Comparison of the seasonal evolution of the South Asian high associated with two types of El Niño event

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ABSTRACT

El Niño (EN) episodes can be classified based on their time of onset as spring onset EN (SPEN) events and summer onset EN (SUEN) events. To evaluate the different influences of SPEN and SUEN events on the South Asian high (SAH), this study compared the seasonal evolution of the SAH (SESAH) associated with SPEN and SUEN events through analysis of geopotential height and zonal wind data derived from NCEP–NCAR Reanalysis-1 and sea surface temperature data obtained from the Hadley Center. The main features of the SESAH during an EN event are similar to its climatological characteristics. Climatologically, the SAH forms in May, strengthens, and moves northwestward in June and July. It does not change much in August, but then it returns south and weakens during September and October. However, its lifespan is shorter and its intensity weaker during EN periods. Furthermore, there are significant differences between the SESAH during SPEN and SUEN events. During a SPEN episode, the movement of the SAH to the northwest during May and June is slower than during a SUEN event, i.e. the SPEN SAH has a shorter lifespan. In comparison with the SUEN SAH, the SPEN SAH in July and September tends more towards the Tibetan high mode rather than the Iranian high mode. The SPEN SAH in October moves southeastward faster than the SUEN SAH, which also indicates that the SAH has a shorter lifespan during a SPEN event than during a SUEN episode.

1. Introduction

The South Asian high (SAH) is one of the most important atmospheric systems of the summer Asian monsoon (e.g. Tao and Chen 1957; Zhu et al. 1980; Zhang et al. 1988). The seasonal evolution and variability of the SAH has considerable impact on the atmospheric circulation of the Northern Hemisphere in general, and on the climate and summertime weather in Asia specifically (e.g. Tao and Zhu 1964; Zhu et al. 1980; Luo, Qian, and Wang 1982; Sun and Song 1987; Zhang, Wu, and Qian 2002).

Previous studies have shown that many factors play important roles in the development and lifespan of the SAH: atmospheric heating (e.g. Qian et al. 2002); interaction between waves (e.g. Zhang et al. 1988); the subtropical anticyclone (e.g. Tao and Zhu 1964); and interannual variability of the tropical ocean–atmosphere system – in particular, El Niño–Southern Oscillation (ENSO) events (e.g. Shukla and Paolino 1983; Ju and Slingo 1995; Soman and Slingo 1997; He, Liu, and Wu 2014). Zhang, Qian, and Zhang (2000) indicated that the intensity of the SAH has a significant relationship with sea surface temperature (SST) anomalies (SSTAs), i.e. the El Niño (EN)/La Niña (LN) associated with the Tibetan/Iranian high mode of the SAH. Moreover, the SAH is weaker/stronger following the
occurrence of an EN/LN event (Peng et al. 2009; Li, Li, and Tan 2011).

It is known that EN events can be distinguished as different types, not only in terms of the spatial patterns of the SSTAs (e.g. Wang 1995), which has been widely discussed, but also by the onset time of the EN event (Xu and Johnny 2001; Horii and Hanawa 2004). According to the definition of onset time (Xu and Johnny 2001), EN episodes can be classified as spring onset (SPEN) events and summer onset (SUEN) events. Given the importance of the SAH to the atmospheric circulation of the Northern Hemisphere, it is reasonable to investigate the different influences of SPEN and SUEN events on the development and lifespan of the SAH.

The remainder of the paper is organized as follows. The data and analysis techniques used in the study are introduced in Section 2. The seasonal evolution of the SAH (SESAH) associated with both SPEN and SUEN events is described in Section 3. Section 4 presents a discussion and our conclusions.

2. Data and method

This study used 1948–2015 monthly mean geopotential height and horizontal wind data derived from NCEP–NCAR Reanalysis-1 (Kalnay et al. 1996), which can be obtained from http://www.esrl.noaa.gov/psd/. These data have a horizontal resolution of $2.5^\circ \times 2.5^\circ$ and 17 vertical pressure levels from 1000 to 10 hPa. Monthly mean SST data, for the same period as the Reanalysis-1 data, were also used; these data were from the Hadley Center and have a horizontal resolution of $1^\circ \times 1^\circ$ (Rayner et al. 2003).

The main body of the SAH extends from 200 to 100 hPa with similar features, and the SAH at 150 hPa is most robust. Hence, the range of the 14,300-gpm contour at 150 hPa can reflect the influential region of the SAH, and the SAH center is located at the circulation center in this influential region of the SAH.

The SPEN years chosen for this study were 1951, 1957, 1965, 1972, 1977, 1982, 1991, 1994, 1997, 2002, 2006, and 2009; and the selected SUEN years were 1963, 1968, 1986, 1992, and 2004 (Cai et al. 2016). They were distinguished according to the ‘best’ ENSO index based on the combination of the Southern Oscillation Index and the Niño3.4 SST index (Smith and Sardeshmukh 2000) derived from the SST data of the Hadley Center (Rayner et al. 2003).

Composite analysis was employed to compare the SPEN and SUEN SESAHs. The Student’s $t$-test was used to assess the significance of the derived differences.

3. Results

3.1. Seasonal evolution of the SAH

In May, the SAH is located over Southeast Asia and the Bay of Bengal. It has a central intensity of 14,300 gpm near
The SAH moves north and west with increasing intensity and an expanded region of dominance that ranges from the southern side of the Iranian and Tibetan plateaus to northern parts of the Arabian Sea and the Bay of Bengal (Figure 1(b)). The central intensity is about 14,350 gpm near (25°N, 80°E), and the range of the closed 14,300-gpm contour is about 15° of latitude and 100° of longitude. In August (Figure 1(d)), there is little change in the SAH; its location, extent, and intensity remain similar to July. In September, the SAH moves southward, becomes weaker, and has a much smaller range of influence (Figure 1(e)). Its range of extent withdraws to the southern side of the Iranian and Tibetan plateaus and to the northern parts of the Arabian Sea and the Bay of Bengal. Its central intensity is 14,300 gpm near (25°N, 80°E).
Figure 4. SPEN (spring El Niño onset) years mean geopotential height (contours; units: gpm) and horizontal winds (vectors; units: m s$^{-1}$) at 150 hPa: (a) May; (b) June; (c) July; (d) August; (e) September; (f) October. (g–l) As in (a–f) but for the difference between the SPEN mean and 1948–2015 mean.

Note: Significant differences are shown in yellow (90% confidence level) and dark yellow (80% confidence level).
Figure 5. SUEN (summer El Niño onset) years mean geopotential height (contours; units: gpm) and horizontal winds (vectors; units: m s$^{-1}$) at 150 hPa: (a) May; (b) June; (c) July; (d) August; (e) September; (f) October. (g–l) As in (a–f) but for the difference between the SPEN mean and 1948–2015 mean. Note: Significant differences are shown in yellow (90% confidence level) and dark yellow (80% confidence level).
90°E), and the range of the closed 14,300-gpm contour is about 15° of latitude and 85° of longitude (Figure 1(e)). By October, the SAH moves further southeastward over the Bay of Bengal, Southeast Asia, and the Pacific Ocean, with its central location at 15°N, and it weakens further with a central intensity of 14,250 gpm (Figure 1(f)).

### 3.2. Comparison of the SESAH associated with the SPEN and SUEN

The SPEN and SUEN SSTA patterns are very different. Significant positive SSTAs are located in the central and eastern Pacific during a SPEN event (Figure 2), but mainly in the central Pacific during a SUEN event (Figure 3). The positive Pacific SSTAs during a SPEN event become stronger gradually from May to October (Figure 2), and SUEN positive Pacific SSTAs change little from May to October (Figure 3).

The SESAH associated with SPEN (Figure 4(a)–(f)) and SUEN (Figure 5(a)–(f)) events is similar to the climatological SESAH (Figure 1), i.e. the SAH is mature in July and August and weak in May, June, September, and October. However, the lifespan of the SAH is shorter and its intensity lower during EN periods. In May, an anticyclone forms over South Asia during an EN event, which is similar to the climatological SAH but without a closed contour of geopotential height (Figures 1(a), 4(a), and 5(a)). During an EN event, the geopotential height over South Asia in May is significantly different (nearly 20 gpm weaker) than the climatological SAH (Figures 4(g) and 5(g)). The northward movement of the SAH in June during an EN episode is 2°–3° of latitude slower than the climatological SAH (Figures 1(b), 4(b) and 5(b)), and both the eastern and western sides of the SAH during an EN event are characterized as being significantly different (20–25 gpm weaker) with anomalous cyclonic circulations (Figures 4(h) and 5(h)). Hence, the range of the closed 14,300-gpm contour in June during an EN event is significantly different (5°–10° of longitude smaller) than usual (Figures 1(b), 4(b) and 5(b)). In July, under a SPEN event, there is a significant −25 gpm anomaly and anomalous cyclonic circulation over the northern part of the Iranian Plateau, corresponding to the western part of the climatological SAH (Figures 1(c) and 4(i)). Similarly, the SAH is significantly weaker (by 50 gpm) than usual, and there is an anomalous cyclonic circulation over the Tibetan Plateau in July during a SUEN event (Figure 5(i)). The anomalies in August during an EN event are similar to those in July (Figures 4(j) and 5(j)).

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**Figure 6.** Difference of the SPEN (spring El Niño onset) years mean and SUEN (summer El Niño onset) years mean geopotential height (contours; units: gpm) and horizontal winds (vectors; units: m s\(^{-1}\)) at 150 hPa: (a) May; (b) June; (c) July; (d) August; (e) September; (f) October.

Note: Significant differences are shown in yellow (90% confidence level) and dark yellow (80% confidence level).
The anomalies of the SAH in September during a SUEN event are not significant (Figure 5(k)), whereas they are during a SPEN event (Figure 4(k)). The speed of southward movement of the SAH is 2°–3° latitude per month greater than usual, because there are significant positive/negative anomalies of geopotential height near the southern/northern part of the climatological SAH (Figures 1(e) and 4(e)). Then, in October during an EN episode, the SAH moves further east than usual (Figures 1(f), 4(f), and 5(f)).

The western end of the 14,250-gpm contour is 15°–20° of longitude further east in comparison with the climatological SAH (Figures 1(f), 4(f), and 5(f)).

There are also differences in the SESAH between the SPEN and SUEN episodes, e.g. the SPEN SAH is weaker and has a shorter lifespan (Figure 6). Moreover, compared with the SUEN SAH, the SPEN SAH tends more towards the Tibetan high mode (Figure 6). There are similar differences in the geopotential high in May and June during SPEN and SUEN events near the area of the climatological SAH. However, the differences are significant in June but not in May (Figures 1(a), (b), and 6(a), (b)). The SPEN SAH in June (May) moves northwestward slower (has a shorter lifespan) than the SUEN SAH. This is because of the negative geopotential height and cyclonic circulation differences between the SPEN and SUEN SAHs in June (May), which are located on the northwest (west and north) side of the climatological SAH (Figure 6(a) and (b)). In comparison with the SUEN SAH, the SPEN SAH in July and September tends more towards the Tibetan high mode rather than the Iranian high mode. This is because the pattern of difference between the SPEN and SUEN SAHs shows a significant positive geopotential height anomaly with an anomalous anticyclonic circulation located over the Tibetan Plateau in July (Figure 1(c)), and a significant negative geopotential height anomaly with an anomalous cyclonic circulation located over the Iranian Plateau (Figure 1(e)). In August, the differences between the SPEN and SUEN SAHs are not significant (Figure 6(d)). The differences between the SPEN and SUEN SAHs in October are also not significant and their pattern is similar to that in May and June (Figure 6(f)). The negative geopotential height anomalies and anomalous cyclonic circulations near the northwest side of the climatological SAH cause the SAH to have a shorter lifespan and to move southeastward faster during a SPEN event than during a SUEN event (Figures 1(f) and 6(f)).

4. Conclusions and discussion

The present study revealed that the SESAH during SPEN and SUEN events is similar to that of the climatological SESAH. The SAH forms in May, strengthens, and moves northwestward during June and July. It does not change much in August and then returns south and weakens in September and October. However, its lifespan is shorter and its intensity weaker during EN periods. Furthermore, there are also significant differences in the SESAH between SPEN and SUEN events. In May and June, the SPEN SAH moves north and west slower than the SUEN SAH, which results in a shorter lifespan for the SPEN SAH. In comparison with the SUEN SAH, in July and September, the SPEN SAH tends more towards the Tibetan high mode rather than Iranian high mode. In October, the southeastward movement of the SPEN SAH is faster than the SUEN SAH, which again indicates that the SPEN SAH has a shorter lifespan.

The differences in the SESAH between SPEN and SUEN events might be caused by the length of time of the EN influence on the SAH. Therefore, a SPEN event might have greater influence on the SESAH than a SUEN event. Moreover, the shorter lifespan and weaker intensity of the SAH during EN periods might be connected to anomalous convection over the Philippine Islands and Indochina Peninsula (e.g. He, Liu, and Wu 2014). Furthermore, EN events are usually associated with the Tibetan High mode of the SAH (Zhang, Qian, and Zhang 2000), and SPEN episodes might have stronger influence than SUEN episodes, which is a possible reason why the SPEN SAH tends more towards the Tibetan high mode than the SUEN SAH.

In addition, tropical convection is closely connected with EN events (Ju and Slingo 1995), especially that over the southern Philippines and the Indochina Peninsula (He et al. 2006; Liu et al. 2013). Furthermore, the variation in convection over South Asia to some extent controls the SAH’s south/northward movement. Therefore, the SESAH might be affected by the variation in convection over South Asia, which is modulated by SP/SUEN. However, the specific mechanism by which SP/SUEN affects the SESAH remains unclear and needs to be investigated further using models.

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