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Relationship between Reduction of Summer Precipitation in North China and Atmospheric Circulation Anomalies

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Abstract

Based on Reanalysis datasets from National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) and summer rainfall datasets from China National Climate Center (NCC), by using trend analysis and composite analysis methods, the relationship between the reduction of summer precipitation in North China and northern hemispheric circulation changes was investigated. The results show that summer rainfall in North China had a significant decreasing tendency, especially true since 1965 in which an abrupt change occurred. The northern hemisphere atmospheric circulation at 500 hPa had a remarkable change after 1965, from outstanding meridional circulation to outstanding zonal circulation, leading to upper trough activity to decrease, resulting in the rainfall weather processes caused by upward motion behind trough significantly to reduce. At 500 hPa in Mongolian region, air temperature decreased, resulting in lower troposphere pressure to increase, leading to low pressure activity significantly to decrease and rainfall weather processes influencing North China to reduce. At the same time, the decreased air temperature in 500 hPa would caused the upper troposphere geopotential height to reduce, resulting in high–altitude jet southerly location, the East Asian summer monsoon to weaken, then it was difficult for water vapor transport to cross the Yangtze River valley and reach the North China region, with a southerly summer monsoon rainfall zone. The summer precipitation reduction in North China had a good correlation with the northern hemispheric circulation changes.

Keywords: North China, Summer Precipitation, Reduction, Atmospheric Circulation, Anomalies

1. Introduction

Since late 1960s, summer precipitation in North China has shown a significantly decreasing trend with the drought trend being more obvious [1] especially since the 1970s, leading to the deficit of water resources which has a great influence on local industrial, agricultural production and the lives of residents. Recent research conducted by Ding and Zhang [2] shows that abrupt changes happened in the 1970s, leading to summer precipitation decline in North China. Through analyzing 86 stations summer rainfall data of 1951–2007, Xu *et al*. [3] declared that summer precipitation in North China is more than normal, with the precipitation having decreased significantly since 1965. Although the drought trend in North China had eased in the early 1970s, the regional drought continued to intensify in the late 1970s, and extended to the late 1980s and early 1990s. With a brief interruption of increasing precipitation in North China in the early 1990s, the precipitation in North China once again has reduced significantly since 1996 and the drought worsens.

The reasons for summer precipitation reduction in North China and its future trend are widely concerned by scientists and policy–makers [4,5]. Through analyzing a climate abrupt change in the summer precipitation in North China around 1965, Huang *et al*. [6] pointed out that such a climate abrupt change is due to increasing sea surface temperature in eastern tropical Pacific in the mid-1960s. Zhang [7] argued that the summer precipitation reduction in North China is related to the subtropical high anomalies in Western Pacific. After investigating the relationship between snow cover over Tibetan Plateau and China's summer precipitation, Peng *et al.* [8] found a decadal climate jump in accumulated snow amount in the late 1970s, on the basis of which there is a good correlation between North China summer precipitation reduction and the amount of snow cover. The numerical simulation study conducted by Zhu *et al.* [9] further proves the point that snowy winter in Tibetan Plateau would lead to a weakening Tibetan Plateau heat source, which thereby continued into the summer season, causing the East Asian summer monsoon to weaken and as a result, the "South floods and North drought" situation occurs in China with North China even drier. Yu *et al.* [10,11] found that the upper troposphere air temperature in summer was declining since the late 1980s and this had led to the reduction of summer precipitation in North China and an increase in the Yangtze River basin. More studies showed that the reduction of summer rainfall in North China was closely related to weakening East Asian summer monsoon [12-17].

In spite of the fact that many scholars have studied the reasons of summer precipitation reduction in North China, the reasons for North China summer precipitation reduction and the impact factors still remain uncertain, and further investigation is still essential. Herein we will investigate the factors causing North China summer rainfall reduction by means of comparative analysis of the northern hemisphere atmospheric circulation changes since 1965 when an abrupt change occurred.

2. Data and Methods

The data sets for this study are from two sources. Summer precipitation data from 20 stations (**Figure 1**) located in North China during the period of 1951–2008 was provided by the Climate Diagnostics and Prediction Division of China National Climate Center. Atmospheric circulation data were taken from National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis monthly data with a horizontal resolution of 2.5° × 2.5° in 1951–2008, *provided by the NOAA–CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at* http://www.cdc.noaa.gov/ [18].

Abnormal changes in summer precipitation in North China are investigated by means of trend analysis, Mann-Kendall test. Atmospheric circulation anomaly analyses were conducted in terms of composite averaged fields of height, temperature, pressure and wind.

3. Changes of Summer Precipitation in North China

First we analyze the changes in summer precipitation in North China during the period of 1951-2008 (**Figure 2**). **Figure 2** shows that summer rainfall has a great interannual variability, trend curve reflecting an obvious interdecadal change feature. Taking the minimum precipitation year for node, it can be divided into three major stages, namely 1951–1969, 1969–1983, 1983–2008, with a gradually declining trend in average rainfall in the three stages. Linear analysis conducted on precipitation change pass through 95% significant level, indicating that linear decline is significant during recent 58 years, with an average reduction of 14.9 mm every ten years.

Then, we analyze whether there are abrupt changes in summer precipitation in North China. Mann-Kendall test has special advantages in depicting abrupt changes [19], and in particular, it can determine the time period when the abrupt changes occur. Herein we will use this method to investigate whether there are abrupt changes occurring in summer precipitation in North China. **Figure 3** is the results of Mann-Kendall tests. We can find an abrupt change in 1965, and since then summer precipitation has

Figure 1. Spatial distribution of stations in North China.

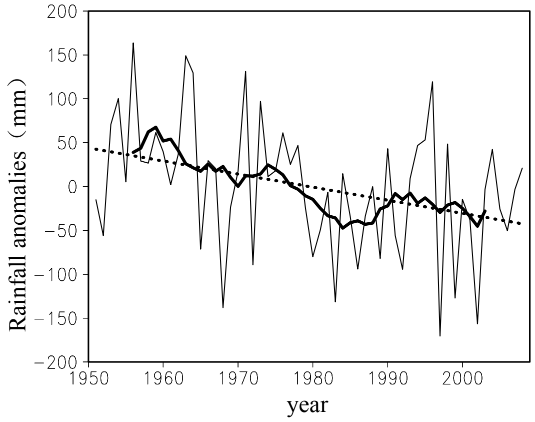


Figure 2. Variation of 1951–2008 summer precipitation in North China (thin solid for annual variation, thick solid for running-11yr mean, dashed for linear tendency).

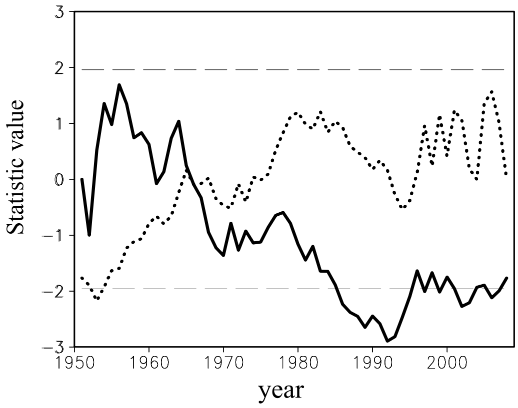


Figure 3. *Mann–Kendall* test of summer precipitation in North China (solid for C_1, dotted for C_2, dashed for 95% significant level).

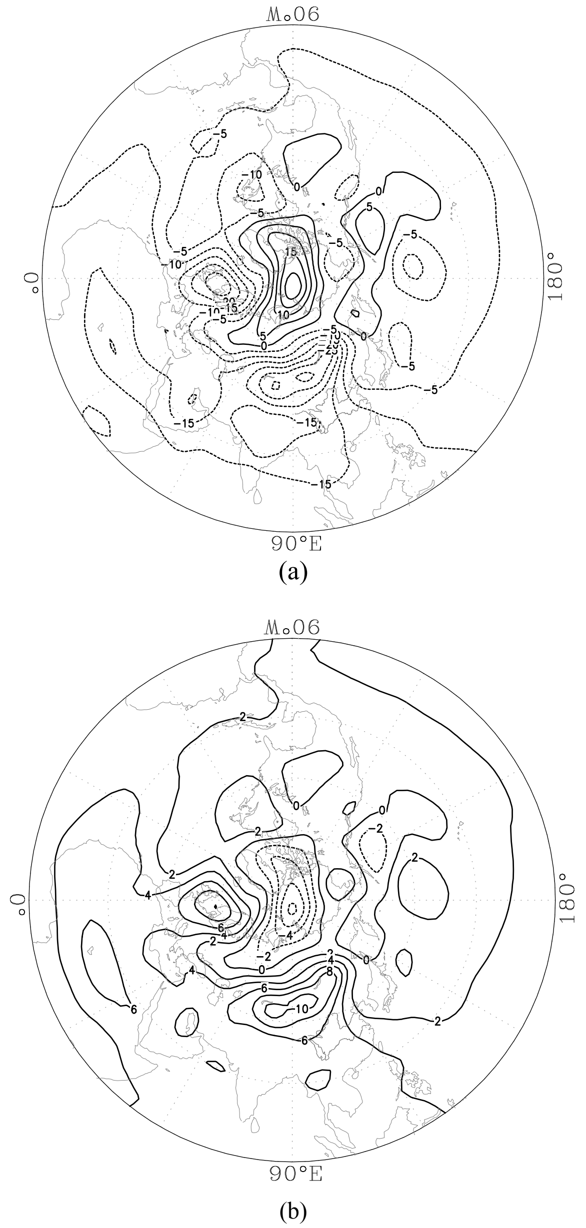
significantly reduced.

4. Circulation Changes

For the precipitation is closely related with water vapor conditions (summer monsoon water vapor transport), upward motion conditions (surface low pressure, upper–level trough, upper–level jet) and the strength of the summer monsoon. Based on the abrupt change occurring in 1965 for summer precipitation reduction in North China, we take 1965 as the boundary. Then we conduct comparative analyses of 500 hPa height fields and air temperature fields, 850 hPa wind fields, sea-level pressure fields between 1951-1965 and 1966-2008 respectively , in order to understand the relationship between reduction of summer precipitation in North China and changes in atmospheric circulation.

4.1. 500 hPa Geopotential Height Field Changes

At 500 hPa height field the trough and ridge activities often resulted in upward motion after the upper-level trough, causing more precipitation weather processes. In order to understand the circulation changes after 1965, we make a comparative analysis of 500 hPa height field in the summer of 1951–1965 and 1966–2008 respectively (**Figure 4**).



(a)

(b)

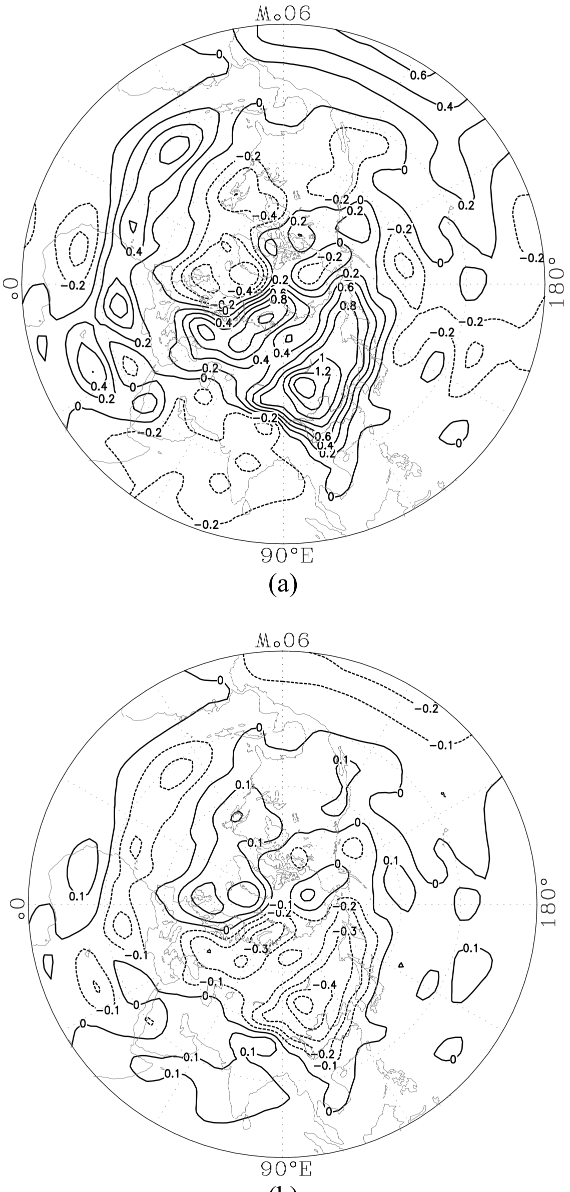
Figure 4. Difference of summer 500 hPa height field, light-colored line for terrain boundary, unit: gpm. (a) 1951–1965 minus 1951–2008; (b) 1966–2008 minus 1951–2008.

The positive polar anomaly in **Figure 4(a)** indicates a shallower polar vortex during 1951–1965. The North Atlantic coast of Europe negative anomaly, the Urals positive anomaly, Lake Baikal to the Tibetan Plateau negative anomaly, so from Europe, the Urals to Central Asia formation a "–,+, –" Eurasian teleconnection pattern, showing that the European long-wave trough, the trough from Lake Baikal to the northern part of Tibetan Plateau are deeper, a stronger ridge of high pressure over the Urals. This distribution leads to a lot of activities of troughs and ridges, outstanding performance of meridional circulation. As a result, there will be more upward motions in North China with the Lake Baikal trough shifting frequently southeastward. **Figure 4(b)** opposite with **Figure 4(a)**, but anomaly value is obviously smaller. Polar negative anomaly shows a bit deeper polar vortex. Positive anomaly over the European coast of the North Atlantic, negative anomaly of the Urals, and positive anomaly from Lake Baikal to the Tibetan Plateau, form a "+,–,+" Eurasian teleconnection pattern from Europe, the Ural Mountains to the Central Asia, which shows that European long-wave trough, and the trough at Lake Baikal to the northern part of Tibetan Plateau are shallower, weak ridge of high pressure over the Urals. This distribution makes activities of troughs and ridges very weak, outstanding performance to zonal circulation. As a result, upward motion in North China caused by the Lake Baikal trough has significantly reduced. It can be seen that Eurasian teleconnection pattern at 500 hPa height field is significant during the summer months, whose changes can affect zonal index circulation over the East Asia, alter the frequency and intensity of the trough and ridge activities over Mongolian and Yellow River Loop area, and then affect summer precipitation in North China.

4.2. 500 hPa Air Temperature Field Changes

As is know, the rising or declining air temperatures at upper–level can affect not only the lower troposphere pressure, but also the location of upper-level westerly jet. Next, we make a comparative analysis of air temperature changes at 500 hPa layer (**Figure 5**). As is shown in **Figure 5(a)**, we can see North Atlantic Ocean subtropical region with positive anomaly, the high latitude regions from North Atlantic Ocean to Europe, North America coast with negative anomaly, high latitude Europe with positive anomaly, Ural Mountains with small positive anomaly, northwestern Mongolia to Yellow River Loop with positive anomaly. This reveals that in the summer of 1951–1965 at the 500 hPa level, air temperature over Mongolian area is higher, causing the lower troposphere pressure to reduce, resulting in more low pressure weather processes activity, leading to an increase in precipitation. Meanwhile, the pressure of the upper troposphere over the region increases, leading to the pressure gradient to reduce in the south side of the region and to increase in the north side of the region, resulting in upper–level jet with northerly location, then the summer monsoon rainfall area northerly. **Figure 5(b)** is contrary to **Figure 5(a)**, but the anomalous value is smaller. From Mongolia to the northwest to Yellow River Loop with the maximum intensity, broadly area negative anomaly. This shows a significantly lower air temperature over the Mongolian region in 1966–2008. At 500 hPa layer, the dropping air temperature lead to a rise of the lower troposphere pressure in the region, resulting in both low–pressure activity and precipitation weather processes to decrease, thereby reducing precipitation. At the same time, the upper troposphere geopotential height decreases over the region, causing the south side pressure gradient of the region to increase and the north side pressure gradient to decrease, resulting in upper–level westerly jet with southerly location, then the summer monsoon rainfall area southerly.

4.3. Changes in 850 hPa Wind Field



(a)

(b)

Figure 5. Same as Figure 4, except for 500 hPa air temperature (unit:℃).

Now that the 850 hPa wind field plays a key role in transferring water-vapor which may has a remarkable influence on precipitation. Herein we conduct a comparison analysis to the 850 hPa wind field (**Figure 6**).

Comparing **Figure 6(a)** with **Figure 6(b)**, we find that the Indian summer monsoon blows mainly from west to east. Moreover, comparing that in 1966–2008 with 1951–1965, we find Indian summer monsoon wind speed exhibits almost no change, being consistent with India summer precipitation reduction tendency not obviously [20]. The East Asian summer monsoon blows mainly from the South China Sea to North China, Northeast. **Figure 6(a)** shows that the East Asian summer monsoon wind speed is the same as the Indian summer monsoon in 1951–1965, extending to the Northeast China area from the South China Sea. Besides, in Mongolian area exists an obvious cyclone circulation, which produces the wind direction convergence nearby Yellow River loop. **Figure 6(b)** is obviously different from **Figure 6(a)**. First, the East Asian summer monsoon wind speed has remarkably decreased after crossing 30ºN, with a very small value compared with Indian summer monsoon wind speed, indicating that east Asian summer monsoon very rarely crossed the Yangtze River and arrived in North China in 1966–2008, which, in turn, produced a wind speed convergence in the Yangtze valley. Second, the cyclone circulation in the Mongolian region vanished, and the wind direction convergence nearby Yellow River loop was very weak. Therefore, rainy in the summer of 1951–1965 in North China were possibly due to the effective water vapor transportation by East Asia summer monsoon and the wind direction convergence nearby Yellow River loop, while rainy in the summer of 1966–2008 in Yangtze valley were possibly due to the wind speed convergence over there created by the East Asian summer monsoon. So there are different characteristics in the two places. In 1966–2008, less precipitation in North China was possible because of the shortage of effective water vapor transportation and the weakness of the wind direction convergence nearby the Yellow River loop.

In order to further analyze 850 hPa wind anomaly changes, we calculated the difference field of horizontal wind speed during 1951–1965, and 1966–2008 respectively, shown in **Figure 6(c)**, and **Figure 6(d)**. **Figure 6(c)** shows that the Indian summer monsoon basically has no exceptional changes, but the East Asian summer monsoon presents an obvious southerly wind anomaly, with cyclone circulation in the Mongolian area, weak anticyclone circulation in the northwest Pacific Ocean, and an obvious wind direction convergence circulation nearby Yellow River loop. **Figure 6(d)** is basically opposite to **Figure 6(c)**. That is to say, the Indian summer monsoon has no exceptional changes, but the East Asia monsoon presents a northerly wind anomaly, with anticyclone circulation in Mongolian area, weak cyclone circulation in the northwest Pacific, and wind direction divergence circulation nearby the Yellow River loop.

The facts added together, the 1966–2008 relative to the 1951–1965, though variation of the intensity and position of the northwest Pacific Ocean subtropical high is not remarkable, and changes of intensity of the Indian summer monsoon is not too obvious, but the East Asian summer monsoon weakens remarkably. In 1951–1965, East Asia summer monsoon is stronger, with prevailing southerly wind anomaly in the mid-latitude area of East Asia, which extending to the Northeast China area. The stronger southerly air stream of the East Asian summer monsoon and the stronger southeast air stream of the Subtropical High can effectively transport water vapor to the North China, which meets with northwest cold air flow near the Yellow River loop from Mongolia region, producing convergence upward motion, resulting in more summer precipitation in North China. In 1966–2008, the east Asian summer monsoon weakens remarkably after crossing 30ºN, which made it difficult for the water-vapor to be transported across 30°N by south wind and arrive in North China. Meanwhile, the Mongolian western cold air flow also becomes weaker. These two factors cause the summer precipitation to reduce in North China.

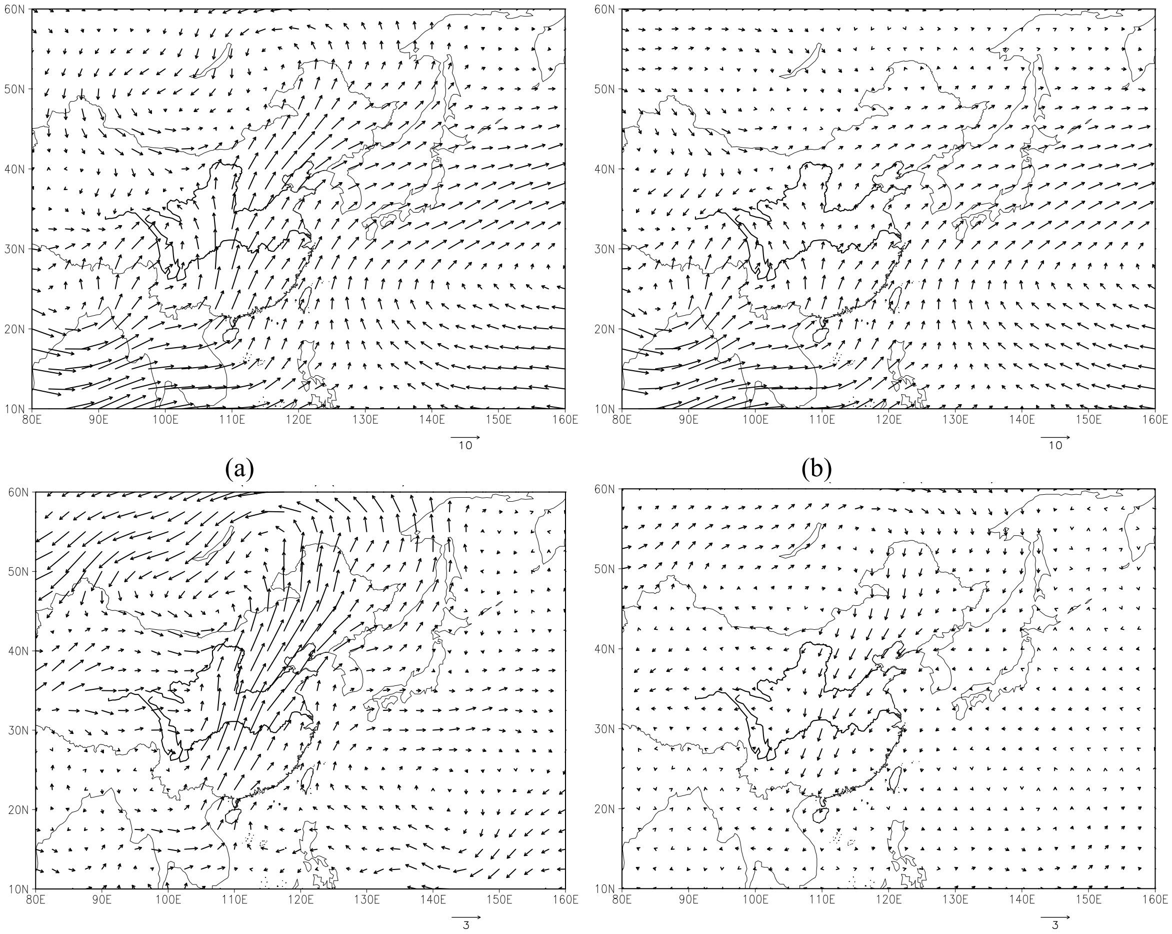
4.4. Changes in the Sea Level Pressure Field

The change in sea surface pressure field is the very important indicator in prediction of summer precipitation, thus, we conduct a comparison analysis with the pressure changes before and after 1965 (**Figure 7**). On the mean map of the sea level pressure field in the summer of 1951–2008 (figure omitted), the Arabian Peninsula to India, Mongolia was a low pressure center respectively, the North Pacific and North Atlantic is a stronger high pressure. The low pressure in Arabian Peninsula to India plays an important role in the formation of the Indian summer monsoon and the Mongolian low pressure plays an important role in the formation of the East Asian summer monsoon.

Comparison of **Figure 7(a)** and **Figure 7(b)** indicates that Mongolian region was an obviously negative anomaly during 1951–1965 which changed into a positive anomaly during 1966–2008, with the atmospheric pressure field in the Arabian Peninsula to India having no changes. These indicate that in the summer of 1951–1965, the Mongolian low pressure was stronger, having a good correlation with higher upper–level air temperature over the Mongolian area. The lower Mongolian low pressure caused more low-pressure activities in North China, resulting in more precipitation weather processes, which has a good corresponding relationship with more precipitation days in North China in the past. But in the summer of 1966–2008, the Mongolian low pressure significantly weakened, having a good correlation with dropping upper–level air temperature over the Mongolian area. The weaker Mongolian low pressure caused low–pressure activities in North China to reduce, resulting in reduction of precipitation weather processes, which has a good correlation with the reduction of the number of precipitation days in North China in recent years.

5. Summaries

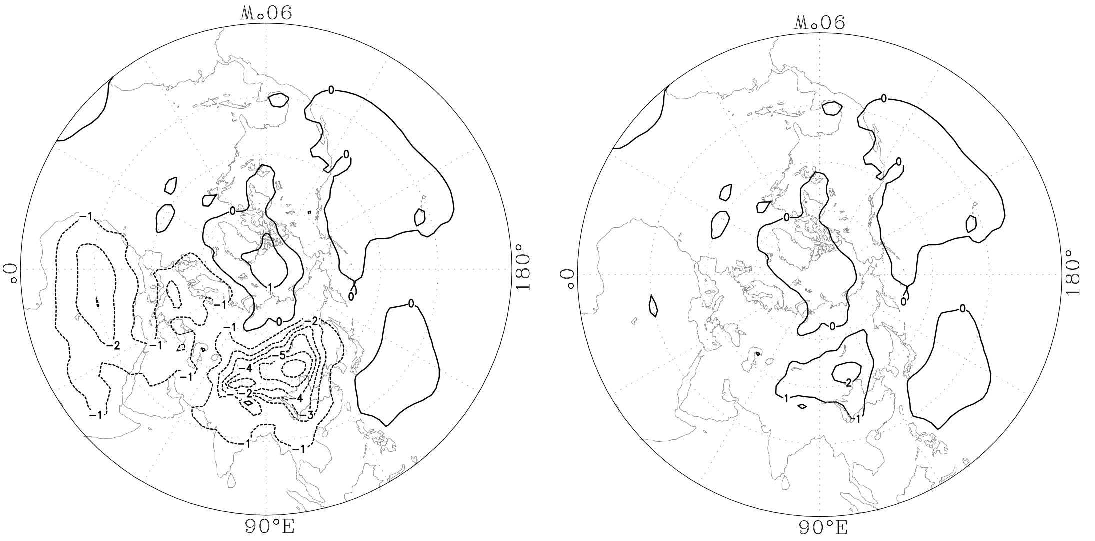
Summer precipitation in North China shows a significant linear decreasing trend from 1951 to 2008, with an average reduction of 14.9 mm for every 10 yr. An abrupt change occurred in 1965, since then, the precipitation decreased more significantly. The atmospheric circulation



(a) (b)

(c) (d)

Figure 6. Difference of summer 850hPa wind field (unit: m.s^{-1}). (a) Composite distribution of 1951–1965; (b) Composite distribution of 1966–2008; (c) 1951–1965 minus 1951–2008; (d) 1966–2008 minus 1951–2008.



(a) (b)

Figure 7. Same as Figure 4, except for sea lever pressure fields, unit: hPa.

has notable changes after 1965.

As in the summer 500 hPa height field, it is found that since 1965, the European trough, Lake Baikal trough have become shallower, Ural mountain high-pressure ridge weaker, the atmospheric circulation converted from prominent meridional circulation to prominent zonal circulation, leading to trough and ridge activities reduction, resulting in the precipitation weather processes caused by the upward motion behind trough significantly to decline. At 500 hPa, air temperature dropped in Mongolia area, which caused the lower troposphere pressure in the region to increase and low pressures activities in North China to reduce, thus resulting in reduction of the precipitation weather processes in North China. Meanwhile, lower air temperature caused the upper troposphere geopotential height to reduce in the region, resulting in the south side pressure gradient to increase and the north side pressure gradient to decrease in cooling zone, leading to the upper–level jet with southerly location, associated with southerly summer monsoon rainfall area.

In response to the dropping air temperature at 500 hPa in Mongolian areas, the Mongolian low pressure on the ground significantly weakened, leading to low pressure activities to reduce, resulting in reduction of the precipitation weather processes in North China. Meanwhile, in response to the lower air temperature, the upper–level jet with southerly location, and the East Asian summer monsoon weakened. So in the 850 hPa wind field, the East Asian summer monsoon wind speed decreased rapidly when reaching 30ºN, thus making it difficult for the monsoon wind to cross the Yangtze River and arrive in North China. However, a wind speed convergence was created in the Yangtze River basin, resulting in more precipitation in this region.

In conclusion, summer precipitation reduction in North China has a good correlation with the changes of the Northern Hemispheric circulation. The reasons for the circulation changes would be explored further in-depth study.

6. Acknowledgements

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