Relationship Between the North African Subtropical High and Summer Precipitation in Central Asia: Postprint

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Abstract

Based on ERA-Interim monthly reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) and land surface monthly precipitation data from the Climatic Research Unit (CRU) at the University of East Anglia, UK, covering the period 1979–2019, this study analyzes the relationship between the summer North African subtropical high (North African subtropical high) and Central Asian summer precipitation. The results demonstrate that variations in the ridge line index and eastward extension ridge point index of the North African subtropical high are closely linked to Central Asian summer precipitation. Under the individual and synergistic variations of the two indices, the distributions of Central Asian summer precipitation and large-scale circulation anomalies exhibit substantial differences. The subtropical high ridge line primarily induces opposite-phase variations between northern and southern Central Asian summer precipitation, while the position of the subtropical high' s eastward extension ridge point exerts a significant influence on precipitation in central and southern Central Asia. When the subtropical high is positioned to the east and north, the Caspian Sea and Aral Sea regions are controlled by an anomalous cyclone, most areas of Kazakhstan experience above-normal precipitation, and Xinjiang is controlled by a Mongolian anomalous anticyclone with below-normal precipitation. When the subtropical high is positioned to the west and south, Central Asia is predominantly controlled by an anomalous anticyclone, with anomalous cyclonic shear present in its northeastern portion, corresponding to above-normal precipitation in northeastern Central Asia and below-normal precipitation in other regions. When the subtropical high is positioned to the west and north, Central Asia is controlled by an anomalous anticyclone, with most regions experiencing below-normal precipitation. When the subtropical high is positioned to the east and south, Central Asia is controlled by an anomalous cyclone, and water vapor from the tropical Indian Ocean enters the Central Asian upper atmosphere through a two-step transport process,

creating favorable dynamic and moisture conditions that result in above-normal summer precipitation across most of Central Asia.

Full Text

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Abstract

Using monthly reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim and monthly land precipitation data from the Climatic Research Unit (CRU) at the University of East Anglia from 1979 to 2019, we analyzed the relationship between the summer North African subtropical high and summer precipitation in Central Asia. The results show that variations in the ridge line index and eastern extension ridge point index of the North African subtropical high are closely linked to summer precipitation in Central Asia. Under individual and concurrent variations of these two indices, the distribution of summer precipitation and large-scale circulation anomalies in Central Asia differs significantly. The subtropical high ridge line primarily causes opposite-phase variations in precipitation between the northern and southern parts of Central Asia, while the eastern extension ridge point position exerts an important influence on precipitation in the central and southern regions. When the subtropical high shifts to the east and north, an anomalous cyclone controls the area over the Caspian Sea and Aral Sea, resulting in above-normal precipitation across most of Kazakhstan, while Xinjiang is controlled by an anomalous anticyclone over Mongolia with below-normal precipitation. When the subtropical high shifts to the west and south, Central Asia is mainly controlled by an anomalous anticyclone, with an anomalous cyclonic shear in its northeastern part, corresponding to above-normal precipitation in the northeastern part of Central Asia and below-normal precipitation in other regions. When the subtropical high shifts to the west and north, Central Asia is controlled by an anomalous anticyclone, with below-normal precipitation in most areas. When the subtropical high shifts to the southeast, Central Asia is controlled by an anomalous cyclone, and water vapor from the tropical Indian Ocean enters Central Asia through a two-step transport process, forming favorable dynamic and moisture conditions that lead to above-normal summer precipitation across most of Central Asia.

Keywords: North African subtropical high; subtropical high ridge line; subtropical high eastern extension ridge point; concurrent variation; summer precipitation over Central Asia

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1.1 Study Area Overview

Central Asia is the world' s largest inland arid region, comprising the Republic of Kazakhstan, the Republic of Uzbekistan, the Republic of Tajikistan, the Republic of Kyrgyzstan, the Republic of Turkmenistan, and Xinjiang, China (Fig. [Figure 1: see original paper]). During the period of 1979–2019, summer precipitation in Central Asia exhibited a distribution pattern of more precipitation in the north and less in the south, with precipitation concentrated mainly in the Tianshan Mountains and Pamir Plateau regions [] (figure omitted). Precipitation showed a decreasing trend to the west and an increasing trend to the east, with particularly significant increases in western Xinjiang and the Pamir Plateau region during summer [] (figure omitted).

1.2 Data Sources

The European Centre for Medium-Range Weather Forecasts (ECMWF) Interim monthly reanalysis dataset [] includes wind fields, specific humidity, surface pressure, and geopotential height data. The spatial resolution of wind fields, specific humidity, and surface pressure data is 2.5°$×2.5°, *while geopotential height data has a spatial resolution of* 1.0°×1.0°. *The Climatic Research Unit* (*CRU*) This dataset has been widely applied in climate change research in Central Asia [].

1.3 Research Methods

The eastern extension ridge point index and ridge line index are used to describe the spatial position variations of the North African subtropical high. Based on the calculation method for the western extension ridge point index of the Western Pacific subtropical high [], the eastern extension ridge point index of the North African subtropical high is defined. The ridge line index of the North African subtropical high adopts the method provided by the National Climate Center. The specific calculation methods are as follows:

North African subtropical high ridge line index: Within the region of 10°–60°N, 20°–60°E, at 500 hPa, the average latitude position of the subtropical high center (where geopotential height is greater than 5840 gpm and zonal wind $u = 0$) along each meridian serves as the ridge line position index of the North African subtropical high.

North African subtropical high eastern extension ridge point index: The longitude position of the easternmost point of the 5870 gpm contour line at 500 hPa within the region of 10°–80°E serves as the eastern extension ridge point index of the North African subtropical high.

When analyzing the relationship between the subtropical high index and Central Asian precipitation, a univariate linear regression method is used. The specific calculation formula is as follows:

$$y_i = ax_i + b$$

where x_i is the subtropical high index; y_i is the summer precipitation in Central Asia; a is the regression coefficient; and b is the constant term.

When analyzing water vapor transport, integration is performed from the surface to 300 hPa. The specific calculation formula is as follows:

$$Q = \frac{1}{g}\int_{p_{300}}^{p_s} q\mathbf{V}dp$$

where Q is the water vapor flux ($\mathrm{kg} \cdot \mathrm{m}^{-1} \cdot \mathrm{s}^{-1}$); g is gravitational acceleration ($\mathrm{m} \cdot \mathrm{s}^{-2}$); p_s is surface pressure (hPa); p_{300} is the upper integration limit (300 hPa in this study); q is specific humidity; and $\mathbf{V}$ is the two-dimensional wind vector.

Summer in this study refers to the average of June–August.

Fig. 1 [Figure 1: see original paper] Topographic distribution over Central Asia

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2.1 Relationship Between Individual Variations of the North African Subtropical High Ridge Line and Eastern Extension Ridge Point and Summer Precipitation in Central Asia

To facilitate discussion of the interannual variation characteristics of the summer North African subtropical high and its relationship with summer precipitation in Central Asia, the eastern extension ridge point index and ridge line index of the North African subtropical high are standardized and denoted as x_i and y_i, respectively (where i represents the year). In terms of interannual variation, the ridge line index of the North African subtropical high shows an overall decreasing trend, indicating that the subtropical high has gradually shifted southward in recent years (Fig. [Figure 2: see original paper]a). The eastern extension ridge point index shows no significant trend (Fig. [Figure 2: see original paper]b). In terms of spatial position changes, the north-south position variation of the North African subtropical high is not significant; even in the years with maximum and minimum ridge line indices, the position difference from the average is small (Fig. [Figure 2: see original paper]c). However, the east-west position variation is substantial, spanning approximately X degrees of longitude, with the westernmost position in year X and the easternmost position extending to southwestern Central Asia (Fig. [Figure 2: see original paper]d).

Figure 3 presents the linear regression distribution between the North African subtropical high indices and summer precipitation in Central Asia. The regression coefficients between the eastern extension ridge point index and precipitation are positive across most of Central Asia, indicating that when the North African subtropical high extends eastward, precipitation increases in most regions of Central Asia. This relationship is significant in the region of 37.5°–45°N (Fig. [Figure 3: see original paper]a). The regression coefficients between the ridge line index and precipitation show a distribution of negative in the south and positive in the north, with significant relationships in the Pamir Plateau, Tianshan Mountains of Xinjiang, and eastern Xinjiang region. This indicates that when the North African subtropical high shifts southward, precipitation increases in southern Central Asia and decreases in the north, and vice versa (Fig. [Figure 3: see original paper]b).

How do different spatial position changes of the subtropical high affect summer precipitation in Central Asia? Table 1 presents eight anomalous spatial position scenarios of the North African subtropical high. The first four scenarios represent concurrent variations where both indices are anomalous, while the last four scenarios represent individual variations where only one index is anomalous.

Table 1 Eight anomalous spatial positions of the North African subtropical high

Spatial Position Type	Eastern Extension Ridge Point Index (x_i)	Ridge Line Index (y_i)
East-North	>0.5	>0.5
East-South	>0.5	<-0.5
West-North	<-0.5	>0.5
West-South	<-0.5	<-0.5
East-Normal	>0.5	|x_i|<0.5
West-Normal	<-0.5	|x_i|<0.5
Normal-North	|y_i|<0.5	>0.5
Normal-South	|y_i|<0.5	<-0.5

Note: x_i is the eastern extension ridge point index; y_i is the ridge line index. The same applies below.

Figure 4 shows the composite distribution of summer precipitation anomalies in Central Asia under individual variations of the North African subtropical high position. When the subtropical high is anomalously positioned to the east (Fig. [Figure 4: see original paper]a), precipitation anomalies are negative in northern Kazakhstan and central Xinjiang, while positive in other regions, with significant increases in the Pamir Plateau region. When the subtropical high is anomalously positioned to the west (Fig. [Figure 4: see original paper]b), summer precipitation decreases significantly across most of Central Asia, except for a few isolated areas. When the subtropical high is anomalously positioned to the north (Fig. [Figure 4: see original paper]c), precipitation anomalies are positive north of X°N and negative south of X°N, with significant decreases in the Pamir Plateau region. When the subtropical high is anomalously positioned to the south (Fig. [Figure 4: see original paper]d), precipitation anomalies are positive in western Central Asia and southern Xinjiang, while significantly negative in northwestern Central Asia.

Variations in the spatial position of the subtropical high have important impacts on regional circulation and water vapor transport []. Composite analysis is further employed to discuss how subtropical high position shifts affect regional circulation and water vapor transport. As shown in Figures 5 and 6, when the North African subtropical high is anomalously positioned to the east, Central Asia is controlled by anomalous cyclones and anticyclones from west to east. Under their combined influence, central and southern Central Asia experience anomalous southerly winds, forming favorable dynamic conditions for precipitation, while northern Central Asia experiences anomalous northerly winds, which are unfavorable for precipitation. When the subtropical high is anomalously positioned to the west (Fig. [Figure 5: see original paper]b), Central Asia is controlled by an anomalous anticyclone with prevailing northerly winds, which is unfavorable for precipitation across most of Central Asia. When the subtropical high is anomalously positioned to the north (Fig. [Figure 5: see original paper]c), northern Central Asia is controlled by an anomalous cyclone while southern Central Asia is controlled by an anomalous anticyclone, favoring precipitation in the north but not in the south. When the subtropical high is anomalously positioned to the south (Fig. [Figure 5: see original paper]d), southern Central Asia is controlled by an anomalous cyclone while northwestern Central Asia is controlled by an anomalous anticyclone, favoring precipitation in the south but not in the north.

Figure 6 shows the composite distribution of water vapor flux anomalies when the North African subtropical high is anomalously positioned to the east. The Western Pacific subtropical high intensifies, enhancing the northward transport of water vapor from the western Pacific. Combined with the anomalous cyclonic circulation over North China, this transports water vapor westward. When the subtropical high is anomalously positioned to the west (Fig. [Figure 6: see original paper]b), water vapor from both the tropical Indian Ocean and northwestern Pacific is unfavorable for transport into Central Asia. When the subtropical high is anomalously positioned to the north (Fig. [Figure 6: see original paper]c), an anomalous cyclone over the Indian Peninsula makes northward water vapor transport difficult. The East Asian summer monsoon intensifies, transporting water vapor from the western Pacific to North and Northeast China. Combined with the cyclonic circulation over Mongolia, this can transport water vapor westward to northern Central Asia, providing moisture conditions for precipitation there. When the subtropical high is anomalously positioned to the south (Fig. [Figure 6: see original paper]d), although an anomalous anticyclone over the Indian Peninsula can transport Indian Ocean water vapor northward, the cyclone over Central Asia is relatively weak, resulting in weak transport of the southern branch of water vapor, with moisture mainly originating from the northwestern Pacific.

2.2 Relationship Between Concurrent Variations of the North African Subtropical High Ridge Line and Eastern Extension Ridge Point and Summer Precipitation in Central Asia

The previous section discussed precipitation changes and anomalous distributions of large-scale circulation and water vapor transport under individual variations of the North African subtropical high ridge line and eastern extension ridge point. This section further analyzes the concurrent variation of these two indices. As shown in Figure 7, when the North African subtropical high shifts to the east and north, summer precipitation anomalies in Central Asia exhibit a negative-positive-negative distribution pattern from south to north. Most areas of Kazakhstan show positive anomalies, while the northern boundary of Kazakhstan and Tajikistan and Uzbekistan to the south show negative anomalies. Most regions of Xinjiang, except for the Tianshan Mountains, have negative precipitation anomalies. When the subtropical high shifts to the west and south (Fig. [Figure 7: see original paper]b), most areas of Central Asia show negative precipitation anomalies, with positive anomalies in the northwest. When the subtropical high shifts to the east and south (Fig. [Figure 7: see original paper]c), most regions show positive summer precipitation anomalies. When the subtropical high shifts to the west and north (Fig. [Figure 7: see original paper]d), except for northern Xinjiang and northern Kazakhstan where precipitation is above normal, other regions receive below-normal precipitation.

Figure 8 shows the composite distribution of 500 hPa wind anomalies under concurrent variations of the North African subtropical high position. When the subtropical high shifts to the east and north (Fig. [Figure 8: see original paper]a), an anomalous anticyclone over the Arabian Sea facilitates the northward transport of tropical ocean water vapor. Combined with the cyclonic circulation over the Caspian Sea and Aral Sea, this further transports water vapor to mid-high latitude regions. Meanwhile, an anomalous anticyclone over the region south of the Yangtze River in eastern China, together with an anticyclone over Mongolia, can transport water vapor from the western Pacific westward, though this water vapor transport is relatively weak. When the subtropical high shifts to the west and north (Fig. [Figure 8: see original paper]b), anomalous cyclones over the Arabian Sea and Indian Peninsula are unfavorable for northward transport of Indian Ocean water vapor, resulting in relatively weak moisture conditions across most of Central Asia. An anomalous anticyclone over central China can transport water vapor from mid-latitude oceans to North and Northeast China.

Combined with the cyclonic circulation over Mongolia, this further transports water vapor westward, providing moisture conditions for summer precipitation in northwestern Central Asia. When the subtropical high shifts to the east and south (Fig. [Figure 8: see original paper]c), anomalous anticyclones over the Arabian Sea and cyclones over Central Asia allow water vapor from the tropical Indian Ocean to enter Central Asia. The East Asian summer monsoon weakens, preventing water vapor from the western Pacific from reaching eastern Central Asia. When the subtropical high shifts to the west and south (Fig. [Figure 8: see original paper]d), an anomalous cyclone over the Arabian Sea makes it difficult to transport Indian Ocean water vapor to Central Asia. However, the East Asian summer monsoon intensifies, and water vapor from the western Pacific flows along the eastern side of the Tibetan Plateau, passes through the Hexi Corridor, and enters eastern Central Asia (Xinjiang, China), providing moisture conditions for summer precipitation there.

The influence of the Western Pacific subtropical high is also considered. Figure 10 shows the linear regression distribution between the summer North African subtropical high eastern extension ridge point index, the Western Pacific subtropical high western extension ridge point index, and summer precipitation in Central Asia. The Western Pacific subtropical high western extension ridge point index shows a linear negative correlation with summer precipitation in Central Asia, with significant relationships in Tajikistan, Kyrgyzstan, and the western side of the Tianshan Mountains and Tarim Basin in Xinjiang. This indicates that when the Western Pacific subtropical high shifts westward, summer precipitation increases in the region south of Central Asia, and vice versa. The above analysis demonstrates that both the North African subtropical high and the Western Pacific subtropical high influence summer precipitation in Central Asia. How do their combined effects influence summer precipitation in Central Asia? This requires further discussion.

3 Discussion

This study discusses the relationship between spatial position variations of the summer North African subtropical high and summer precipitation in Central Asia, revealing the influence processes of the summer North African subtropical high on Central Asian summer precipitation. However, several limitations exist: (1) The study does not consider the close relationship between surface heating and the position variation of the Western Pacific subtropical high []. Non-uniform spatial distribution of diabatic heating affects the break and closure of the Western Pacific subtropical high []. Surface sensible heat flux over North America determines the position variation and seasonal movement of the North American subtropical high [], while condensation latent heat determines the position and intensity changes of the Eastern Hemisphere subtropical high. How diabatic heating affects the North African subtropical high has received little attention, and the influencing mechanisms remain unclear, requiring further analysis.

4 Conclusions

Using univariate linear regression and composite analysis methods, this study analyzed the relationship between the North African subtropical high ridge line index and eastern extension ridge point index and summer precipitation in Central Asia from 1979 to 2019, revealing anomalous characteristics of summer precipitation, circulation, and water vapor transport under individual and concurrent variations of the two indices. The main conclusions are as follows:

(1) During summer, the east-west position of the North African subtropical high shows large variations, while the north-south position remains relatively stable. The eastern extension ridge point index of the North African subtropical high shows a significant linear positive correlation with summer precipitation across most of Central Asia. The ridge line index exhibits a south-negative, north-positive linear regression pattern with summer precipitation in Central Asia, with significant linear negative correlations in the Pamir Plateau and Tianshan Mountains of Xinjiang.

(2) Under individual variations of the subtropical high indices, when the summer North African subtropical high is anomalously positioned to the east (west), precipitation increases (decreases) across most of Central Asia, with anomalous southerly (northerly) winds prevailing in southern Central Asia and water vapor transported from the eastern oceans (poor water vapor transport conditions). When the ridge line position shifts southward (northward), precipitation increases (decreases) in southern Central Asia and decreases (increases) in the north. Southern (northern) and northern (southern) Central Asia are controlled by anomalous cyclones (anticyclones) and anticyclones (cyclones), respectively, with water vapor originating from the western Pacific.

(3) Under concurrent variations of the subtropical high indices, when the summer North African subtropical high is anomalously positioned to the east (west) and south (north), precipitation increases (decreases) across most of Central Asia. Central Asia is controlled by anomalous cyclones (anticyclones) with favorable (unfavorable) water vapor transport conditions. When the subtropical high shifts to the east and north, precipitation increases in central Central Asia, with anomalous southerly winds prevailing and water vapor transported from the Arabian Sea to Central Asia. When the subtropical high shifts to the west and south, except for northern Xinjiang, China, and northern Kazakhstan, most areas of Central Asia receive below-normal precipitation.

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Note: Figure translations are in progress. See original paper for figures.