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# A SUDDEN CHANGE IN SUMMER RAINFALL CHARACTERISTICS IN KOREA DURING THE LATE 1970S

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## ABSTRACT

We have examined long-term climate change in Korea by studying daily rainfall data over a period of 48 years (1954–2001). The results show that there is a more frequent heavy rainfall anomaly larger than 100 mm per 3 months in recent years. For further investigation, we divide the whole period into two 24 year intervals, 1954–77 and 1978–2001. Two well-defined rainfall peaks occur during summertime in both intervals. During the earlier interval, primary and secondary rainfall peaks are found in early July and early September, respectively. In the later interval, on the other hand, the secondary peak is found in mid–late August, mainly attributed to enhanced heavy rainfall ($\geq$30 mm day$^{-1}$) events. Although a similar shift occurs in the primary peak, it is much smaller. Thus, the relatively dry spell between the two peaks becomes shorter in the later interval compared with the earlier one.

The domain-mean geopotential height at 700 hPa ($\Phi_{700}$) over mid-latitude Asia (30–50 °N, 60–120 °E) for the summer also experienced a sudden increase in the mid 1970s. A comparison of the spatial distribution of $\Phi_{700}$ between the two intervals shows large positive differences over the central-eastern Asian continent in the later interval. In contrast to the positive anomaly of $\Phi_{700}$ in the later interval, there is a decreasing trend in surface temperature. The increased $\Phi_{700}$ introduces a stronger northerly wind over East Asia and possibly produces a moisture convergence, enhanced convective activity, and heavy rainfall over the region, in particular over Korea and central China. Copyright © 2003 Royal Meteorological Society.

KEY WORDS: East Asian summer monsoon; Changma; climate change; deforestation

## 1. INTRODUCTION

Over the past several decades many studies have been performed on the Asian summer (June–July–August) monsoon related to large-scale circulation structures and seasonal variations of rainfall (e.g. Krishnamurti, 1985; Lau *et al*., 1988; Lim *et al*., 2002). The Asian summer monsoon defines the rainy season of a large area extending from India to northeast Asia and consists of two major subcomponents, namely the Indian summer monsoon and East Asian summer monsoon. As documented by Lau *et al*. (2000), the variability of the Indian summer monsoon is governed by Rossby-wave dynamics and that of the East Asian summer monsoon is characterized by a multi-cellular meridional circulation over East Asia, extending from the tropics to the mid-latitudes.

The East Asian summer monsoon consists of many regional subcomponents, which are known by different names: *Meiyu* in China, *Baiu* in Japan, and *Changma* in Korea. Climatologically, the monsoon begins as a monsoon trough forms over the South China Sea in mid May. As it accompanies continuous heavy rainfall over the South China Sea, the monsoon trough moves northward along the East Asian coastline in concert

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with an expansion of the North Pacific High in the northwestern Pacific. The monsoon trough is found over central China and Japan in early June, over Korea in late June, and finally over northern China in early July.

More than half of the annual rainfall in Korea is concentrated in the two summer rainy periods (Ho and Kang, 1988). The primary rainy period commences, forming a monsoon trough over the Korean peninsula, in late June associated with the eastward movement of the Tibetan High and westward movement of the North Pacific High to East Asia (Kang *et al*., 1999). This primary rainy period is termed *Changma*. As the monsoon trough moves further north to northeastern China in mid July, the primary rainy period ends. In late August, when the monsoon trough retreats southward to the Korean peninsula, the secondary rainy period, known as the *Autumn Changma*, starts. During the secondary rainy period, typhoons account for some of Korea's precipitation.

Since *Changma* is a part of the East Asian summer monsoon system, its characteristics may be affected by changes in the surface temperature and sea-level pressure field in the mid-latitudes. Indeed, the recent characteristics of rainfall, especially for the summer, show a significant difference from the climatological features of a few decades ago. In particular, we have recently experienced record-breaking rainfall and flash floods during the month of August in 1998 and 1999 (Hwang and Park, 2000; Yun *et al*., 2001). Yun *et al*. (2001) proposed that the merging effect between tropical wave propagation and the southward/westward 30–60 day wave produces heavy rain in Korea. However, it is still uncertain whether these extreme events are episodic or part of a long-term climate variation.

The motivation of the present study is to investigate the link between interdecadal variabilities of summer rainfall and heavy rainfall events/amounts and also to study the causes for such changes. For the investigation of the variation of precipitation and atmospheric variables, we collected data for the period 1954–2001. In Section 2 we describe the data used in the present study. In Section 3, the variations of the summer rainfall in Korea and the surface temperature and geopotential height at 700 hPa ($\Phi_{700}$) over the Asian continent are examined. Also in this section we discuss a possible cause of the changes in the summer rainfall associated with changes in the surface temperature and $\Phi_{700}$. Lastly, the conclusions of the study are summarized in Section 4.

## 2. DATA

The data used include area-averaged precipitation in Korea, geopotential height, surface temperature, precipitation, specific humidity, and wind measurements obtained from National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) daily reanalysis from 1954 to 2001. The area-averaged daily precipitation data are obtained by averaging over the 11 weather stations across the Korean peninsula, which are evenly distributed to represent an area mean value. Table I shows the longitude and latitude, elevation, and observational period of the 11 weather stations. The precipitation data are available from 1904 to 1944 for presentation with a missing period from 1950 to 1953 corresponding to the Korean War.

The geopotential height, precipitation, specific humidity, horizontal wind, and vertical wind data from NCEP–NCAR reanalysis have a horizontal resolution of $2.5^\circ \times 2.5^\circ$ longitude–latitude, and the surface temperature is available on a T62 Gaussian grid ($\sim 1.875^\circ \times 1.875^\circ$) (Kalnay *et al*., 1996). Currently, the data are available for 1949–2001 and can be obtained from the NCEP Web site (http://wesley.wwb.noaa.gov/ncep_data/index_sgi62.html). In the present study, the analysis period is confined to 1954–2001 to avoid the period of missing Korean precipitation data.

## 3. RESULTS

We first examine the long-term variability of the summertime precipitation over Korea to investigate any changes occurring in its characteristics. After that, we analyse the long-term variation of the surface temperature and 700 hPa geopotential height over East Asia using the NCEP reanalysis data for the same time period as the precipitation data.

 

Table I. Geographic position, elevation, and observation starting date of the 11 weather stations in Korea

| Station | Geographic position | | Elevation (m) | Observation starting date (year/month/day) |
|---|---|---|---|---|
| | Longitude (°E) | Latitude (°N) | | |
| Gangneung | 37.73 | 128.88 | 25.91 | 1911/10/03 |
| Seoul | 37.56 | 126.96 | 85.50 | 1907/10/01 |
| Incheon | 37.46 | 126.62 | 68.85 | 1904/08/29 |
| Pohang | 36.02 | 129.36 | 1.88 | 1944/07/17 |
| Daegu | 35.87 | 128.62 | 57.64 | 1907/01/31 |
| Jeonju | 35.82 | 127.15 | 53.48 | 1918/06/23 |
| Ulsan | 35.55 | 129.31 | 34.69 | 1932/01/06 |
| Gwangju | 35.17 | 126.88 | 70.53 | 1939/05/01 |
| Pusan | 35.10 | 129.03 | 69.23 | 1904/04/09 |
| Mokpo | 34.80 | 126.38 | 37.88 | 1904/04/08 |
| Yeosu | 34.73 | 127.73 | 66.05 | 1942/03/01 |

### *3.1. Variation of the precipitation in Korea*

In order to examine the climatic variability of the summertime rainfall in Korea, the time series of the summertime rainfall anomaly is obtained for the period of 1954–2001 over the Korean peninsula (Figure 1). The anomaly value is simply the deviation from the long-term mean, 641 mm per 3-month period. The anomaly evidently shows the large variability of the summertime rainfall amount for the period over Korea. The standard deviation of the interannual variability in the precipitation is 163 mm, 25% of the mean value. The estimated linear trend for the total summer precipitation is 21 mm per 3-month period per decade for the entire period.

Also shown is the 5 year moving average anomaly (solid line) to depict the long-term trend by smoothing the high-frequency noise. Overall, the 5 year moving average indicates a gradual increase with time due to more frequent occurrences of heavy rainfall in recent years. For example, when the entire period is divided into two 24 year intervals separated at 1977–78, the number of years with a positive anomaly larger than 100 mm per 3 month period is much larger in the later interval: 3 years versus 9 years. In particular, there are 5 years with large positive anomalies in the period from the mid 1980s to mid 1990s. The number of significant dry summers with values less than -100 mm per 3 month period also shows a similar abrupt change between the two intervals, i.e. 9 years versus 5 years. Thus, it is noted that 1977–78 is more likely to be a jump point from Figure 1. Some previous studies indicated the existence of a similar interval shift in the late 1970s in Chinese summer rainfall and the North Pacific High (e.g. Gong and Ho, 2002).

An enhancement of total rainfall during a given time period is due either to an increase of rainy events and/or an increase of the rainfall rate. To examine the cause of changes in the precipitation pattern in Korea, we analysed the number of rainy days and the cumulative rainfall. Figure 2(a) shows the total number of rainy days ($\geq$1 mm day$^{-1}$), averaged over 5 years (solid line), and the cumulative rainfall (bar). The average number of rainy days is about 48 for the entire period. While there is seemingly a positive trend in the number of rainy days, especially from the late 1980s, the rainfall for days with more than 1 mm day$^{-1}$ does not show a significant increase similar to the time series of total summer rainfall in Figure 1. Thus, it is determined that the changes in the number of rainy days do not account for the increase of the summer rainfall. On the other hand, the number of heavy rainfall events in excess of 30 mm day$^{-1}$, accounting for 35–50% of total rainfall, shows a gradual increase (Figure 2(b)). The average number of heavy rain events in the 1980s and 1990s is 7.0 days, higher than that in the 1960s and 1970s of 5.4 days. The cumulative rainfall also represents such a steady increase. In particular, there are clear jumps in the early 1980s in both the number of heavy rainfall events and the rainfall amount due to these events. The increasing trend of cumulative rainfall from $\geq$30 mm day$^{-1}$, 31 mm per 3-month period per decade, is even stronger than that of the total summer rainfall shown in Figure 1. A $t$-test of the

 

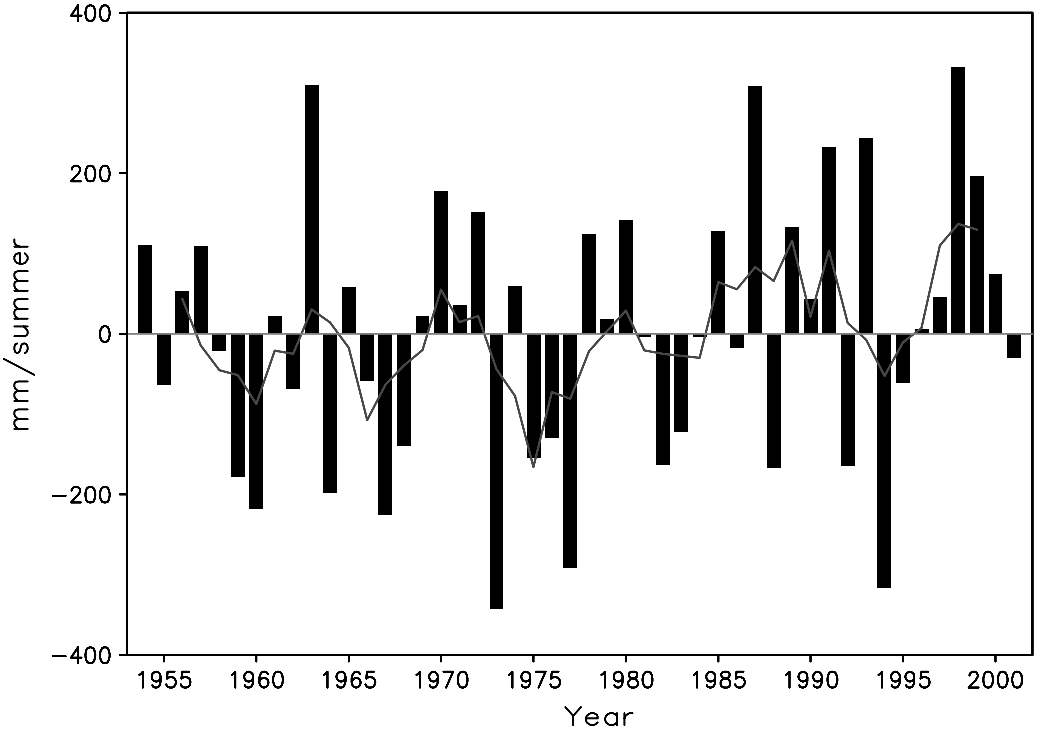


Figure 1. Time series of Korea's summer precipitation anomaly

time series indicates that this decadal change of the collocated precipitation rate is significant at the 95% confidence level.

Also, the significance tests of the changes in two cumulative rainfall amounts shown in Figure 2(a) and (b) are examined using a Kendall-tau test (see Suppiah and Hennessy (1998) for detailed methodology). The results show that the Kendall-tau values are 0.33 and 0.55 for $\geq$1 mm day$^{-1}$ and $\geq$30 mm day$^{-1}$, respectively. In both cases, the number of total data points is nine. Thus, it is found that the change in the cumulative rainfall $\geq$30 mm day$^{-1}$ is statistically significant at the 95% confidence level. However, that is not true for $\geq$1 mm day$^{-1}$.

For a further examination of the long-term variability of Korean rainfall, the whole study period is divided into two 24 year periods, namely earlier (1954–77) and later (1978–2001) intervals. From Figures 1 and 2(b) it is clear that there is a separation of rainfall characteristics centred on the mid 1970s. The main results of this paper remain largely unchanged if the reference year is changed to the early 1970s, late 1970s, or early 1980s. Figure 3 shows the precipitation climatology of the two intervals for a 5-day moving average. Two well-defined rainfall peaks are found during the summer, from mid June to early September, in both time series, associated with the primary and secondary rainy periods. The difference between the two climatologies is shown by the shaded regions. In particular, there is a significant difference in the precipitation for April and summer months between the two intervals.

During the earlier interval, the primary and secondary rainfall peaks are found in early July and early September respectively. For the later interval, however, the secondary rainfall peak is clearly shifted toward mid- to late-August. On the other hand, the primary rainfall peak shifts are much smaller, by about a few days. Accordingly, the dry spell between the two rainy periods becomes shorter in the later interval. Also, the precipitation increases (decreases) in August (September) in the later interval compared with the earlier interval because of an earlier onset of the secondary rainy period. August precipitation increased by up to 40% but the September precipitation decreased in the later interval. Owing to a

 

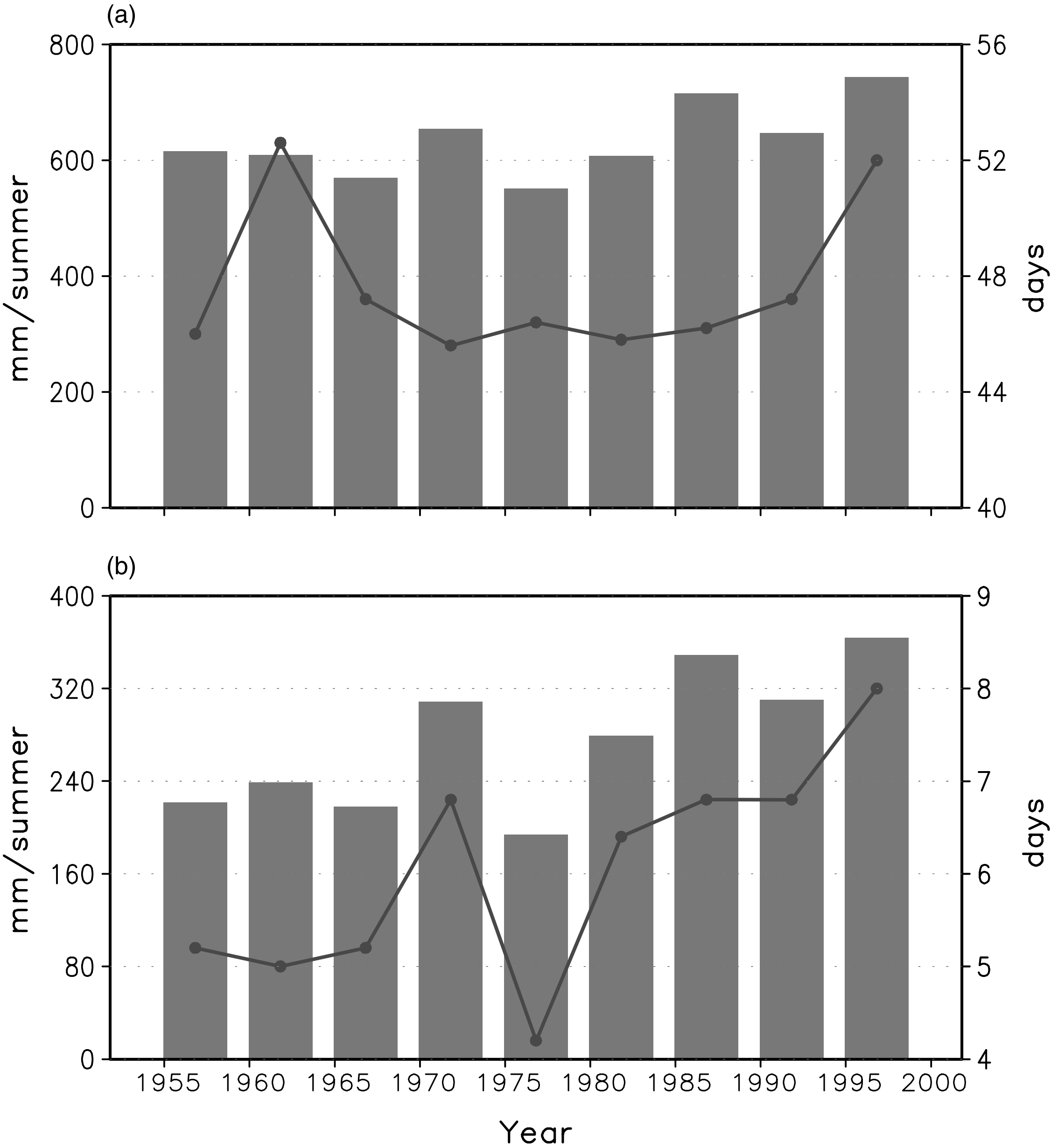


Figure 2. The 5-year average precipitation and number of rainy days during summer for rain rate $\geq$1 mm day$^{-1}$ (a) and rain rate $\geq$30 mm day$^{-1}$ (b). Solid line indicates the number of rainy days and bar represents the total summer precipitation

large increase in August precipitation, the overall rainfall amount is enhanced for summertime in the later interval.

In the above, we have examined long-term changes in the Korean summertime rainfall averaged over 11 stations. However, there are inhomogeneities in the observations because daily rainfall data are utilized in this study. Note that Korea is a relatively small country having longitudinal and latitudinal extents of 300 km and 450 km respectively. The heavy rainfall distribution shows similar characteristics over the whole nation. Thus, inhomogeneity of the data does not have a considerable impact on the domain-averaged value. Generally, the heavy rainfall frequency increases suddenly around the mid–late 1970s and

 

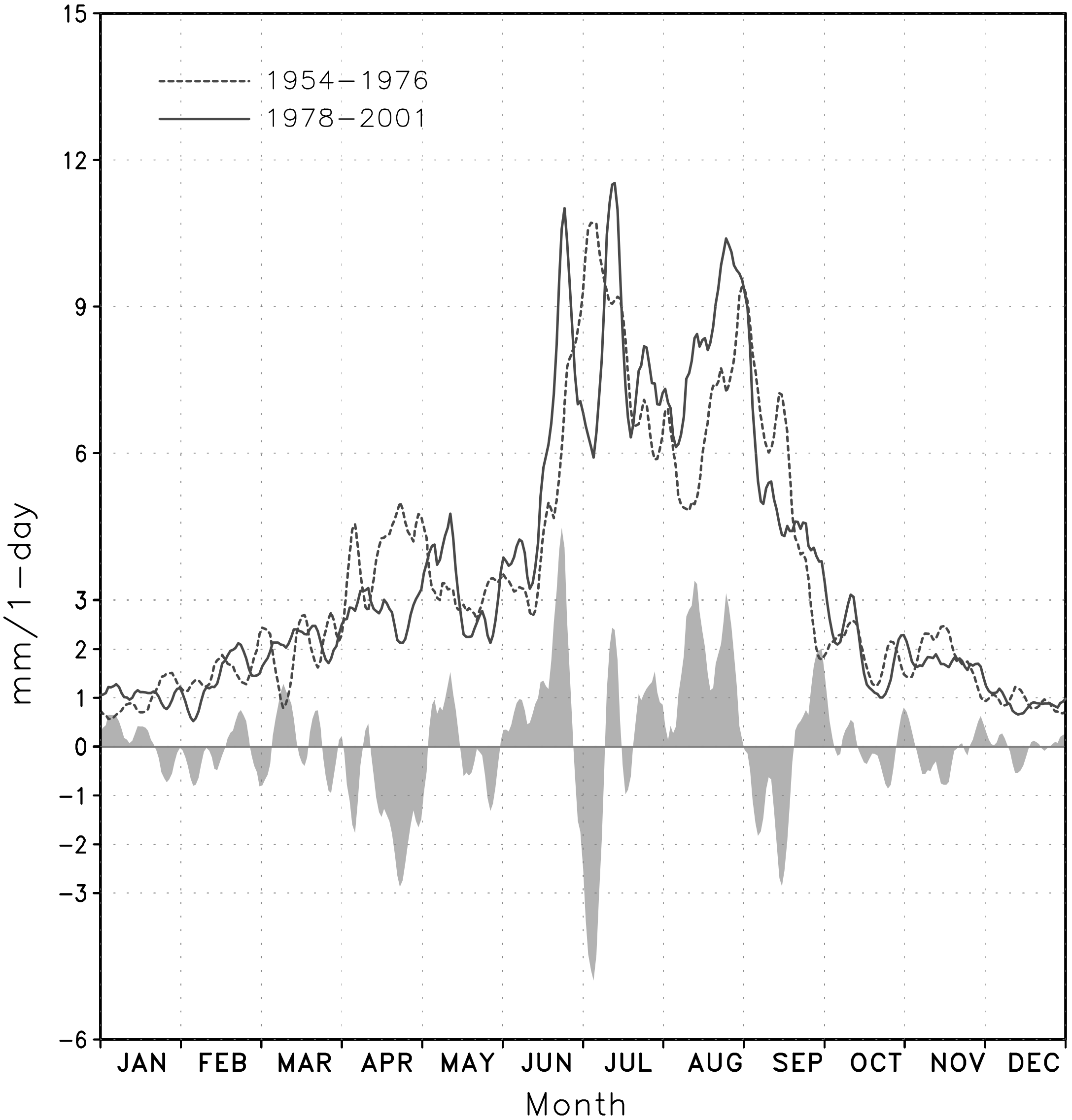


Figure 3. Time series of two sets of 5-day moving average precipitation climatologies. One is taken from 1954 to 1977 (dashed line) and the other from 1978 to 2001 (solid line). The difference of the two climatologies (1978–2001 minus 1954–77) is shown by the shaded area

the summertime dry spell becomes shorter at most stations. The changes are more significant in the southern part of Korea.

### *3.2. Changes in the surface temperature and $\Phi_{700}$ over the Asian continent*

While the global-mean surface temperature indicates a clear warming trend since the 1950s, the summertime surface temperature over East Asia shows a cooling trend (Yatagai and Yasunari, 1994; Nitta and Hu, 1996). Yatagai and Yasunari (1994) showed that the absolute value of the cooling trend is larger than 0.4 °C decade$^{-1}$ in northern and central China. The present study also shows that the domain-mean surface temperature anomaly within northern China and Mongolia (35–45 °N, 90–110 °E) has a clear discontinuity (Figure 4(a)). The anomaly in the surface temperature shows a sudden drop in the late 1960s rather than a continuous drop

 

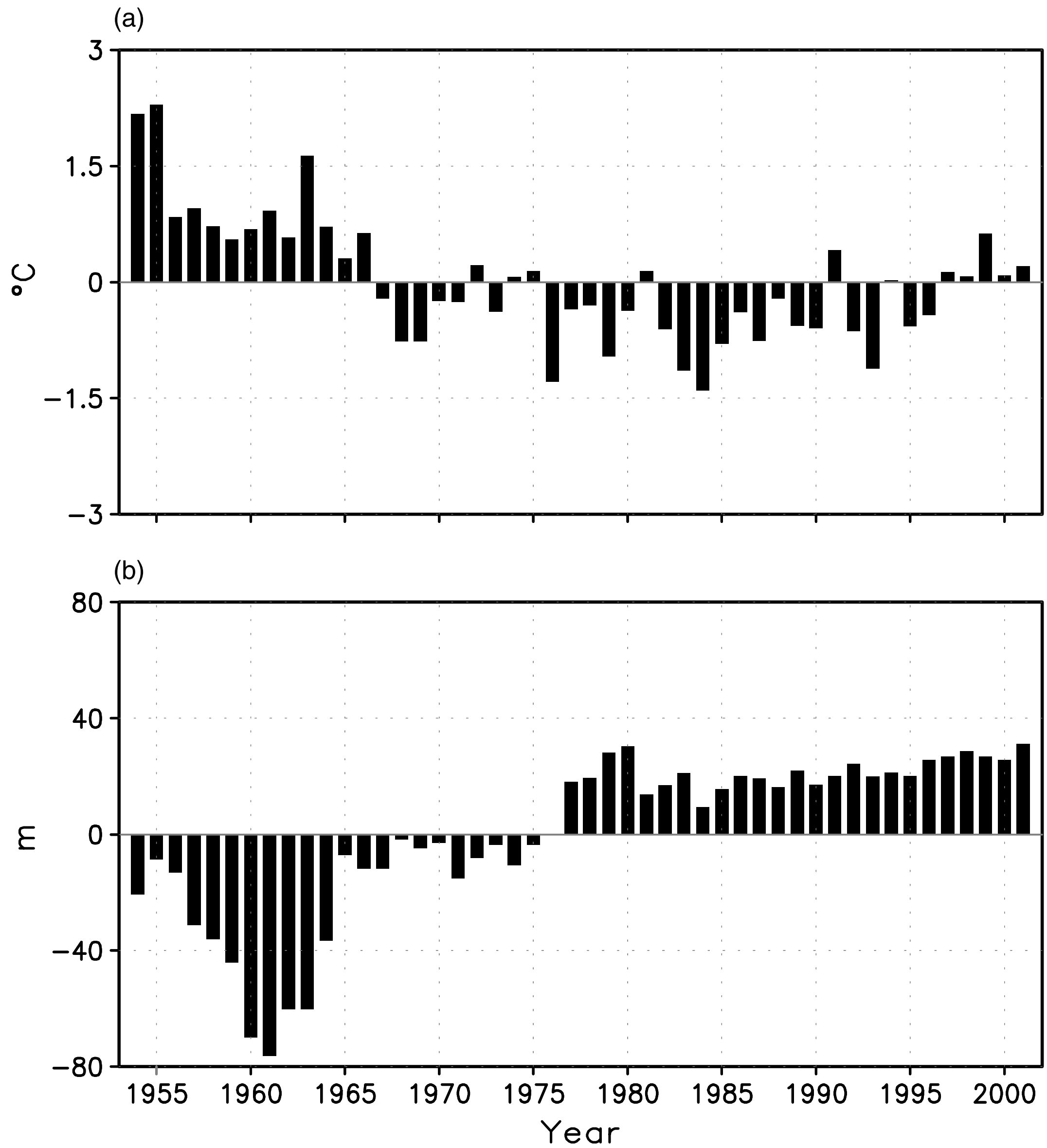


Figure 4. Same as in Figure 1, except for domain-mean surface air temperature within 35–45 °N, 90–110 °E (a), and geopotential height at 700 hPa within 30–50 °N, 60–120 °E (b)

during the whole period. Here, it should be noted that, as the current study uses the reanalysis data, there is a possibility that the magnitude of the trend differs from that obtained from the actual observation data.

The corresponding $\Phi_{700}$ variation averaged over East Asia in the mid-latitudes (30–50 °N, 60–120 °E) is shown in Figure 4(b). In contrast to the surface temperature anomaly, the $\Phi_{700}$ anomaly shows a sudden jump in the early 1970s. A simple conceptual model could explain this negative correlation between surface temperature and $\Phi_{700}$. As the decrease of surface temperature is equivalent to the increase of the sea-level pressure due to the increased air density, it introduces an anomalous sinking motion and leads to the increase of $\Phi_{700}$. However, on the other hand, it should be mentioned that surface cooling might also result in a decrease of the thickness of the lower troposphere, resulting in the decrease of $\Phi_{700}$. Also, it is interesting to note that the zonal-mean of $\Phi_{700}$ within 30–50 °N excluding the Asian continent does not show such a sudden increase (result not shown). Thus, we conclude that the increase of $\Phi_{700}$ is mainly a result of changes in the Asian continent and surrounding regions. Further explanation will be presented later in this paper in association with the changes in vertical motion at 500 hPa.

To examine the spatial structure of the surface temperature and $\Phi_{700}$ changes, in particular over the Asian continent, we show the difference of the two values between the two intervals (1978–2001 minus 1954–77) in Figure 5. Similar to the domain-mean changes, the spatial difference of the surface temperature shows large negative values, up to $-2\,^{\circ}$C, over northwestern China and Mongolia (Figure 5(a)). There is a vast area of negative difference (shaded area in the figure) over mid-latitude central Asia and the northwestern Pacific Ocean. Overall, the difference of $\Phi_{700}$ (Figure 5(b)) is negatively correlated to that of the surface temperature in East Asia. The centre of the positive $\Phi_{700}$ difference is located over Mongolia, reaching up to 70 m. As for long-term average trends, in the lower troposphere, a thermal low is located over the Asian continent, while the subtropical high is located over the mid-latitude western Pacific, which is the main feature of the East Asian summer monsoon. Thus, the combination of a large increase of geopotential height over land and the insignificant increase of geopotential height over the ocean indicates the weakening of the East Asian monsoon circulation in a global context (Chen *et al*., 1992).

The vertical distribution of the geopotential height, averaged within 30–50 °N, also shows broad positive values, except for the upper troposphere near 120 °E (Figure 5(c)). In general, the difference has a barotropic structure below 600 hPa and a westward tilt with a height within the layer of 100–600 hPa. Large positive differences in the lower troposphere are mostly found over central-eastern Asia, similar to the $\Phi_{700}$ differences. The barotropic structure indicates that the geopotential height changes occur throughout the entire lower troposphere.

Recently, it has been indicated that the NCEP–NCAR reanalysis data has a problem in encoding surface and mean sea-level pressure into the assimilation system for the period 1948–67 (visit http://lnx21.wwb.noaa.gov/images/psfc/psfc.html for details). The impact of the encoding error was estimated by computing the difference between corrected and uncorrected simulations for July 1953. The error results in a negative bias of sea-level pressure, up to −2 hPa, in particular over northeastern China. Thus, some of the differences in surface temperature and geopotential height between the two intervals may arise from data problems. However, we possess observational evidence for the shift of surface pressure over East Asia in the mid 1970s. Kaiser (2000) examined station data sets over China for the period 1954–96 and found an indication of an increasing trend in surface pressure and a decreasing trend in the total cloud amount over much of China.

Although not the main purpose of the present study, we propose brief possible causes for the confinement to the Asian continent of the area of negative surface temperature and positive geopotential height in the lower troposphere as shown in Figure 5. The variation of the lower tropospheric geopotential height is highly correlated with that of surface temperature and sea-level pressure. As noted before, there is an apparent cooling trend of the surface temperature in Mongolia, which can be accounted for by deforestation and expansion of the arid area (Wang and Li, 1990; Xue, 1996), which may be associated with climate change. The deforestation increases the surface albedo, reflects more shortwave radiation, and leads to a decrease of the surface temperature over the domain. With the deforestation, the frequency of dust events may increase, resulting in an increase of the Earth's albedo by an increase of backscattered shortwave radiation. Also, there may be more outgoing longwave radiation due to reduced atmospheric moisture and cloud coverage.

To compensate for the surface cooling, an anomalous downward motion develops as a secondary circulation. The difference of vertical motion at 500 hPa ($-\omega_{500}$) between the earlier and the later intervals shows a clear sinking motion up to 30 hPa day$^{-1}$ over northern China and Mongolia (Figure 6(a)). Thus, we conclude that the adiabatic warming by the anomalous sinking motion mainly accounts for the lower tropospheric warming (positive anomaly of $\Phi_{700}$). The changes in sensible heat flux and latent heat flux also increase the geopotential height in the lower troposphere. Furthermore, the Asian continent is dynamically active during the summertime; thus, vigorous transient eddies enhance the mixture of energy in the lower troposphere, especially over the Asian continent.

As can be seen in Figure 6(a), the anomalous sinking motion in Mongolia will produce lower tropospheric convergence in central China, where an anomalous rising motion of $-\omega_{500}$ is developed. There are many

 

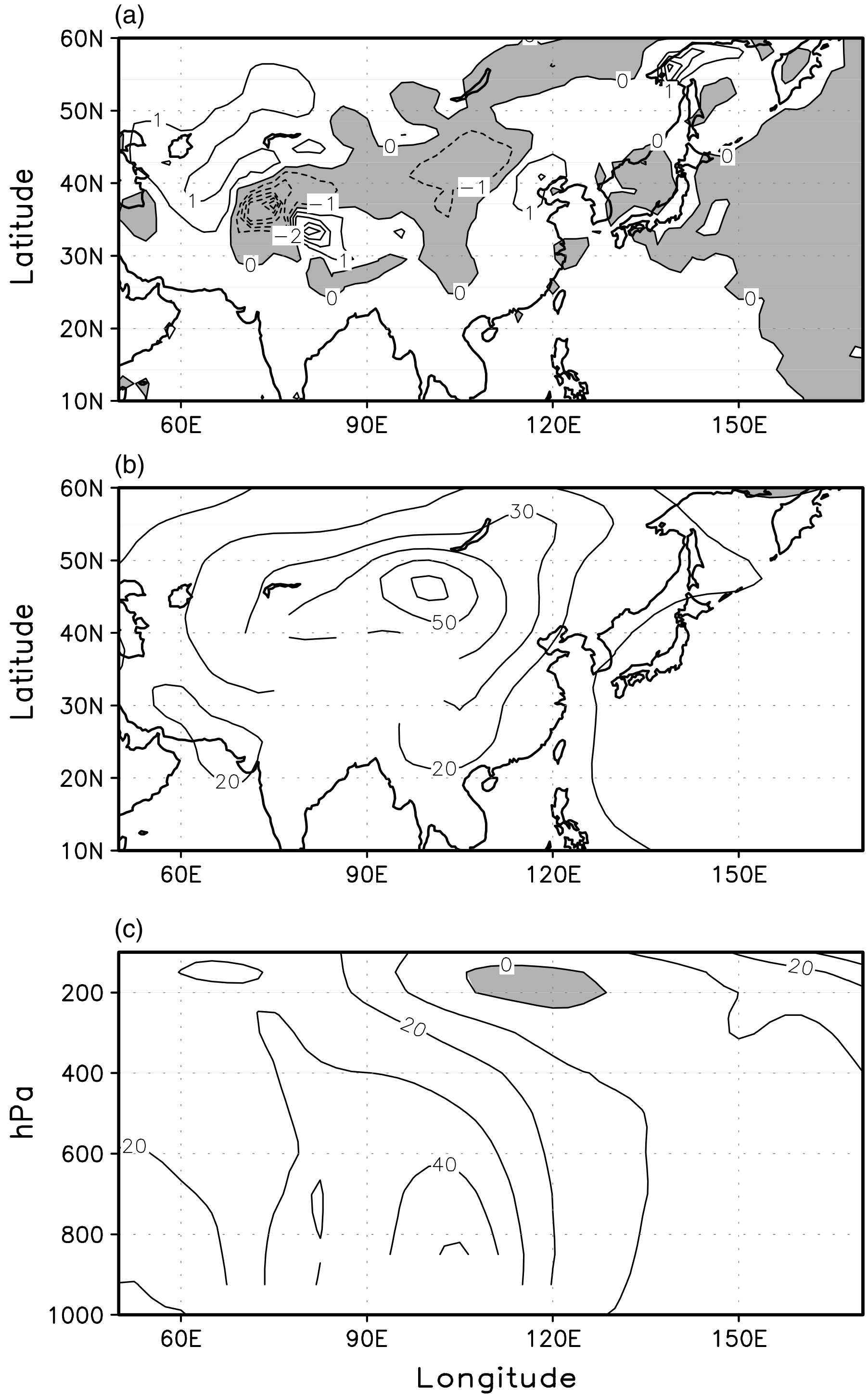


Figure 5. Difference of two sets of climatology (1978–2001 minus 1954–77) during summer for surface air temperature (a), geopotential height at 700 hPa (b), and vertical distribution of geopotential height averaged within 30–50 °N (c). Shading indicates negative values

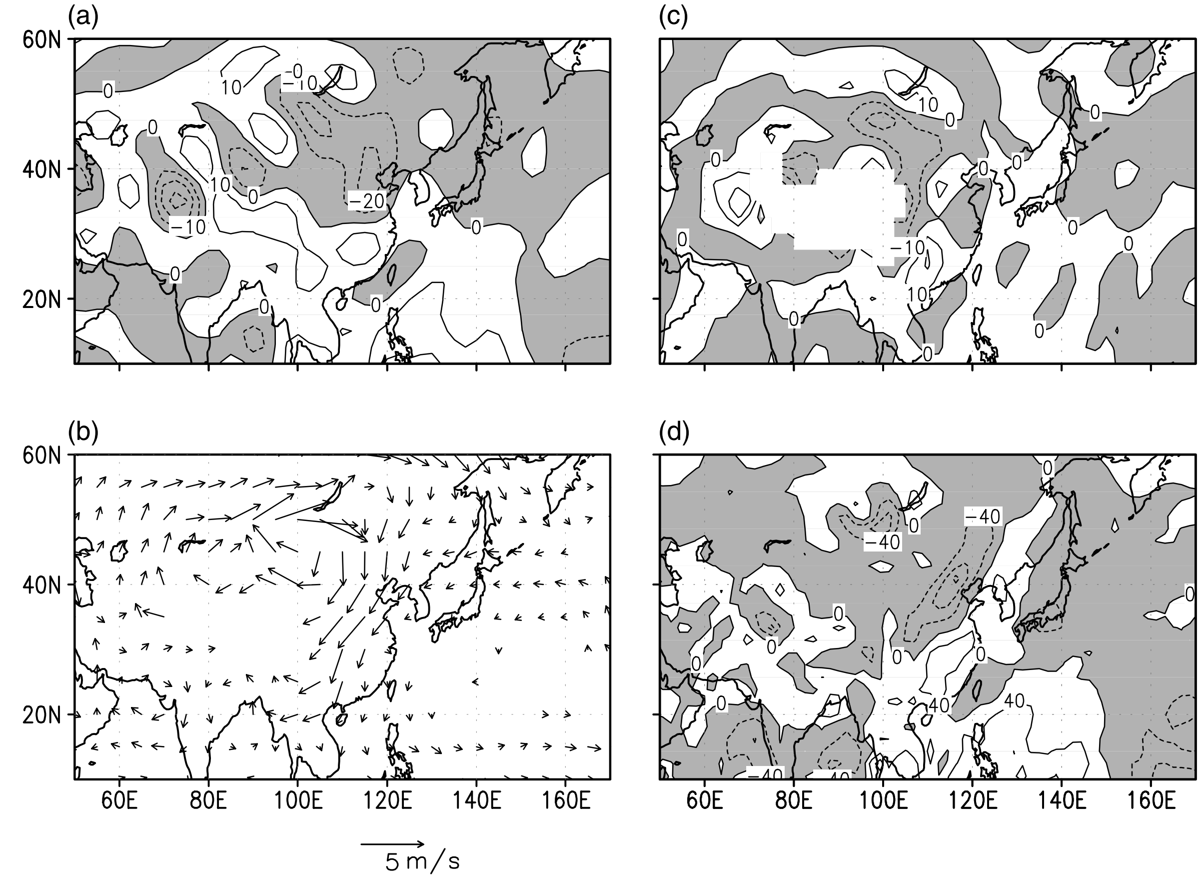


Figure 6. Spatial difference of two sets of climatology (1978–2001 minus 1954–77) during summer for the 500 hPa $\omega$ (a), 700 hPa horizontal wind (b), 700 and 850 hPa moisture convergence (c), and precipitation (d) obtained from NCEP–NCAR reanalysis. Shading indicates negative values

studies that have discussed the increase of summer rainfall in central China in recent years (Yatagai and Yasunari, 1994; Nitta and Hu, 1996; Gong and Ho, 2002). The rising motion induced by the subsidence in Mongolia may help to provide deeper convection and more rainfall over central China during the summertime.

### *3.3. Impact of changes in $\Phi_{700}$ over the Asian continent on Korean precipitation*

The sudden change in the geopotential height over a large area such as the Asian continent will modify global atmospheric circulations and lead to alteration of the East Asian summer monsoon circulation. As the summer precipitation in Korea is strongly connected to the East Asian monsoon system (Kang *et al*., 1999), it is natural to expect an alteration of the summer precipitation in Korea. In Sections 3.1 and 3.2 we show a clear indication of a sudden change both in the large-scale geopotential height and the local-area heavy rainfall frequency. Here, we try to understand the dynamical mechanism responsible, specifically the linkage between the variations of $\Phi_{700}$ over the Asian continent and precipitation in Korea.

As mentioned above, the East Asian summer monsoon is principally maintained by the temperature contrast between the warmer continent and cooler oceans. The decreased thermal contrast during the later interval (large increase of $\Phi_{700}$ over the Asian continent and smaller increase over the northwestern Pacific Ocean) certainly produces an enhanced anomalous anticyclonic circulation centred on central-eastern Asia.

To see whether there is any change in the circulation pattern in the lower troposphere for the period, we plot the difference of horizontal wind, moisture convergence in the lower troposphere, and precipitation from

 

NCEP–NCAR reanalysis between the two intervals (Figure 6(b)–6(d)). Indeed, the figures show a much stronger northerly flow over the eastern part of the Asian continent in the later interval and a small difference over the adjacent oceans (Figure 6(b)). The difference in moisture convergence at 850 and 700 hPa shows an increase of moisture convergence over Korea and central China in the later interval (Figure 6(c)). Thus, this anomalous circulation is related to the enhanced rainfall during summer in Korea. However, it is very hard to estimate how much of the precipitation changes in Korea are the result of the moisture convergence. Further, although moisture convergence indicates frequent synoptic disturbances over the region, it does not directly lead to increased precipitation. For an alternative estimation of the influence of moisture convergence on precipitation change, we show total summer rainfall differences from NCEP–NCAR reanalysis (Figure 6(d)). Overall, the changes in moisture convergence and precipitation demonstrate quite a similar spatial distribution. Thus, we conclude that the enhanced moisture convergence accounts for much of the increased precipitation in Korea.

Although the simple mechanism proposed can explain the possible linkage between changes in $\Phi_{700}$ and Korean precipitation during summer, it does not completely explain why the increase in the precipitation is significant only in August. During the primary and secondary rainy periods, a zonally elongated frontal zone is frequently sustained for longer than 1 week over the whole of East Asia. Since the frontal zone is characterized by massive convective activity, the northerly wind superimposed on the southerly flow may not exert a significant impact on the precipitation amount during the rainy periods. However, during the dry spell in August, the superimposed northerly wind escalates atmospheric instability and leads to deep convection. Also, the northerly anomaly in August is related to the speed of the seasonal southward shift of low-level circulation systems. In August, the rainy belt climatologically shifts to the north of the East Asian summer monsoon region. The rapid shift means a longer rainy season and more rainfall for the month of August in Korea.

## 4. CONCLUSION

The present study reveals that the domain-mean of $\Phi_{700}$ within central-eastern Asia has a sudden increase during the Northern Hemisphere summer in the mid 1970s. The domain-averaged summertime precipitation over Korea also shows more frequent heavy summer rainfall in recent years. To examine the changes in Korean precipitation over long-term time scales, the whole period of 1954–2001 is divided into two intervals centred on the late 1970s: 1954–77 and 1978–2001. In both intervals, two well-defined rainfall peaks are found for summertime. During the earlier interval, primary and secondary peaks are found in early July and early September respectively. In the later interval, on the other hand, the secondary rainy season starts earlier, implying an increase (decrease) of the rainfall for the month of August (September). It is mainly accounted for by the increased occurrence of heavy rainfall ($\geq$30 mm day$^{-1}$) events. Similar changes are found in the primary rainy season, but they are not significant.

Consistent with the sudden increase of the domain-mean $\Phi_{700}$ in the mid 1970s, the spatial difference of $\Phi_{700}$ between the two intervals indicates that the geopotential height is higher than the earlier interval over the whole of Asia. Interestingly, however, most large positive differences ($\geq$30 m) are confined to central-eastern Asia in the mid-latitudes. The vertical difference of the geopotential height portrays a barotropic structure below the level of 600 hPa; thus the entire lower troposphere shows the same sudden increase. Some of the increase of geopotential height may be explained by the encoding error of surface pressure into the NCEP–NCAR assimilation system. However, observational evidence strongly supports the increase of surface pressure in the mid 1970s associated with surface cooling (Yatagai and Yasunari, 1994; Nitta and Hu, 1996) and the decrease of the total cloud amount over much of China, particularly in summer (Kaiser, 2000).

The increased geopotential height over the Asian continent leads to a strengthening of the anticyclonic circulation anomaly in the later interval. Therefore, a northerly wind is enhanced in East Asia along the eastern boundary of the anticyclone. The northerly wind transports relatively cool and dry air to East Asia. It later superimposes on the prevailing southerly wind that is warm and moist. In this case, moisture convergence and convective activity would be intensified, and thus might increase the chance of heavy rainfall. The enhanced deep convection results in the increase of Korean summertime precipitation.

 

Finally, we postulated a simple dynamical linkage between the sudden increase in the geopotential height in the Asian continent and the gradual increase in Korean rainfall. However, it is not clearly understood why the variation of rainfall does not follow such a sudden increase in the mid 1970s similar to the geopotential height in the lower troposphere. There could be a more complicated dynamical and physical mechanism responsible for their linkage. The changes in sea-surface temperature on an interdecadal time scale may constitute one possible cause.

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