SLHF and SSHF in the preceding winter show opposite anomalous patterns between strong and weak spring WPSH. The sharp differences in SLHF anomalies mainly occur in areas over the ocean. For instance, during strong years, there are positive SLHF anomalies north of 15°N and negative anomalies south of 15°N over the northwest Pacific. Anomalies are almost opposite in polarity for the weak years; the evident differences in the SSHF anomalies mainly appear in the south of Tibetan Plateau and Okhotsk Sea. Distribution of differences in SSHF anomalies in areas over the ocean is similar to the SLHF anomalies, but is almost reversed over the mainland (Fig. 2).

Surface sensible heat flux anomalies and wind anomalies at 500 hPa in spring are taken into account for simultaneous relationships between WPSH anomaly and surface heat flux (Fig. 3). SSHF anomalies in spring display a zonally oriented band structure for both strong and weak years. Additionally, SSHF anomalies over the mainland are positive for the strong years and negative for the weak years, except in the south and west of the Tibetan Plateau and in high latitude areas. An opposite distribution is more remarkable in areas over the ocean, and more centralized than in the preceding winter. Distribution of the SLHF anomalies in areas over the ocean is similar to the SSHF anomalies (figure omitted).

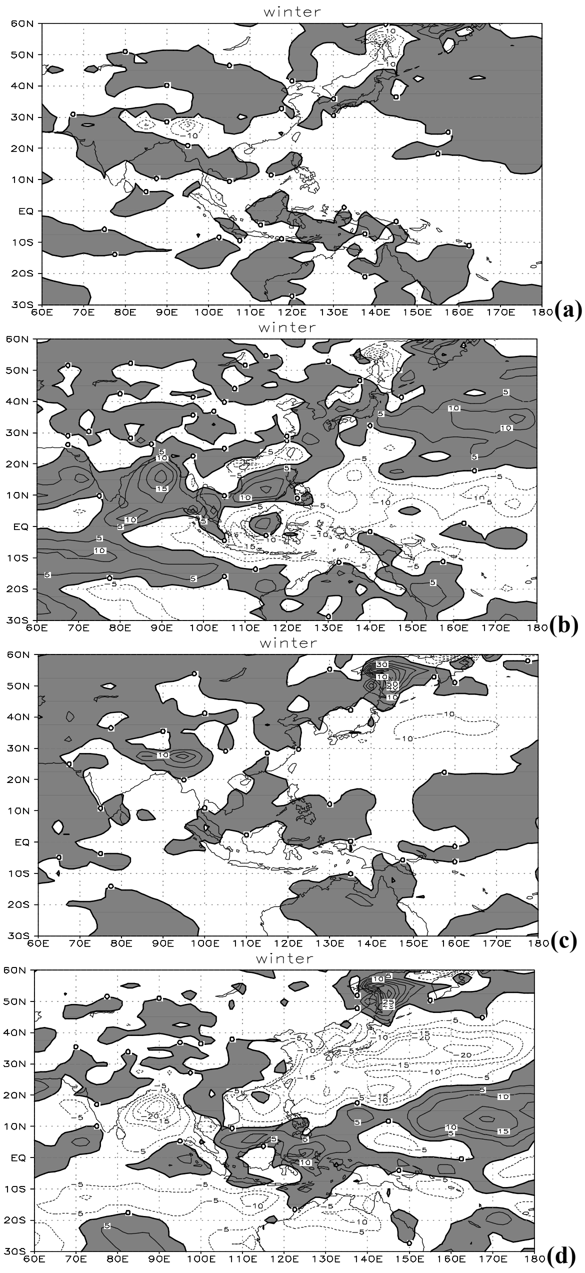


Fig.2 Surface heat flux anomalies in the previous winters for the strong and weak WPSH intensity in springs. (unit: W/m^2) (a), (b): strong years; (c), (d): weak years; (a & c): sensible heat flux anomalies; (b & d): latent heat flux anomalies. Positive anomalies are shaded.

Figure 3 shows the positively correlated SSHF and 500-hPa wind anomalies. For instance, there are anomalous anticyclonic circulations (negative vorticity) for strong WPSH years over the elongated region stretching from the Bay of Bengal to the tropical and subtropical west Pacific (areas where SSHF anomalies are negative). Cyclonic wind (positive vorticity) anomalies for the weak years prevail over the region from the Bay of Bengal to the Philippine Sea, and in the subtropical western Pacific (areas where corresponding SSHF anomalies are also positive).

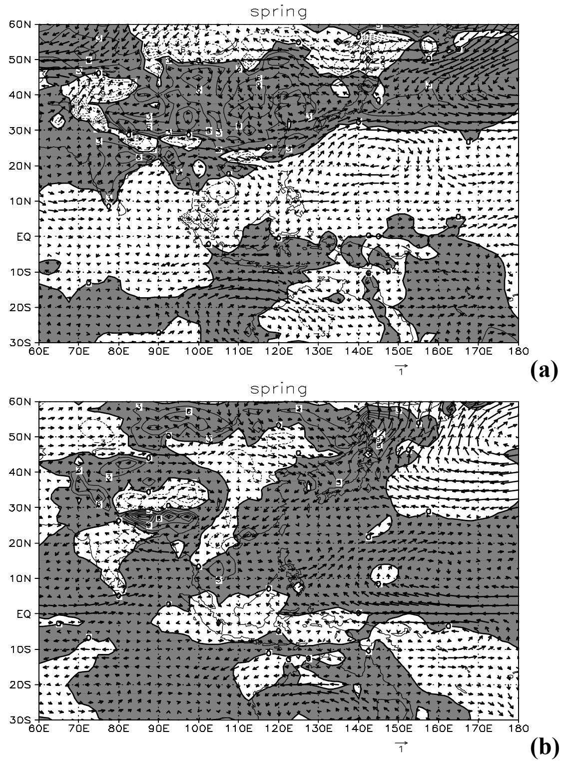


Fig.3 Abnormal distribution of the surface sensible heat flux (isoline and shading, unit: W/m^2) and the wind at 500 hPa (vector). (a): strong years; (b): for weak years. Positive values are shaded.

Characteristics of WPSH anomaly and sensible heat flux in the ensuing summer and autumn are briefly discussed in the following section. In the ensuing summer, SSHF anomalies over East Asia are negative for weak years but positive for strong years. Wind anomalies at 500 hPa over these areas are southwesterly for weak years, which benefit the development of the southwest summer monsoon up to higher latitudes. Central latitudes of WPSH push northward and eastward; the intensity is weak. For strong years, however, anomalous wind at 500 hPa over the northeast of China shows a cyclonic circulation and anticyclonic circulation over the south of China and south of the Tibetan Plateau. Over the high latitudes of east China, there are northerly anomaly circulations wherein WPSH is southward and westward; the intensity is strong. In the ensuing autumn, the different outstanding regions of SSHF anomalies between strong years and weak years remain lying over the west and east of the Tibetan Plateau (negative over the west and positive over the east for strong years, while positive over the west and negative over the east for weak years). Other notable regions are the mainland and areas over oceans at the high latitude. Differences in SLHF anomalies are located over the west Pacific, especially over the coast of the west Pacific and the north of the South China Sea. Distribution over the west Pacific covers a range of '– + – +' for strong years and just the opposite for weak years. Wind anomalies at 850 hPa in the previous and succeeding winter for a spring abnormal WPSH reveal that the East Asian Trough from the preceding winter of strong years is a little stronger and more westward, while the northeast wind is a little weaker, than in the weak years. In the ensuing winter, the East Asian Trough is weaker for the strong years than that for the weak years, while the northeast wind is a little stronger compared to the weak years. The northeast winter monsoon in the ensuing winter of the strong years is stronger than that in the preceding winter, while the difference in the winter monsoon, between the preceding and coming winter is insignificant for the weak years.

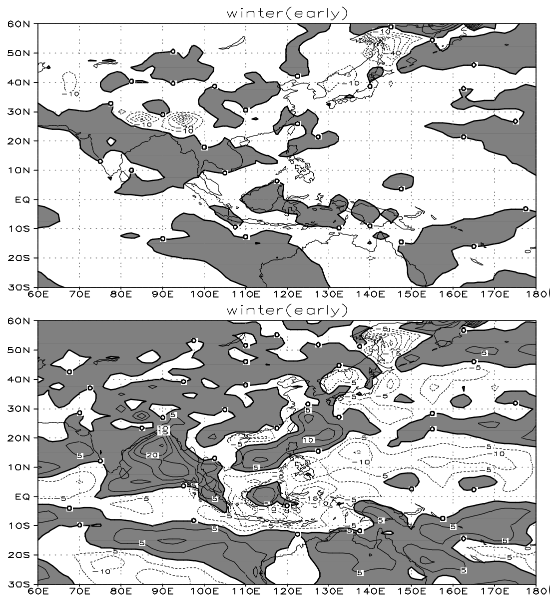
Based on the above analyses, it is clear that the heating anomalies have contrary distributions in both the preceding winter and spring in relation to the strong and weak spring WPSH intensity. This is particularly true for the SLHF anomaly over the ocean. Due to their interaction, heating and circulation constrain each other in spite of the seasonal variation, and thus enable the signals of abnormality for the heating and circulation to preserve themselves in the process. This is the reason behind seasonal persistence in an abnormal WPSH intensity.

2.3 *The surface heat flux distribution in relation to the summer WPSH intensity anomaly*

For China, it is important to know whether there are early signals indicating abnormal WPSH intensity in summer. When WPSH intensity in spring is strong, the intensity in summer is likewise strong; however, if the intensity in spring is weak, the intensity during the summer may not necessarily be weak (Table 1). This paper investigates such surface heating anomaly as a means to explore early signals of abnormal WPSH intensity in summer.

Figure 4 shows the relationship between surface latent and sensible heat flux anomalies in the preceding winter and the ensuing summer WPSH intensity anomalies. A comparison of Fig. 2 and Fig. 4 indicates that anomalies in a preceding winter for a strong summer WPSH (Fig. 4a, b) are similar to those for a strong spring WPSH (Fig. 2a, b). The positively anomalous regions over the northwest Pacific (i.e., south of Japan) is much larger than during the years of strong spring WPSH. The difference in the heat flux of the preceding winter over the northwest Pacific between weak years in spring and weak years in summer shows that the surface heat flux anomaly is negative for the weak spring WPSH but positive for the weak summer WPSH. As mentioned above, a strong summer WPSH comes mainly from persistence. This explains a similar precursory surface heat flux anomaly for the previous winter. However, if WPSH intensity in spring is weak, the intensity for summer may not be necessarily weak. The intensity of WPSH during the summer is connected to the spatial distribution of the surface heat flux (latent and sensible heat flux) anomaly in the previous winter, especially over the Pacific area north and south of 25°N and in the Bay of Bengal. A positive anomaly in winter indicates a strong WPSH intensity for the ensuing summer, while a negative anomaly foretells a weak one.

Surface heat flux anomaly for each month in the preceding spring is also analyzed (figures omitted). It was found that heat flux anomaly in April is at its most distinct form; this is significant for the subsequent WPSH intensity in summer. Both SSHF anomaly over the eastern Indochina Peninsula and SLHF anomaly over the western part during April play quite different roles in the summer WPSH intensity. Surface heat flux anomaly in April over the Indochina Peninsula directly affects South China Sea's (SCS) summer monsoon intensity because SCS summer monsoon breaks out in May over the Bay of Bengal-Indochina Peninsula-SCS. This could have subsequent impact on the WPSH intensity in summer.



(a)
(b)

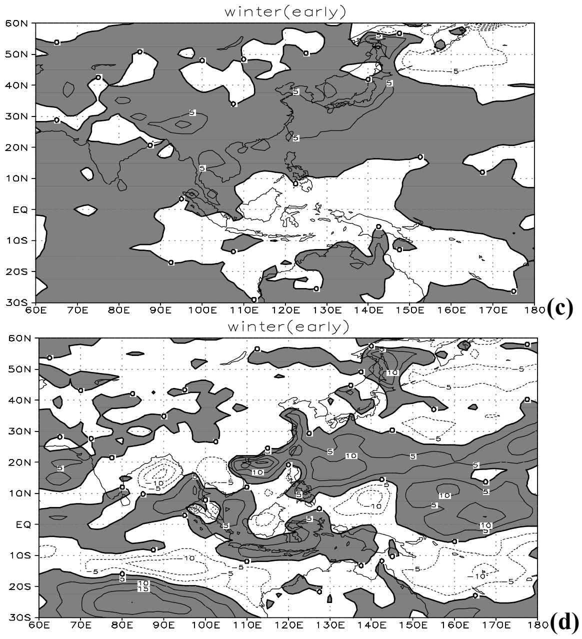


Fig.4 Surface heat flux anomalies in the previous winters for the strong and weak WPSH intensity in summers. Other captions are the same as Fig.2.

The abnormal WPSH intensity in summer inevitably influences the WPSH intensity and surface heat flux for the ensuing season because of the interaction of the circulation anomaly with the surface heat flux anomaly. The surface heat flux anomalies in the next winter (figures omitted) indicate that anomalies in the succeeding winter for the strong WPSH intensity in summer, though relatively small in values, distribute similarly as those in the previous winter for both strong WPSH intensity in spring and summer. Anomalies for the upcoming winter for weak WPSH intensity in summer bear little similarity with the previous winter for weak WPSH intensities in both spring and summer. Meanwhile, the SLHF anomalies for the next winter are significantly smaller than in the previous winter, illustrating that when a surface heat flux anomaly over East Asia in winter corresponds to a weak East Asia winter monsoon, the WPSH intensity for the upcoming spring and summer may be strong, and surface heat flux anomaly for the following winter could weaken the East Asia winter monsoon. The extent of weak intensity is decreased as well. Furthermore, when the surface heat flux anomaly in winter corresponds to a strong East Asia winter monsoon, the WPSH intensity in the ensuing spring and summer are weak, and the surface heat flux anomaly for the following winter may increase the intensity of the East Asia winter monsoon, but the extent is decreased. One can then surmise that the East Asia winter monsoon system has a damping feedback process that stops when winter monsoon intensity anomaly is small enough. Some other undiscovered factors may produce a new winter monsoon anomaly, which could eventually restrain the damping feedback process.

The analysis of the relationship between SCS summer monsoon intensity and surface heat flux anomalies from previous winters also points to a damping circle process. For instance, when East Asia winter monsoon is weak, the SCS summer monsoon intensity is also weakened, and the extent of the weak winter monsoon for the following winter is decreased. Similarly, when East Asia winter monsoon returns to normal or becomes strong, the SCS summer monsoon follows the same pattern (normal or strong), and the extent of strength for the upcoming winter is decreased. However, further work still needs to be done to determine the factors that restrain the damping feedback process.

3 CORRELATION ANALYSIS BETWEEN THE WPSH INTENSITY INDEX AND THE SURFACE HEAT FLUX

The composite analysis in the previous section shows that the heating anomaly for the typical strong years and that for the typical weak years are almost opposite. However, a composite analysis can only illustrate the characteristics of typical years; that is, it remains a question as to whether there is still close relationship between the WPSH intensity index and surface heat flux for the entire period. For this purpose, the correlation analysis is used in the following section.

Based on the simultaneous correlation coefficient between the WPSH intensity index and surface heat flux during winter (Fig. 5), a significant correlation area can be observed at the edge of the East Asia winter monsoon circulation (i.e., high latitude mainland and the coast of East China, as well as the Philippine Sea and subtropical WNP). Since the correlation between the SLHF and the SSHF is negative over the mainland and positive over the ocean[18], the correlation between the WPSH intensity index and the SLHF and that between the intensity index and the SSHF tend to have the same sign over the ocean but opposite sign over the land.

The areas of significant correlation between WPSH intensity index in spring and contemporary surface heat flux resemble those in winter, reflecting some changes in some isolated areas and significant changes in Indonesia and the West Pacific in the Southern Hemisphere (where the correlation coefficient is larger than in winter), and the boreal west Pacific and northwest Pacific (where correlation is smaller). The correlation between the intensity index and SSHF over north China changes into a positive value.

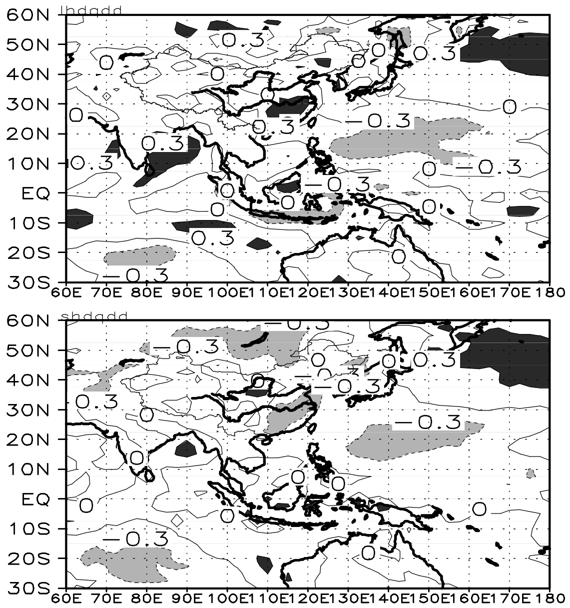


Fig.5 Contemporary correlation coefficients between the WPSH intensity index and the surface heat flux in winter; the upper panel is for SLHF and the lower panel is for SSHF. (The regions above the 95% confidence level are shaded, dark shades are for positive values and light shades for negative ones.)

A remarkable correlation area in summer is located over the austral west Pacific and tropical Indian Ocean where a larger surface heat flux corresponds to a stronger WPSH intensity index. Meanwhile, a stronger WPSH intensity index corresponds to a larger surface heat flux in the area. It is known from combinations of the wind field with the relationship between wind and heat flux (figures omitted) that the two mentioned regions are related to a cross-equatorial flow from the Southern Hemisphere. It is also known that the enhancement of heat flux over these two regions, especially over the tropical eastern Indian Ocean, may strengthen the austral southeast wind and weaken the boreal southwest wind, thereby contributing to the persistence, and even the development, of WPSH intensity.

Figure 6 illustrates the correlation coefficient between WPSH intensity index in spring and surface heat flux from the preceding winter. SSHF from the preceding winter shows the same active region as the SLHF to the WPSH intensity in spring. The different signs over the land and ocean are due to different relationships between SSHF and SLHF over land and ocean. Over the mainland, a strong WPSH intensity is connected to a reduced SSHF and an increased SLHF over the mid-lower Yangtze River area. Furthermore, the correlation coefficient between the SSHF and the intensity index is negative over the high-latitude mainland. Large sensible and latent heat fluxes over the Bay of Bengal, eastern Indian Ocean, and the austral west Pacific from the preceding winter corresponds to strong WPSH intensity in spring. We can then infer that when East Asian winter monsoon is weaker, SST over the Bay of Bengal in winter is higher, SST over low latitude west Pacific is lower, and WPSH intensity in the ensuing spring would be stronger. All of these take into account the relationships of heat flux, winter monsoon circulation, and SST.

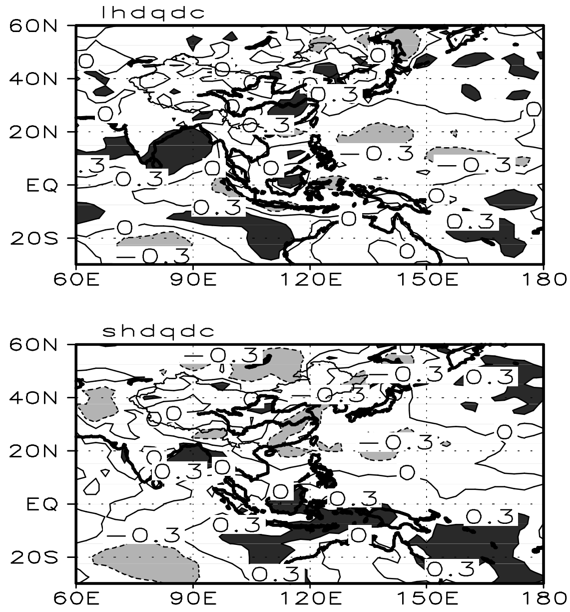


Fig.6 Correlation coefficients between the surface heat flux in the previous winter and the WPSH intensity index in spring; The upper panel is for SLHF and the lower panel is for SSHF. Other captions are the same as Fig.5.

Compared to Fig. 6, it can be seen that the relationship between surface heat flux in winter and WPSH intensity index for the following summer and autumn has changed little, while surface heat flux from the previous winter has little effect on WPSH intensity for the following winter. Surface heat flux over the eastern austral Indian Ocean and the high-latitude mainland continues to influence WPSH intensity for the succeeding winter. Surface heat flux for the preceding winter can then act on WPSH intensity for a lengthened period.

As a result, we can surmise that surface heat flux for the preceding winter is the most important factor in the ensuing WPSH intensity index, especially for spring and summer, and is the foundation for the seasonal persistence of the WPSH intensity index. As soon as heat flux and circulation in the preceding winters change, WPSH intensity in spring changes as well, and WPSH intensity in summer and autumn can persist through the interaction between the circulation and the heat flux.

The correlation coefficient of surface heat flux from the previous winter and contemporary/ensuing WPSH intensity index illustrates that there is a similar key area over the northwest Pacific. The thermal difference index can then be derived as follows: Subtract the area average of the latent (sensible) heat flux of (155°E－180°E，45°N－55°N) from (130°E－160°E，12.5°N－25°N), and then normalize it. The pairwise correlation of latent (sensible) heat flux between seasons and the relation between latent (sensible) heat flux and ensuing WPSH intensity index are listed in Table 3. The correlation coefficient of SSHF between the autumn and upcoming winter exceeds the 95% confidence level, but is less significant between other seasons.

Table 3 Pairwise correlation of each thermal difference index between individual seasons.

	Previous winter and spring	Spring and summer	Summer and autumn	Autumn and winter	Previous winter and next winter
SLHF	0.399	0.329	0.324	0.404	0.062
SSHF	0.214	0.168	0.018	0.345	0.084
SLHF and WPSH intensity index	0.518	0.218	0.113	0.119	-0.197

Table 3 shows that the correlation between SLHF in the preceding winter and WPSH intensity index in spring is significantly higher than in any other seasons. The correlation coefficient between SLHF in the preceding winter and WPSH intensity index in the ensuing summer is 0.387, and that between SLHF in the preceding winter and WPSH intensity index in the ensuing autumn is only 0.165. We can see that the thermal difference index of northwest Pacific in the previous winter can affect the ensuing WPSH intensity index in summer. The persistent effect of the surface heat flux from the previous winter on WPSH intensity in spring and summer makes it possible for seasonal WPSH intensity abnormality to persist.

4 CONCLUSIONS

The seasonal persistence of WPSH intensity is revealed through the correlation analysis. The WPSH intensity persists from spring to summer and from summer to autumn, but not from autumn to winter, throughout the entire period of 1951 to 2001. The WPSH intensity anomaly from the preceding winter lasts until the upcoming autumn but with a decreasing intensity, and the persistence becomes stronger, especially from spring to summer and from summer to autumn, during the period 1977 to 2001.

The composite analysis of surface heat flux from previous, contemporary, and subsequent seasons for the typical abnormal years of WPSH intensity in spring and summer indicates that surface heat flux anomaly from the previous winter and contemporary spring have opposite anomalous patterns for strong and weak spring WPSH intensity, especially so for the surface latent heat flux (SLHF) over the ocean. Surface heat flux from the preceding winter for strong summer WPSH resembles that of the strong spring WPSH, but the positive anomaly is stronger over the northwest Pacific and the south of Japan. Situations are similar for the weak WPSH years, but negative winter surface flux anomalies occur during weak spring WPSH, while positive anomalies occur during weak summer WPSH, over the northwest Pacific. Surface sensible heat flux (SSHF) over the whole research domain tends to display meridional difference (zonal structure) in the anomaly pattern. The SSHF over the mainland shows positive anomalies for the strong years but negative ones for the weak years, except in the south and west of the Tibetan Plateau and the high latitude.

The correlation analysis between surface heat flux and WPSH intensity index in individual seasons show identical key areas of SLHF and SSHF. Over mainland China, the smaller SSHF and larger SLHF over the mid-lower Yangtze River correspond to a stronger WPSH intensity in spring. The SSHF over the high latitude is negatively correlated to the WPSH intensity index in spring. In areas over the ocean, large SSHF and SLHF over the Bay of Bengal, eastern Indian Ocean, and the austral western Pacific, and small SSHF and SLHF over the low latitude and the western Pacific of Northern Hemisphere indicate strong WPSH intensity in spring. This implies that when the East Asian winter monsoon is weak, the SST over the Bay of Bengal is high; similarly, SST over the low-latitude western Pacific in the previous winter is low while the WPSH intensity in spring is strong.

The relationship changes little between the surface heat flux from the previous winter and the summer and autumn WPSH intensity index, but diminishes between the previous and upcoming winter, except on surface heat flux over the high latitude mainland and eastern Indian Ocean of the Southern Hemisphere. Therefore, surface heat flux anomaly from the preceding winter is the most important factor for WPSH intensity in ensuing spring and summer, and is the foundation of seasonal persistence of the WPSH intensity index. Once the surface heat flux and the circulation in the preceding winter change, the WPSH intensity in spring subsequently changes and the relevant WPSH intensity anomalies in summer and autumn are sustained by the interaction between the circulation and the heating field.

A thermal difference index over the northwest Pacific is constructed for the identical key area of surface heat flux affecting the WPSH intensity index across individual seasons. Correlation analysis shows that the thermal index from the previous winter can be an indicator for the WPSH intensity index until the summer. This confirms that the persistent effect of surface heat flux from the previous winter on the ensuing WPSH intensity in spring and summer could lay the foundation for seasonal persistence of the WPSH intensity anomaly.

A damping feedback process of the East Asian winter and summer monsoon is suggested, based on the composite analysis on surface heat flux anomaly and wind anomaly for strong and weak WPSH intensity index years. For instance, when the East Asian winter monsoon is weaker than normal, the WPSH intensity in spring may be stronger than normal, and the East Asian summer monsoon may be weaker than normal; similarly, the East Asian winter monsoon for the subsequent winter may still be weak, but the extent could decrease, making the extent of the weakness increasingly smaller. When the East Asian winter monsoon becomes normal or stronger, another cycle may take place. Specifically, when the East Asian winter monsoon is strong, WPSH intensity in spring may be weak, and the East Asian winter monsoon in the next winter may still remain strong, but maybe with decreasing extent. The duration (in year) and the effective factors for such a cycle remain uncertain. More analyses and numerical experiments are therefore needed for verification.

REFERENCES:

[1] ZHANG Qing-yun, TAO Shi-yan. The anomalous subtropical anticyclone in Western Pacific and their association with circulation over West Asia during summer [J]. Chin. J. Atmos. Sci., 2003, 27(3): 369-380.

[2] LI Jiang-nan, MENG Wei-guang, WANG An-yu, et al. Climatic characteristics of the intensity and position of the subtropical high in the Western Pacific [J]. Trop. Geography, 2003, 23(1): 35-39.

[3] TAN Gui-rong, SUN Zhao-bo. Relationship of the subtropical high and summertime floods/droughts over North China [J]. J. Trop. Meteor., 2004, 20(2): 206-211.

[4] SHU Feng-min, JIAN Mao-qiu. Effects of sensible heating flux and latent heating on seasonal evolution of the subtropical high belt over Asia monsoon region [J]. J. Trop. Meteor., 2006, 22(2): 121-130.

[5] WEN Min, HE Jin-hai. Effect of summer monsoon precipitation latent heat release on the formation and variation of western pacific subtropical high [J]. J. Nanjing Inst. Meteor., 2000, 23(4): 536-541.

[6] DAO Shih-yen, CHU Fu-kang. The 100-MB flow patterns in Southern Asia in summer and its relation to the advance and retreat of the West Pacific Subtropical Anticyclone over the Far East [J]. Acta Meteor. Sinica, 964, 34(4): 385-396.

[7] CAO Jie, HUANG Rong-hui, XIE Ying-qi, et al. The physical mechanism of the West Pacific subtropical high development [J]. Sci. China (Ser. D), 2002, 32(8): 659-666.

[8] WANG Hong-ye, WANG Qain-qian, ZHAO Yu-chun. Characteristics of precipitation anomaly over middle lower reaches of the Yangtze River related to precipitation and temperature anomalies of China [J]. J. Nanjing Inst. Meteor., 1999, 22(4): 685-691.

[9] LIN Jian, HE Jin-hai. The anomalous convection over the Tibetan Plateau in spring and summer and its effect on the western Pacific subtropical high [J]. J. Nanjing Inst. Meteor., 2000, 23(3): 346-355.

[10] GONG Dao-yi, HE Xue-zhao. Interdecadal change in Western Pacific subtropical high and climatic effects [J]. Acta Geograph. Sinica, 2002, 57(2): 185-193.

[11] SI Dong, WEN Min, XU Hai-ming, et al. Analysis of the westward extension of the western Pacific subtropical high during the heavy rain period over the southern China in June 2005 [J]. J. Trop. Meteor., 2008, 24(2): 169-175.

[12] HE Jin-hai, ZHOU Bing, WEN Min, et al. Vertical circulation structure, interannual variation features and variation mechanism of western Pacific subtropical high [J]. Adv. Atmos. Sci., 2001, 18(4): 497-510.

[13] YING Ming, SUN Shu-qing. A study on the respongse of subtropical high over the western Pacific on the SST anomaly [J]. Chin. J. Atmos. Sci., 2000, 24(2): 193-206.

[14] CAI Xue-zhan, WEN Zhen-zhi, WU Bin. Relationship between west Pacific subtropical high and ENSO and its influence on rainfall distribution of rainy season in Fujian [J]. J. Trop. Meteor., 2003, 19(1): 36-42.

[15] GUO Yu-fu, ZHAO Yan, WANG Jia. Numerical simulation of the relationships between the 1998 Yangtze River Valley floods and SST anomalies [J]. Adv. Atmos. Sci., 2002, 19(3): 391-404.

[16] HAO Li-sheng, LU Wei-song. Mechanism for SSTA impact on summer rainfall in North China [J]. Arid Meteor., 2006, 24(2): 5-11.

[17] CHEN Xing-fang. The research and the long term prediction of the subtropical high [J]. Meteor. Sci. Tech., 1984, 1: 8-14.

[18] YAN Mi, QIAN Yong-fu. Composite study of the surface thermal anomaly over the east Asia in strong and weak SCS summer monsoon [J]. Acta Sci. Nat. Univ. Sunyatseni, 2009, 48(2): 124-130.

Citation: YAN Mi and QIAN Yong-fu. Seasonal persistence of the west Pacific subtropical high and its relationship with the surface heat flux anomaly. *J. Trop. Meteor.*, 2010, 16(1): 42-50.