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Statistical characteristics of the double ridges of subtropical high in the Northern Hemisphere

ZHAN Ruifen[1,2,3], LI Jianping[1] & HE Jinhai[2]

1. State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China;
2. Department of Atmospheric Sciences, Institute of Meteorology, Nanjing University of Information Science and Technology, Nanjing 210044, China;
3. Graduate School of the Chinese Academy of Sciences, Beijing 100039, China

Correspondence should be addressed to Li Jianping (email: ljp@lasg.iap.ac.cn)

Abstract **The generality and some climatological characteristics of the double ridge systems of subtropical high (SH) are investigated statistically by using the daily NCEP/NCAR reanalysis data from 1958 to 1998. The results show that the SH double-ridge event is a common phenomenon in the Northern Hemisphere, with the distinct seasonal and regional features, that is, the majority of SH double-ridge geneses concentrate over the eastern North India Ocean-western North Pacific as well as the central North Pacific in the period from mid-July to mid-September. Especially over the western North Pacific subtropics, the SH double-ridge events are extremely active. It is found that the life cycle of most double-ridge events of western Pacific subtropical high (WPSH) is shorter but some still last longer. The WPSH double-ridge events occur most frequently from July to September, while there is a paucity of occurrences during November-March. Also, it is shown that the WPSH double-ridge events have a strong interannual variation with a certain periodicity which possesses a remarkably abrupt change in the mid-1970s. Additionally, the relationship between the WPSH double ridges and the meridional movement of WPSH is discussed.**

Keywords: subtropical high, double ridges, statistical characteristics, meridional movement.

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The subtropical high (hereafter, called SH) is a link between the tropics and extratropical belt in the weather and climate, and making sure its formation and variation is the important issue to further research in understanding the atmosphere general circulation and global climate change. From the 1920s to the present, a remarkable number of studies have been performed on the SH[1]. Generally, researches on SH fall into two basic classes[2]: (1) the inner structures and dynamics of SH and its effect on weather and climate[3−6] and (2) the factors impacting on the SH activities[7−11].

In most previous studies, the emphasis has been on a single-ridge SH structure. However, a more interesting phenomenon, the SH double ridges (SHDR), is in existence, which has been documented in recent work by Zhan et al.[12]. They indicated that from July 8 to 13,1998, two high ridges visibly emerge at 500 hPa over East Asia-western Pacific subtropical latitudes, which is defined as an SHDR event. Also, it is found that the appearance of such event could be often seen in daily stream fields.

The summer monsoon rainfalls over East Asia are identified as Mei-yu in China and Baiu in Japan[13,14]. Many studies have emphasized the important impacts of the meridional shift of the WPSH ridge on the location and intensity of Mei-yu or Baiu[13, 15,16]. For example, the second Mei-yu in the summer of 1998, causing unprecedented heavy floods with property damage up to 180 billion RMB (Yuan), is closely relative to persistent southward stagnancy of SH[17]. Further, it was demonstrated that the SHDR event plays an important role in this short-term variation of WPSH[12], that is, not only this event itself provides an important omen for the 1998 second Mei-yu over the Yangtze River Valley, but also its persistence exerts certain influence on the rainfall pattern in eastern China. Thus, some questions will arise naturally as to whether the SHDR phenomenon is common, what the spatial and temporal climatological characteristics of the SHDR are, and what its relationship with the meridional movement of SH is. The aim of this paper is to answer these questions by conducting a statistical analysis for the SHDR events in the Northern Hemisphere, especially in the western North Pacific from 1958—1998. In this study, we will use the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis daily data[18] from 1958 to 1998 and the characteristic line of u=0 and $\partial u/\partial y>0$ over subtropics to identify SH ridge[19].

1 Climatological characteristics of the SHDR events in the Northern Hemisphere

The frequence of daily SHDR events at 500 hPa in the Northern Hemisphere is calculated as follows: If the SH is structured by the double ridges on some day at some longitude during 1958—1998 (defined as an SHDR event), the frequency is added by 1/41 on this day at this longitude. After all longitudes in the Northern Hemisphere are calculated in 41 years, the time-longitude cross section of the daily frequency distribution of 500 hPa SHDR events in the Northern Hemisphere for the period 1958—1998 is presented in Fig. 1. A prominent feature is the distinct seasonal and regional character in the SHDR genesis. Generally, the SHDR events occur first over the central North Pacific (roughly 150 °E—150 °W) in the middle ten days of March, and afterwards extend gradually eastwards and westwards, respectively. There are three aspects worth noticing in Fig. 1: (1) It is in late April-early May that the SHDR event appears over the western and central North Indian Ocean (60 °—80 °E), gradually expanding eastward as far as nearly 120°E in the middle ten days of May; (2) The majority of SHDR geneses concentrate in the period from mid-July to mid-September, especially over the eastern North India Ocean-western North Pacific as well as the central North Pacific where the frequency of SHDR genesis increases by 50 percent; (3) The SHDR events, to most degree, simultaneously vanish in the Northern Hemisphere in late October.

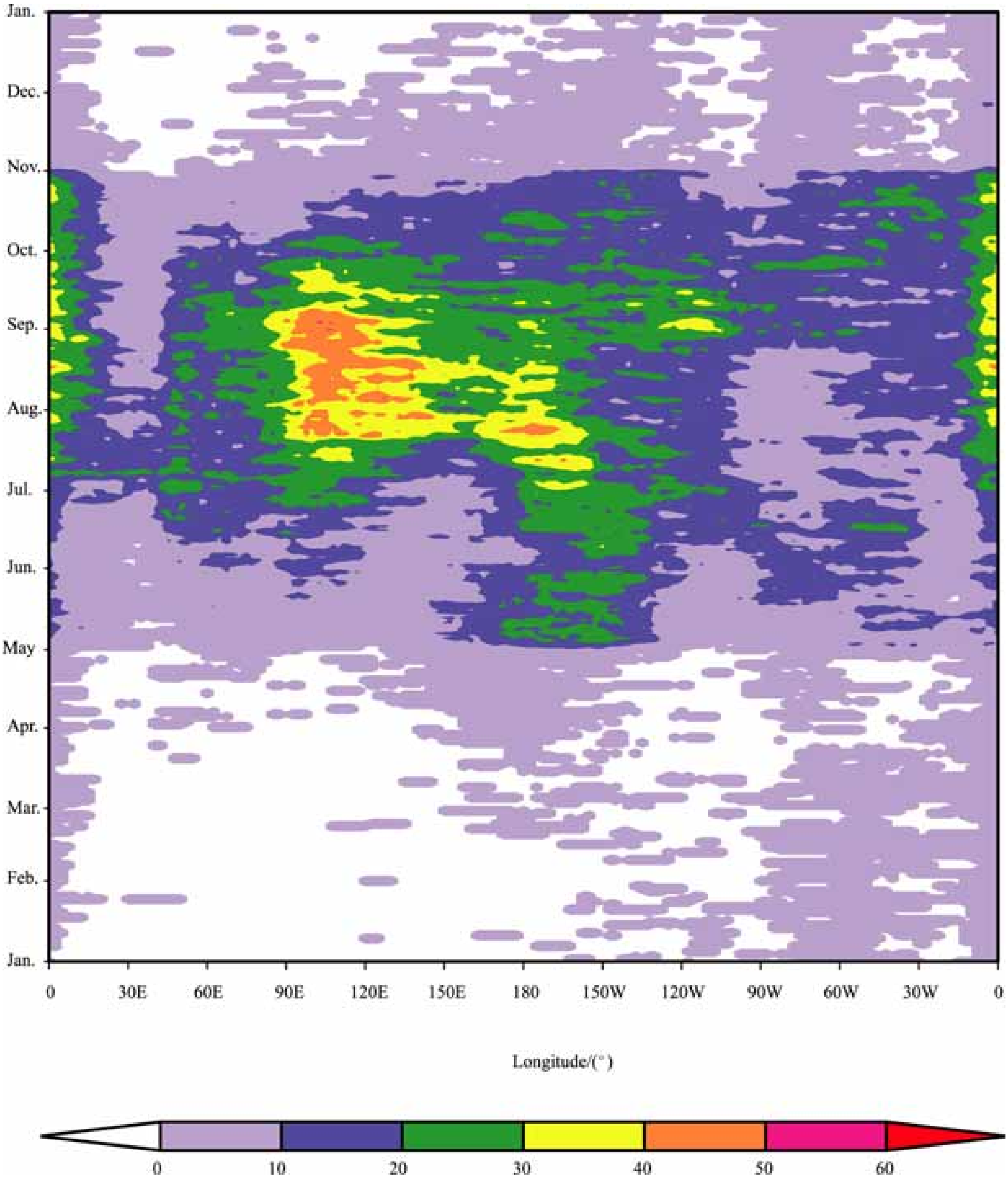

Fig. 1. Time-longitude cross section of the daily frequency (%) of the 500 hPa subtropical high double-ridge (SHDR) genesis in the Northern Hemisphere for the period 1958—1998.

The results above indicate that the central North Pacific and the western-central North India Ocean are the two main seasonal transition sources of SHDR geneses. In the latter, the SHDR event spreads eastwards and consequently prevails from 90 °to 120 °E. It is generally recognized that this longitude range (90 °—120 °E) is the key region to the onset of the Asian summer monsoon[13,20]. Recently, Mao et al.[21] also revealed intimate relationships between the onset of the South China Sea summer monsoon and the structure of the Asian subtropical high. Then, whether there is a seasonal transition character of the SHDR event over the eastern North India Ocean-western North Pacific related to the Asian summer monsoon onset will be examined in subsequent work.

2 The double-ridge events of the western Pacific subtropical high (WPSH)

It is well known that the WPSH is one of the most important members of the East-Asian monsoon system, furthermore, as mentioned above, the SHDR event is fairly robust over the western North Pacific over 110 °—150 °E (briefly defined as WNP). Thus more attention will be paid to the WNP in the following studies. A WPSH double-ridge (WPSHDR) event is defined as follows: The WPSHDR event starts once the SHDR occur at some longitude of WNP on some day, while this event is over marked by no SHDR phenomenon at any longitude of WNP.

Fig. 2 depicts the frequency and duration of the 500 hPa WPSHDR events for the period 1958—1998. Most events are short-lived events, and there are dramatically fewer long-lived events. It should be noted, however, that some events persisted as long as 16 days. In fact, the frequency of the events lasting 3 days or more is considerable at about 32% against all events.

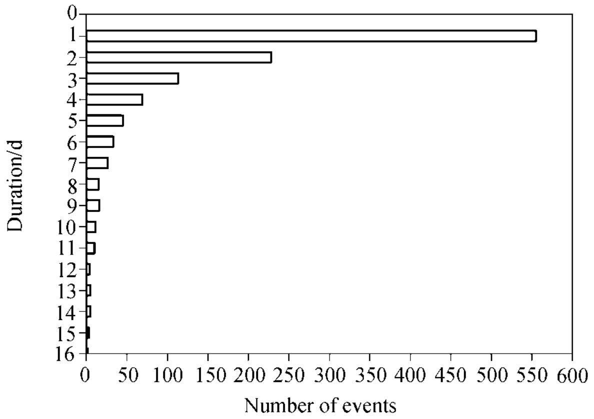

Fig. 2. Total number of the western Pacific (110 °—150 °E) subtropical high double-ridge (WPSHDR) events versus duration (days) at 500 hPa for the period 1958—1998 lasting at least a given number of days.

Fig. 3 shows the seasonal evolution of the daily total numbers of the WPSHDR events for the period 1958—1998. The seasonal variation in the activity of the PSHDR events is visible clearly. The maximum number of WPSHDR events occurs in August and the minimum in January-February period. There is a rapid increase of the daily cases in early May and a sudden decrease in November. In general, the most frequent occurrence of WPSHDR events was identified from July to September (mid-summer to early autumn), while there is a paucity of occurrences during November-March (winter to early spring). Thus, it is reasonable that the WPSHDR events during July-September (JAS) are selected as representative events in order to examine their interannual variation.

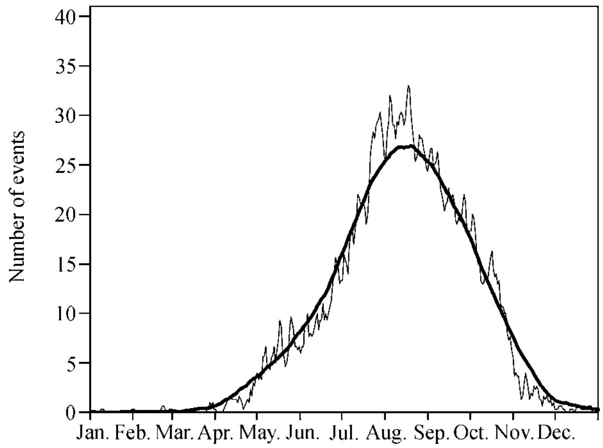

Fig. 3. Seasonal evolution of daily total numbers of the WPSHDR events for the period 1958—1998. The thin line stands for the original data, and the thick line for 61-day running mean.

The time series of the number of JAS WPSHDR events is shown in Fig. 4(a). The number of JAS WPSHDR events possesses a large interannual variability. The maximum number was as much as 20 in 1970, and the minimum number was only 9 in 1985 or 1997. To further investigate the variation of WPSHDR events, Fig. 4(b) depicts an evolving periodogram of the JAS WPSHDR events with time in the form of a wavelet analysis. Most of the power is concentrated within the two bands of 4—9-a and 2—4-a, although there is appreciable power at shorter periods. The 4—9-a band occurs before the mid-1970s, significant at the 95% confidence level, and the 2—4-a band after the mid-1970s, with the smaller period significant at the 95% confidence level. Therefore, it might be expected that the period of WPSHDR events possesses a remarkably abrupt change in the mid-1970s.

As mentioned in above references, the meridional shift of the WPSH ridge has important impacts on the location and intensity of the monsoon rainbelt[13,15,16], and the WPSHDR event during July 1998 plays an important role in the nonseasonal north-south movement of WPSH[12].

However, the conclusion is drawn only from a case, and is not representative. The question to be tackled is, from the climatological point of view, what the relationship of the WPSHDR event with the meridional movement of WPSH is. Fig. 5 shows the frequency distribution of the north- south variation amplitude of the WPSH ridge after the WPSHDR event is over in the period 1958—1998. A biased structure can be clearly seen in the frequency distribution although both the conditions of southward withdrawal and northward movement of WPSH ridge after a WPSHDR event are in existence. The higher values of frequency mainly direct into the side of the southward withdrawal, and the maximum is 17% in the position where the amplitude of southward withdrawal is 5°. In comparison, the frequency of northward movement is less, and its value gradually reduces with amplitude. In order to well examine such influence of the WPSHDR, the value of |2.5°| is defined as a threshold. The amplitude higher (less) than 2.5° means northward movement (southward withdrawal) of the WPSH ridges, and the value between –2.5° and 2.5° means their stagnancy. As a whole, the percentages of southward withdrawal, northward movement and stagnancy of the WPSH ridges after a WPSHDR event are 45%, 27%, and 28%, respectively (figure omitted), that is, the condition of southward withdrawal after a WPSHDR event is dominant.

3 Conclusions and discussions

In this study, the climatological characteristics of the double ridge systems of subtropical high (SH) are investi

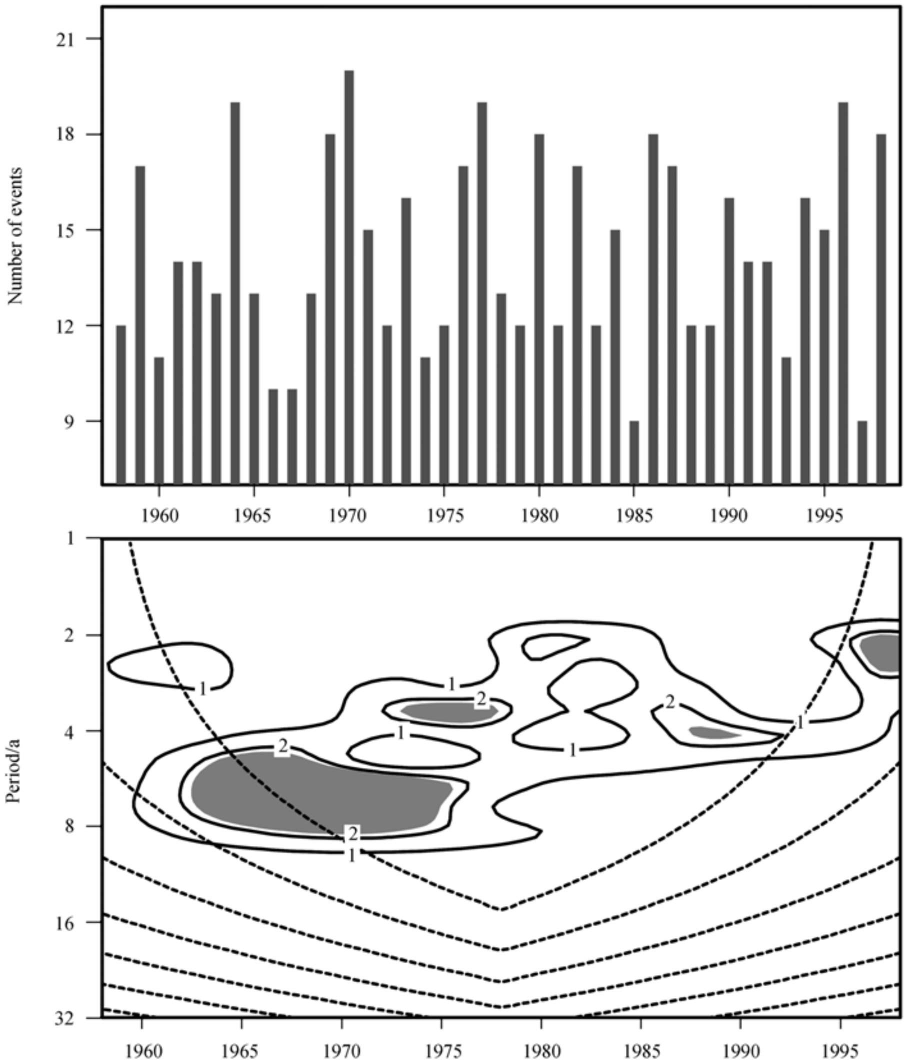

Fig. 4. (a) The time series of the number of WPSHDR events during July-September (JAS). (b) The local wavelet power spectrum for (a) from the Morlet wavelet. The contours are at normalized variances of 1 and 2, while the shaded areas are significant at the 95% confidence level. The dashed areas on the right and left of the power spectrum distribution indicate the limitations of the data to define variance of a particular period at a particular time of the data record.

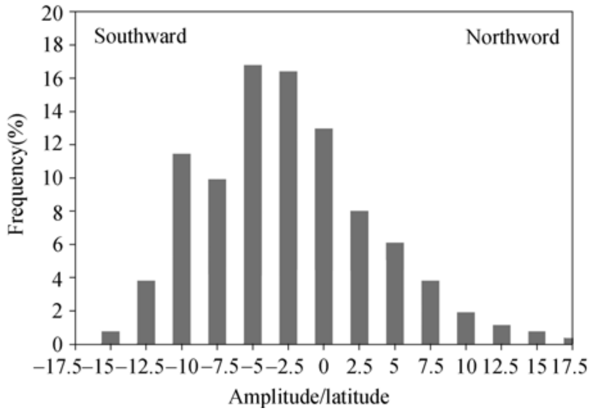

Fig. 5. Frequency distribution in the north-south variation amplitude of the WPSH ridge after the WPSHDR event is over in the period 1958—1998. Northward denotes northward movement of WPSH ridge (amplitude>0), and southward denotes southward withdrawal of WPSH ridge (amplitude<0).

gated. It has been indicated that the SH double-ridge event is a common phenomenon in the Northern Hemisphere, with the distinct seasonal and regional characters. A primary focus of the study on the SHDR phenomena has been on the WNP. It is found that some WPSHDR events could last longer and even as long as 16 days. The highly frequent season in the activity of the WPSHDR events is identified from mid-summer to early autumn, while the fairly rare season from winter to early spring. Moreover, the WPSHDR events appear a strong interannual variation and some periodicity, and the dominant period of the latter causes an abrupt decrease in the mid-1970s.

The previous researches showed that the ENSO period decreased throughout the last part of the 20th century[22,23]. Gershanov et al.[24] further noted that the change in the ENSO period is consistent with the change in phase of the Pacific Decadal Oscillation (PDO). It is clear that the characters in Fig. 4(b) are consistent with the conclusion drawn by Mokhov et al. to a great extent, and it can be also seen that the decrease of the ENSO period gets ahead of that of the WPSHDR period through further analysis (not shown). Then, whether the abrupt change of the WPSHDR period is related to the interdecadal variability of the ENSO signal and whether the change in phase of the PDO can exert its influence on the WPSHDR period are not currently known, however, two signals mentioned above are possible clues to understand the mechanisms of the WPSHDR interannual and interdecadal variations in the future. This study also analyses the relationship of WPSH double ridges with the meridional movement of WPSH, and suggests that it is mostly characterized by the southward withdrawal of WPSH after a WPSHDR event. However, the cause for the above relationship, its dynamic mechanisms and detailed processes remain unclear. A more important issue concerns whether the seasonal transition character of the SHDR event is related to the Asian summer monsoon onset. If this is the case, what is the relationship? All these questions will be major challenges for future studies.

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