Influence of the south-north bias of the South Asia High on the water vapor distribution in the upper troposphere-lower stratosphere of the Asian monsoon region

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Abstract: Based on the ERA-40 reanalysis data provided by the European Interim Numerical Forecast Centre from 1958 to 2002, the influence of the north-south bias of the South Asia High(SAH) on the water vapor distribution in the upper troposphere-lower stratosphere of the Asian monsoon region is analysed. It is shown that: (1) The north-south bias of SAH has little influence on the position of the 200 hPa water vapor high value centre, which mainly affects its intensity; and it has a great influence on the position and intensity of the 100 hPa water vapor high value centre; It has little effect on the water vapor distribution at 70 hPa. (2) In the south years of SAH, the anti-cyclone is abnormally weak, the vertical ascending motion is relatively insubstantial, and the water vapor transported to the upper troposphere is less than the north years. Therefore, the water vapor high value in the south years is smaller than that in the north years. (3) Abnormal temperature distribution of 200 hPa in anticyclone is consistent with the abnormal distribution of water vapor, and the warm centre is conducive to the formation of high water vapor. It is shown that the distribution of water vapor in the anticyclone range is caused by the interaction of temperature field and circulation field. This study has a certain reference meaning for understanding the stratospheric-tropospheric exchange of the Asian monsoon region.

1. Introduction
There is a strong and stable semi-permanent High in the upper troposphere-lower stratosphere (UTLS) region of the Tibetan Plateau and adjacent areas in summer, called the South Asia High(SAH). SAH starts from the western coast of Africa and western Pacific, making up for about half of the earth's latitude. It is the most powerful and stable control circulation system except the polar vortex in the summer[1-3]. SAH is attached to the bottom of the stratosphere and the top of the troposphere. Therefore, its change reflects both the variation characteristics of the stratospheric circulation and the tropospheric circulation[4].In summer, with the strengthening of the Asian summer monsoon, SAH gradually moved northward, and stabilized near the Tibetan Plateau and Iran Plateau at 200-100 hPa, and there was a solid land-atmosphere interaction with the plateau. [5]. This significant seasonal change in SAH directly affects the atmospheric circulation of the northern hemisphere and affects the weather and climate of Asia[6].

In the past, there have been numerous studies on the positional movement of the SAH. Tao have contacted China's weather and climate, and found that the SAH has significant changes in the latitudinal direction, that is, the east-west oscillation [2]. Luo analysed the location and shape of the SAH, and divided the SAH into 3 types: the eastern type, the western type and the strip type with the
boundary of 100°E [7]. Subsequently, Zhang concluded that one of the main climatic features of the SAH is the bimodal distribution at the longitude of the SAH centre. That is, the location of the SAH centre can be not only on the Qinghai-Tibet Plateau around 90°E, but also at Iranian plateau around 60°E. From the perspective of bimodality, SAH bimodal development and maintenance mainly depends on the thermal conditions of the atmosphere over the Qinghai-Tibet Plateau and its surroundings[8]. And the bimodality of SAH also has an important impact on the UTLS water vapor distribution in the Asian monsoon region [9]. Excepts the east-west oscillation in the latitudinal direction, SAH also holds the characteristics of north-south movement in the longitude direction [10, 11]. From May to early June, the SAH moved northwest to the Indo-China Peninsula, and then moved over the Indian peninsula. In the middle and late summer, SAH gradually grew stronger and moved northward, stabilizing over the plateau. At the same time, the northward movement of the SAH corresponds to the northward movement of the Chinese summer rain belt[11,12].

In summer, the SAH not only affects weather and climate change, but also has a significant impact on the water vapor distribution in the UTLS region through continuous deep convection. And the accompanying water vapor transport has an important impact on the stratospheric and tropospheric water vapor distribution [13,14]. The water vapor is mainly concentrated below 500 hPa. In the UTLS region, the water vapor content is about 2 to 4 orders of magnitude lower than that of the lower troposphere. The water vapor content of this height and above is very low, but water vapor is an important greenhouse gas, and the radiative forcing caused by its change and distribution can change the energy balance of the Earth-Atmosphere system. So it has an important impact on global climate change. In addition, the water vapor in the stratosphere participates in the atmospheric chemical reaction process, which is a major source of hydroxyl radicals in photochemical reactions, affecting the climate through photochemical reactions [15]. Previous studies have less research on the north-south bias of SAH, and there are few studies linking the north-south bias of SAH with water vapor distribution. Many details are not obvious. Built on the predecessors, this paper combines the north-south bias of SAH to study the distribution characteristics and mechanism of water vapor near the UTLS region in the Asian monsoon region.

2. Data and Method

2.1Data

The data used in this paper is the ERA-40 reanalysis data provided by the ECMWF with a horizontal resolution of 2.5°×2.5° and the vertical direction from 1000 hPa to 1 hPa with 23 layers. The physical quantities used include the monthly average potential height, humidity, temperature and horizontal wind field, the length of time is 1958-2002, for a total of 45 years.

2.2Method

In order to study north-south bias characteristics of the SAH and its influence on the distribution of water vapor and its variation characteristics in the UTLS, First, we must define a north-south bias index. In this paper, we use the north-south bias index defined by Wei [11]. The average ridge line of the SAH is located near 27.5°N, with the boundary of 27.5°N, and the north side (27.5°N~32.5°N,50°E~100°E) and the south side (22.5°N~27.5°N,50°E~100°E), standardize the average 200 hPa geopotential height difference (north side minus south side) of the two areas, Obtained the SAH North-South Bias Index (SAHI). Table 1 shows the south and north years of the SAH.

Figure 1 is a normalized time series of the north-south index of the SAH from 1958 to 2002. When the index is positive and greater than 0.8, the SAH is north, when the index is negative and less than -0.8, it means that the SAH is located south.

It can be observed in the table 1 that the SAH index is greater than 0.8 for 10 years, and the index is less than -0.8 for 8 years. Depending on this, the 200 hPa geopotential height field is synthesized for the SAH anomaly south and north years. As showing in Fig. 2, Fig. 2a is a high-
### Table 1: Anomaly north and south years of SAH

| North years | 1959 1960 1961 1962 1963 1964 1967 1971 1973 1978 |
|-------------|--------------------------------------------------|
| South years | 1979 1982 1983 1987 1992 1993 1997 2002           |

Index years synthesis, showing that the overall position of the SAH is north, and the ridge line is about 29°N; Figure 2b is the synthesis of the low-index years, showing that the overall position of the SAH is south. The ridge line is located near 26°N. It can be seen that the index defined by the method can objectively reflect the north-south bias characteristics of the SAH. The positive index indicates that the SAH position is northward, and the negative index indicates that the SAH position is southward. In addition, it can be seen from Fig. 2 that the north-south bias of the SAH has a very significant change, and there is a very sizable southerly trend, and its linear trend reaches a significant level of 99%. In addition, the low-index annual synthesis of the SAH area in Figure 2 is too large and the intensity is strong. This is mainly due to the fact that the years of low-index synthesis are all after 1979, and the area and intensity of the SAH also have an interdecadal increase trend.

![Figure 1. Normalized sequence of north-south index of the SAH from 1958 to 2002 (red solid line is linearly fitted)](image)

![Figure 2. SAH abnormal north years (a) and abnormal south years (b) 200 hPa geopotential height field synthesis (unit: gpm)](image)

**3. South-North bias of SAH corresponds to water vapor distribution characteristics in UTLS region**

Figure 3 shows the synthesis of the 200 hPa water vapor field and water vapor anomalies in the north and south years of the SAH in summer. It can be seen from Fig. 3a that the SAH is abnormally north, the northwest side of the SAH is an obvious water vapor low value area, and the water vapor high value area (>10ppmv) is about (20°N~32°N, 80°E~105°E), the water vapor high value centre is in Qinghai-Tibet Plateau and its eastern region, and the maximum value is near (25°N, 93°E). The distribution of water vapor in the south years is basically similar to that in the north years. The difference is that the distribution of water vapor in the south years is weaker than that in the north years, the range of high water vapor is small, and the range of high water vapor (>10ppmv) moves to southwest, the maximum centre of the water vapor moves southwest to (22°N, 88°E), but its high value centre is offset southward compared to the north years. From 200 hPa water vapor anomaly field, the north years (Fig. 3c), in the range of 61°E~88°E, with 20°N as the boundary, in the range of 23°N~35°N water vapor is high; The water-off anomalous field distribution in the south years is basically opposite to that in the north years, and the water vapor is low in the range of 22°N~38°N (Fig. 3d). In general, at 200 hPa, the high water centre of the SAH is located in the Qinghai-Tibet Plateau and its eastern region. Compared with the high value centre of the geopotential height field,
the high value centre of the water vapor is more east. The water vapor intensity in the high value centre is stronger than the average field; in south years, the water vapor distribution is weaker than normal, the water vapor high value range is small, and the water vapor high value centre is shifted to the southwest from the north years. It can be seen that the north-south change of the SAH location has little effect on the location of the 200 hPa water vapor high value zone, but has a greater impact on the intensity.

Figure 3. SAH north (a, c) and south years (b, d) 200 hPa average water vapor field (a, b) and water vapor anomaly field (c, d) (unit: ppmv)

It can be seen from Fig. 4a and 4b that at 100 hPa, the distribution of water vapor in the anomalous north years of the SAH is basically the same as that of the SAH. The high water vapor region (>0.41ppmv) is distributed at (23°N~31°N, 62°E~105°E). It is distributed in a strip shape, the high value centre (>0.46ppmv) is located at (27°N, 90°E); The water vapor distribution of the south years is similar to that of the north years. The difference is that the water vapor concentration is greatly weaker than that of the north years, and the large value centre is completely consistent with the SAH centre. From the 100 hPa water vapor anomaly field, in the north year of SAH, the water vapor is abnormally high in the range of 25°N~40°N and 80°E~110°E, which is exactly the same as the SAH centre, This is also consistent with the high value zone of water vapor in Figure 4a (Figure 4c). Water-off anomalous field distribution in the south years is completely opposite to that in the north years, and the water vapor is lower in the anti-cyclone control range (Fig. 4d). In general, at 100 hPa, north years of the SAH, The centre of high vapor is consistent with the SAH centre. The distinguished value centre has a higher water vapor intensity than the average field; in the south years, the water vapor high value area cooperates with the SAH centre. It is also very consistent, and the water vapor is significantly weaker than the average field in the high value area of the geopotential height field. Therefore, the north-south bias and intensity change of the 100 hPa water vapor high value centre in the Asian monsoon region are consistent with the change of the SAH, That is, the north-south bias of the SAH has a great influence on the position and intensity of the 100 hPa water vapor high value area in the Asian monsoon region.

At 70 hPa, in the north years, the water vapor content at low latitude is high and the range is widespread (Fig. 5a). The high water vapor value area is widely distributed in most parts of the Iranian plateau and the western part of the Qinghai-Tibet Plateau. And the water vapor in the whole range is larger than the climatic average water vapor (Fig. 5c). In the south years, there are also high water vapor distribution areas at low latitudes, mainly distributed in the east, and most of them have low water vapor content (Fig. 5b). The north years have a wide range of water vapor, high intensity, and small water vapor range in the south. The intensity is small. In the south years, the water vapor content
of the Iranian plateau and most of the Qinghai-Tibet Plateau is smaller than the average climate. It can be concluded that the north-south bias of SAH in the 70 hPa does not have much influence on the location of the water vapor high value zone.

By comparing and analysing the distribution of the UT 200 hPa, the tropopause near 100 hPa, and the lower stratosphere 70 hPa, it can be seen that at the UT, the high value centre of the north and south years of the SAH is distributed in the central and eastern Qinghai-Tibet Plateau, and the water vapor in the south years is negative, while the north years is positive, that is to say, the north-south bias of the SAH has a greater impact on the high intensity centre of the 200 hPa water vapor. With the increase of height, at the 100 hPa near the top of the troposphere, the location of the high value centre of the water vapor is basically the same as the centre of the north-south bias of the SAH, and the intensity of the centre of the high value centre is also strong, indicating that the north-south bias of the SAH has a position and intensity of the 100 hPa water vapor high value centre. The greater impact, and the north years, the water vapor is stronger than the south years. At 70 hPa in the lower stratosphere, the north-south bias of the SAH position does not have much impact on the location of the high value centre of the water vapor in the range.
4. Influence of circulation field on water vapor distribution

With the north-south bias of the SAH, the position and intensity of the water vapor high value centre in the UTLS region have different changes. In order to deeper study the mechanism of water vapor change, high and low altitude circulation configurations are given below.

Figure 6 indicates the synthesis of the 100 hPa anomalous wind field and the anomalous vertical velocity field in the north and south years of the SAH, and the difference field between the north and south years. It can be observed that in the north years of the SAH (Fig. 6a), there is an obvious anti-cyclonic circulation field over the northern Iranian plateau. The centre is located near (37.5°N, 67.5°E), indicating that in the north years of SAH, the Iranian plateau is strong, and the vertical velocity is positive in its circulation centre and the eastern Iranian plateau. The potent anti-cyclonic circulation anomaly makes the upper atmosphere an abnormal convergence. There is a weak anti-cyclonic circulation anomaly in the eastern Qinghai-Tibet Plateau and eastern China. The vertical velocity in the central, eastern, northern and eastern Tibetan Plateau is positive, indicating that the SAH is stronger in the inner and eastern Qinghai-Tibet Plateau and in eastern China. Weak anti-cyclonic circulation anomaly causes the upper atmosphere to be anomalous divergence, which is favourable for the ascending motion and the ascending motion is enhanced, which is consistent with the water vapor enhancement in the SAH control zone in Figures 4a and 4c. In the south years (Fig. 6b), The northern Qinghai-Tibet Plateau and southeaster China has obvious subduction airflow anomalies. On the east and southeast sides, there is a strong negative vertical velocity anomaly, the ascending motion is weakened, and the low-level water vapor transport is reduced, making 100 hPa water vapor weak. There is a weak cyclonic circulation anomaly in northeaster China, and the vertical velocity in the centre of the circulation is negative, indicating that the SAH is weaker in the south years, which is not conducive to the occurrence of ascending motion. The difference between the north and south years of the SAH shows (Fig. 6c) that there is an observable cyclonic circulation anomaly in the northern part of the Iranian plateau, and an anti-cyclone circulation anomaly has occurred in the northeaster Japan to the eastern Japan. The cyclonic circulation is much weaker than the northern Iranian plateau.

![Figure 6. 100 hPa anomalous circulation field (arrow) and anomalous vertical velocity synthesis (filling contour, unit: -10^{-2} Pa/s)(a: SAH north years; b: SAH south years; c: SAH north and south years difference)](image)

Figure 7 is a synthesis of 200 hPa anomalous circulation flow fields and abnormal vertical velocity. It can be seen from the anomalous circulation field that the distribution of the anomalous circulation field is similar to that of 100 hPa in both the north and south years, except that the intensity of the circulation field and the anomalous circulation field is enhanced compared to 100 hPa. In the north years, the anomalous anti-cyclonic circulation in the northern Iranian plateau is stronger, and the range
of the positive vertical velocity is higher than that of 100 hPa, indicating that the north years SAH is stronger than 100 hPa at 200 hPa. The ascending motion is greater than 100 hPa (Fig. 7a). In the south years, the SAH is weaker than 100 hPa, and the rising motion over the Iranian plateau is drained (Fig. 7b). South year’s water vapor transport is weaker than the north years.

Figure 7. The same as Figure 6, but for 200hPa

From the high-altitude circulation field configuration, the anomalous circulation field of the 200in the troposphere of the south-north years of SAH is similar to the 100 hPa anomalous circulation field, but the intensity is similarly different. With the increase in height, the anomalous circulation field is strong at 200 hPa, and it is weakened up to 100 hPa near the top of the troposphere. In the north years of SAH, the wind field is stronger than the south years. The ascending motion is stronger than the south years, and it is stronger than the average years. More water vapor is transported to the UTLS, so the north year’s water vapor is unusually strong. In the south years, the SAH circulation field is weaker than the average years and weaker than the north years, so the water vapor is weaker than the north years.

5. Influence of temperature field on water vapor distribution

In addition to the circulation field, the temperature at the tropopause has an important influence on the distribution of water vapor in the stratosphere. The low temperature dehydrates the water vapor and makes it hard enter a higher level [16, 17]. Figure 8 shows the synthesis of the temperature field and temperature anomalies at 200 hPa in the north and south years of SAH in summer. It can be seen from Fig. 8a and 8b that the north and south years of SAH, the distribution of the high-temperature region is similar to that of the SAH. This is mainly because the warm space is favourable for the maintenance of the anti-cyclonic. It is compatible with the "heating" characteristics of the SAH [18]. The difference is that the temperature range of the south years is narrower than that of the north years, and the warm centre is weaker than the north years. From the temperature anomaly field, in the north years, the temperature of northern SAH is higher, while the temperature of southern SAH is weaker (Fig. 8c). The temperature anomaly field distribution in the south years is opposite to the north years (Fig. 8d). The distribution of the 200 hPa water vapor anomaly field in Figures 3c and 3d is consistent. It can be seen that in the north years, the temperature of 200 hPa is higher, which is conducive to the formation and maintenance of the SAH, and is also conducive to the upward transport of water vapor, and generate more water vapor here. In the south years, the strength of the warm centre is weakened, the range is reduced, the centre is slightly moved southward, and a certain amount of water vapor is generated over the plateau, but the concentration of water vapor is lower than that of the north years.
6. Summary and Conclusion

Based on the ERA-40 reanalysis data, this paper analyses the distribution characteristics of water vapor in the UTLS region of the Asian monsoon region during the north-south bias of the SAH. The north-south bias of SAH affects the possible mechanism of water vapor anomaly distribution in the UTLS region is discussed, and draws the following conclusions:

1. The north-south bias of SAH has little influence on the position of the 200 hPa water vapor high value centre, which mainly affects its strength; and it has a great influence on the position and strength of the 100 hPa water vapor high value centre; 70 hPa, the impact is small.

2. The anomalous circulation field of the troposphere 200hPa in the troposphere and the south-north years is similar to the 100 hPa anomalous circulation field near the tropopause, but the intensities are different. The anomalous circulation field is strong at 200 hPa, and weakening near the top of the troposphere to 100 hPa. In the north years, the stronger SAH makes the vertical ascending motion stronger, reaching a height of 100 hPa, and transporting the low layer rich water vapor upward. In the south years, an abnormal cyclonic circulation is formed in the range of 60°E- 80°E. SAH is abnormally weak, and the water vapor transport to the upper troposphere is less than the north years. Therefore, the high concentration of water vapor is weaker than the north years. The water vapor reaching 100 hPa is less, which makes the distribution of water vapor in the south years a small range and weak intensity.

3. The temperature field is another important factor affecting the distribution of water vapor at 200 hPa. Abnormal temperature distribution of 200 hPa in the range of anticyclone is consistent with the abnormal distribution of water vapor, and the warm centre is conducive to the formation of high water vapor. It is shown that the distribution of water vapor in the range of SAH is caused by the interaction of temperature field and circulation field.

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