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Circulation changes associated with the interdecadal shift of Korean August rainfall around late 1960s

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[1] The impacts of local/remote thermodynamic conditions and large-scale circulations on the timing of the peak rainy season shift over the Korean Peninsula are investigated. The Korean August rainfall is strongly associated with the westward expansion of the western North Pacific subtropical high and the presence of the Bonin high. The westward expansion of the subtropical high is primarily associated with the teleconnection due to the energy propagation of the stationary Rossby wave along the Asian jet from the upstream region. The enhanced north-south thermal gradient plays an important role in modulating the interdecadal change in the East Asian jet stream, which in turn increases the August rainfall. Both the July and August rainfall are influenced by the interdecadal variability in upper-level temperature and Asian jet stream, which are significantly associated with the dynamical circulation change after the late 1960s. However, the influence on the July rainfall seems to be offset by the impact of a predominant Pacific-Japan pattern, whereas the August rainfall is affected by a strong Eurasian wave-like pattern.

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1. Introduction

[2] Previous studies have noted that the summer rainfall in Korea increased substantially after 1977–78 [*Ho et al.*, 2003; *Cha et al.*, 2007; *Wang et al.*, 2006]. *Kwon et al.* [2007] demonstrated a climatic shift of summer mean precipitation in the mid-1990s, which might be related to the change in the number of typhoon passing through Southern China. By analysis of a long-term 230-year record in Seoul rainfall *Ha and Ha* [2006] showed that the seasonal variation in subseasonal timescale is more important for explaining the interannual variability and climate change than the annual mean, which poses the increase of "August rainfall" in terms of EOF analysis. *Wang et al.* [2007] found that the amplitude of the interannual (2–6 years) variation of summer precipitation shows a prominent fluctuation with a 50-year rhythm.

[3] The Changma in Korea is responsible for the late June–July rainfall, which is similar to the Meiyu and Baiu [*Ha et al.*, 2005]. The July rainfall is mainly characterized by the northward evolution of the summer monsoon frontal rainband. On the other hand, the August rainfall originates from the complex atmospheric precipitation mechanisms such as direct and indirect effects of typhoons, mesoscale complex systems, and thunderstorms. Despite of the different characteristics from the July rainfall, the August rainfall has not been focused in most precipitation studies. In this study, we focus on the interannual and interdecadal variability in August rainfall.

[4] A number of studies for climate change in the summer rainfall have emphasized a trend toward decreased or increased precipitation. For example, *Quan et al.* [2003] found a decreased trend over northeast China, and reported its remote association with the persistent dryness in the sub-Sahel region of Africa. *Wang et al.* [2007] with a long-term data based on one station over Korea found that the season summit in rainfall shows a delayed occurrence from Changma season to post-Changma season. Those results show that there are changes in a subseasonal variation or a peak shift in an intraseasonal timescale in precipitation. However, there are lacks of finding in a significant change for a subseasonal timescale. Moreover, understanding of the dynamical link associated with the climate change in peak shift is required. The present study investigates the change in subseasonal timescale precipitation and attempts to describe the dynamical circulation change as a possible mechanism.

2. Data and Method

[5] To understand the long-term variability in Korean rainfall, we used two precipitation data sets obtained from the Korean Meteorological Administration (KMA) from 1912 to 2006 and the Climate Research Unit (CRU) from 1901 to 2002. Five synoptic stations which operated

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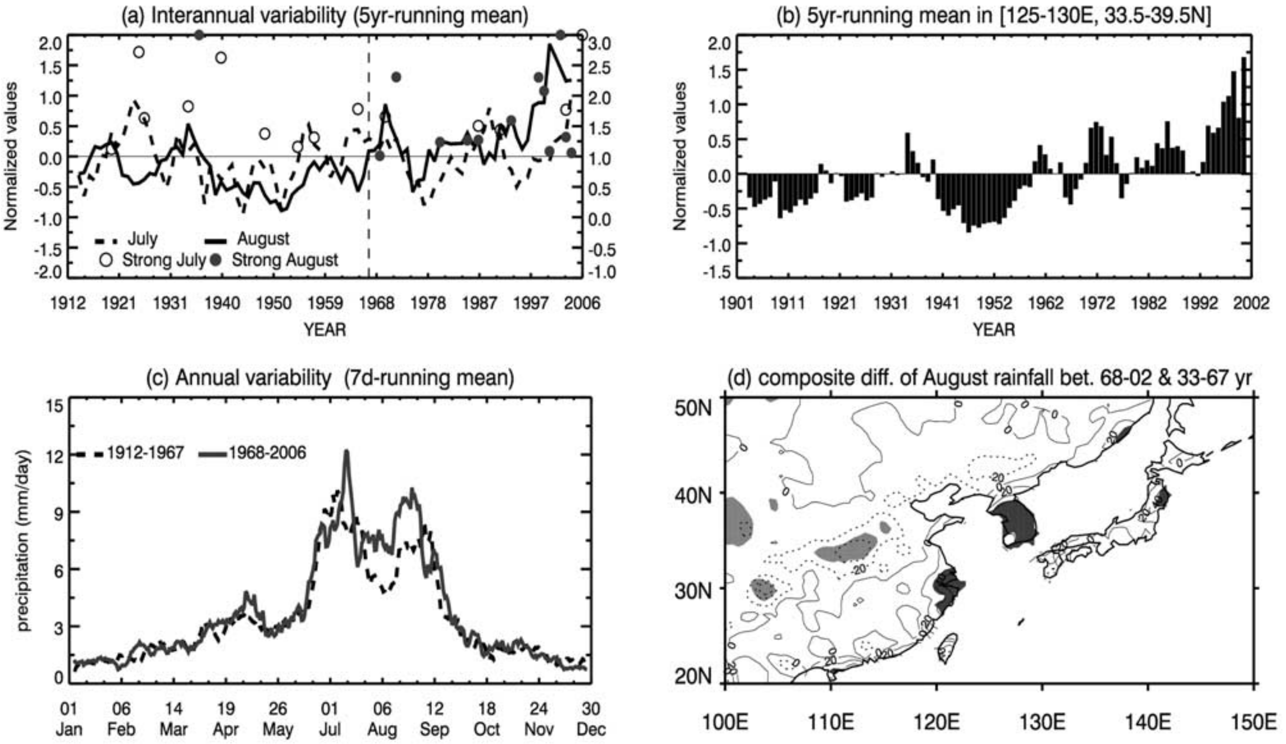


(a) Interannual variability (5yr-running mean)

(b) 5yr-running mean in [125-130E, 33.5-39.5N]

(c) Annual variability (7d-running mean)

(d) composite diff. of August rainfall bet. 68-02 & 33-67 yr

Figure 1. (a) Interannual variability of the 5-year running average for the July and August rainfall from five synoptic stations. The open (closed) circles indicate the July (August) rainfall when the normalized value for the climatology from 1912 to 2006 is greater than 1.0 standard deviation (right axis), and the perpendicular dashed line denotes the change point (1967) of the August rainfall. (b) Interannual variability of the 5-year running average for the August rainfall from CRU averaged over the Korea region [125°–130°E, 33.5°–39.5°E]. (c) The temporal variability of the 7-day running averaged rainfall during 1912–1967 (black dashed line) and during 1968–2006 (gray solid line). (d) The composite difference of the August rainfall obtained from CRU data between the periods of 1968–2002 and 1933–1967. The heavy (light) shading indicates the positive (negative) anomalies significant at the 95% confidence level.

consistently from 1912 to present were selected for the analysis: Gangneung (37.73°N, 128.88°E), Seoul (37.56°N, 126.96°E), Daegu (35.87°N, 128.62°E), Busan (35.10°N, 129.03°E), and Mokpo (34.80°N, 126.38°E).

[6] First we considered the detection of climatic change over the long-term record. We used the *Pettitt* [1980] test, which is a nonparametric method for detection of change in the median of the sequence of observations and a stout test of the change point resistant to outliers. The Pettitt test [*Ha and Ha*, 2006] was applied to the detection of precipitation. For the July and August precipitation, the Pettitt test was performed with a significance level of 1%.

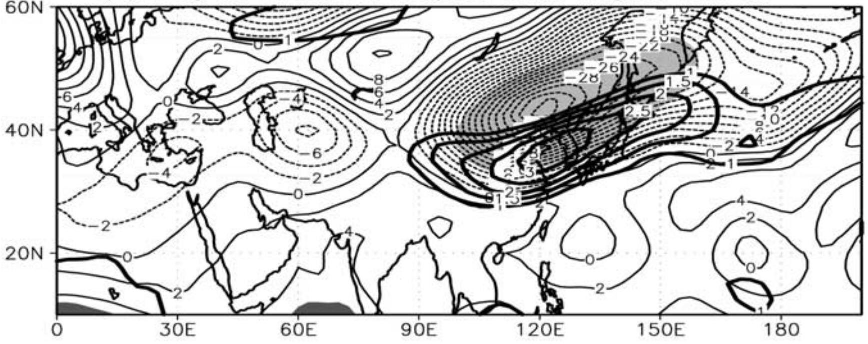
[7] The composite and regression analysis for the circulations are carried out to find the association with the large-scale environment with the use of the National Center for Environmental Prediction/National Centers for Atmospheric Research (NCEP/NCAR) reanalysis data (hereafter NCEP) from 1948 to 2006 (59 years) [*Kalnay et al.*, 1996] and European Centre for Medium-range Weather Forecasts (ECMWF) Reanalysis (ERA-40) data from 1958 to 2001 (44 years) [*Uppala et al.*, 2005].

[8] In the present study, the findings are mainly shown by the NCEP reanalysis data (i.e., Figures 2, 3, 5, 6, 8, and 9) because of a longer data record. We have found that the result from NCEP is remarkably consistent to that given by ERA-40 data for the upper-level circulation, even though it was reported that the NCEP reanalysis data have some errors at lower-level variables before 1979 [*Inoue and Matsumoto*, 2004].

3. Change of August Precipitation Around 1967

[9] To investigate the long-term variability of rainfall, the interannual variability of 5 year running averaged rainfall for July and August is shown in Figure 1a. While the July rainfall does not exhibit any significant change trend with the interdecadal oscillation, the August rainfall follows an increase trend after 1960. The most significant change point for the August rainfall is found in 1967. The change point in August rainfall corresponds to the global climate shift in the late 1960s shown in the studies of *Quan et al.* [2003] and *Baines and Folland* [2007]. Interestingly, the interdecadal change to a trend of decreased precipitation in northeast China started in the late 1960s [*Quan et al.*, 2003]. A number of studies [*Trenberth and Hurrell*, 1994; *Zhang et al.*, 1997] have shown that the eastern tropical Pacific Ocean has become warmer beginning around the mid-1970s. The difference in the timing of the two changes

(a) Reg of Z200hPa August onto August rainfall



(b) Reg of Z500hPa August onto August rainfall

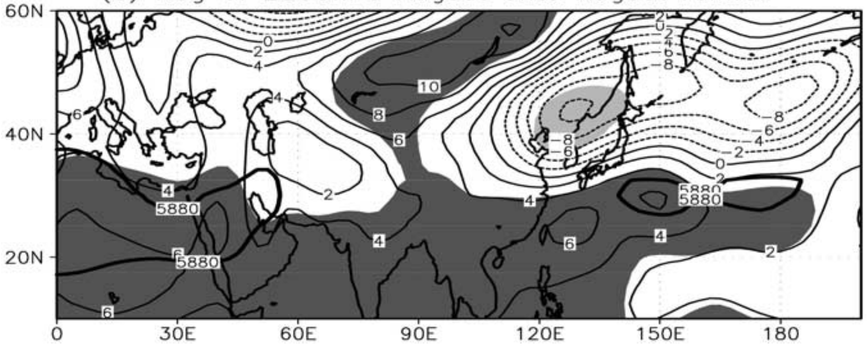


Figure 2. (a) Regression of the August 200-hPa geopotential height against the August rainfall anomalies. The thick solid line denotes the regressed 200-hPa U-wind anomalies greater than 1.0 onto the August rainfall anomalies. (b) Regression of the August 500-hPa geopotential height against the August rainfall anomalies. The thick solid line indicates the climatological distribution of 5880 m. (a, b) The shading indicates the values significant at the 95% confidence level.

suggests that the changes in regional precipitation shown in this study were not initially forced by the changes of the Pacific SST. In order to see the details of this change, extreme July and August rainfall years are displayed (Figure 1a). A "strong wet event" is identified as values greater than 1.0 standard deviation of the rainfall, for July and for August means. It highlights distinct characteristics before and after the change point of August rainfall. Most of the strong August rainfall events occur after 1967, while the strong July rainfall events occur mainly before 1967. The change in annual structure is also investigated from 1912 onward (Figure 1c). There are two subsequences (1912–1967 and 1968–2006), before and after the change point.

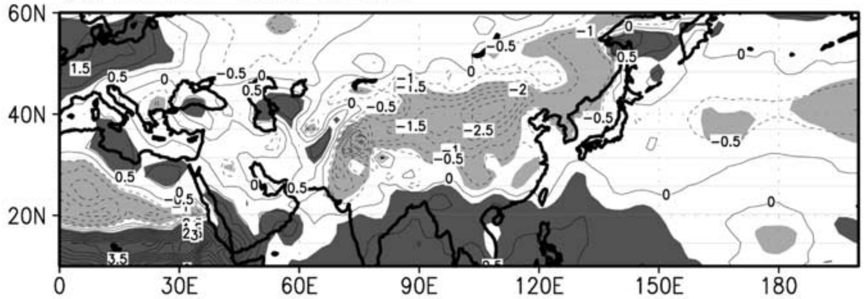
[10] Such a rainfall change in August can be represented by CRU precipitation data from 1901 to 2002 years. The composite analysis of August rainfall between each 35 years before and after the change point shows a significant increase in precipitation over the Korean Peninsula (Figure 1d). Along the continental boundary of East Asia, positive rainfall anomalies appear. The negative anomalies appear over the west of the positive rainfall anomalies. The anomalies structure is slightly tilted toward the northwest of the increased rainfall. The 5-year running average, spatially averaged over the Korean Peninsula (i.e., 125°–130°E, 33.5°–39.5°N), is also an evidence for the increasing August rainfall. The correlation coefficient of August rainfall obtained from synoptic stations (Figure 1a) and CRU data (Figure 1b) exhibits a high correlation of 0.92. In the following section, we will investigate the change in circulations before and after the change point shown in Figure 1a.

4. Characteristics of the 1967 Change in Circulations

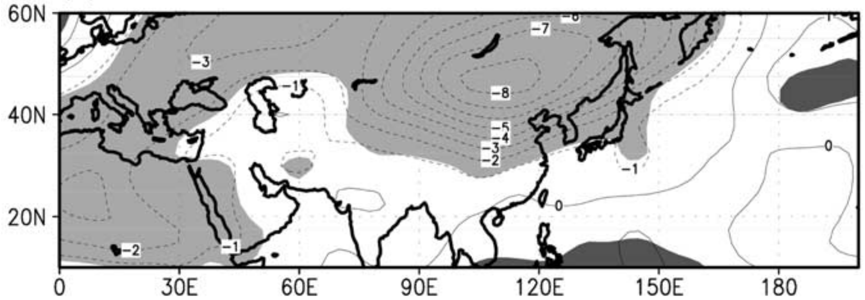
[11] In this section, we investigate the circulation changes corresponding to the August rainfall anomalies. Figure 2 shows the regression of the August 200-hPa and 500-hPa geopotential height anomalies against August rainfall anomalies. The anomalies exhibit an equivalent barotropic structure with the amplitude increasing with height. In particular, at the upper level (200 hPa), the height anomalies coincide with strong zonal wind anomalies (shown by the thick solid line in Figure 2a). Note that the Asian jet plays an important role as a waveguide for stationary Rossby wave. *Enomoto et al.* [2003] emphasized that the Silk Road teleconnection is most apparent in August, which is consistent with the August rainfall change. This suggests that the interannual variability of August rainfall is significantly related to a stationary Rossby wave over the Asian jet stream. On the occasion of the 500-hPa height the anomalies show a well-defined wave (Figure 2b), the high-pressure anomalous pattern over the south of Japan is distinguished from the western North Pacific (WNP) subtropical high (shown by thick solid line in Figure 2b). As hinted in *Ha and Lee* [2007] during the retreat of Changma, the westward extension of the WNP high is probably responsible for the "Bonin high" as found in previous

Composite diff. bet. 68–06 & 48–67 (August)

(a) Surface Temp at 2m



(b) 500hPa–200hPa Thickness



(c) 200hPa UWND

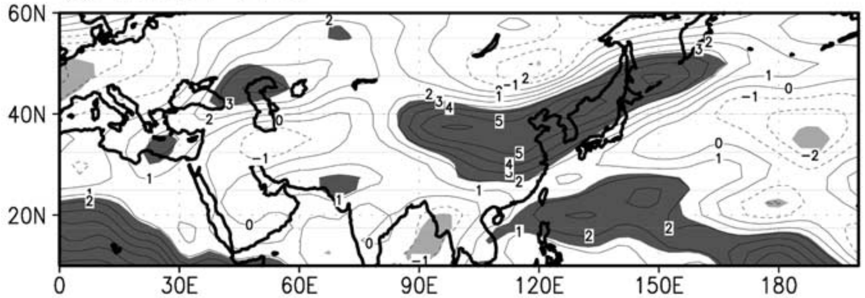


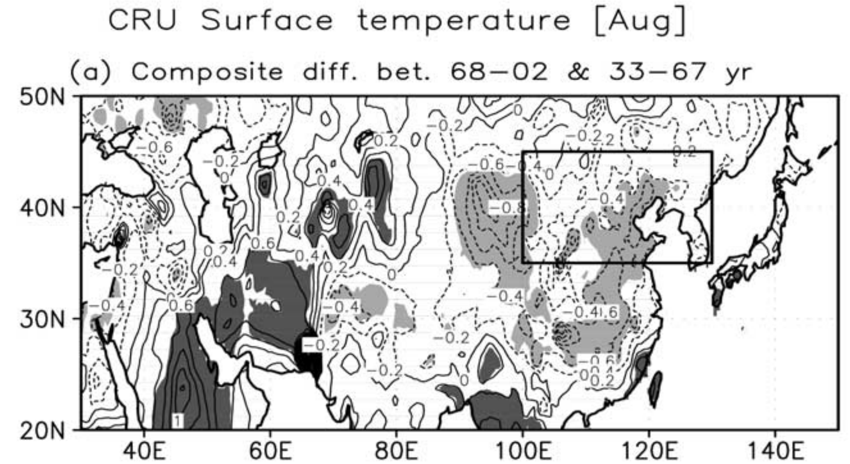
Figure 3. Composite difference of the August (a) surface temperature at 2 m (°C), (b) thickness between 500 and 200 hPa (dam), and (c) 200-hPa U-wind (m/s) between two periods for 1948–1967 and 1968–2006. The shading indicates the values significant at the 95% confidence level.

studies [e.g., *Enomoto et al.*, 2003]. This hypothesis can be also supported by the composite analysis of 500-hPa geopotential height anomalies for the strong and weak August rainfall years (not shown).

[12] In the previous studies [*Lu*, 2004; *Zhou and Yu*, 2005], the importance of the East Asian jet stream (hereafter, EAJS) has been emphasized for the circulation change in the interannual variability in late summer rainfall. To investigate the relation between EASM and EAJS, we have composited the surface temperature, 500-hPa–200-hPa thickness, and 200-hPa U-wind anomalies between, before and after 1968 (Figure 3). Significant cooling covers a large area of the Eurasian continent (Figure 3a). The tropospheric cooling trend was firstly reported by *Yu et al.* [2004], with the East Asian summer monsoon weakening over the north China. In the present study, it is also found that warming occurs over the western Pacific and Indian Ocean (Figure 3a). The thermal change is very significant in terms of the upper-level (i.e., 500 hPa–200 hPa) thickness. Consequently, the enhancement of the north–south temperature gradient in the upper levels induces the enhancement of the EAJS through the thermal wind balance [e.g., *Zhang et al.*, 2006; *Yu and Zhou*, 2007]. In particular, the enhancement of EAJS is dominant in its exit region (i.e., 100°E–150°E). Eventually this enhancement corresponds to the spatial structure in the regressed U-wind anomalies against the August rainfall (Figure 2a). This U-wind anomaly implies a southward shift of the EASJ, which is probably important for the increased rainfall over Korea.

[13] To convince the main finding in Figure 3, we used the surface air temperature at 2 m given by CRU. Figure 4 represents the composite difference of the surface temperature between 35 years before and after 1968. It shows good agreement with the structure in Figure 3a. The cooling trend is evidently shown in the interannual variability averaged over the region [100°E–130°E, 35°N–45°N] (Figure 4b). After late 1950s, the cold anomalies appear and it is remarkably clear in the period after late 1960s.

[14] The vertical structure of interdecadal change in EAJS can be approximated by a linear trend during 59 years of zonal wind and air temperature anomalies, as shown in Figure 5. In this calculation, the zonal wind and temperature



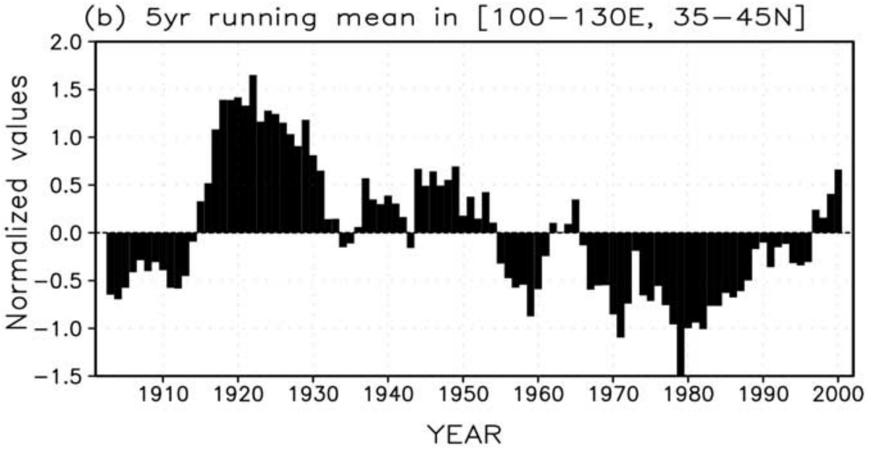


Figure 4. (a) The composite difference of the surface air temperature at 2 m obtained from CRU data between the periods of 1968–2002 and 1933–1967. The heavy (light) shading indicates the positive (negative) anomalies significant at the 95% confidence level. (b) The interannual variability of the 5-year running averaged anomalies averaged over the region [100°–130°E, 35°–45°E] shown by the box in Figure 4a.

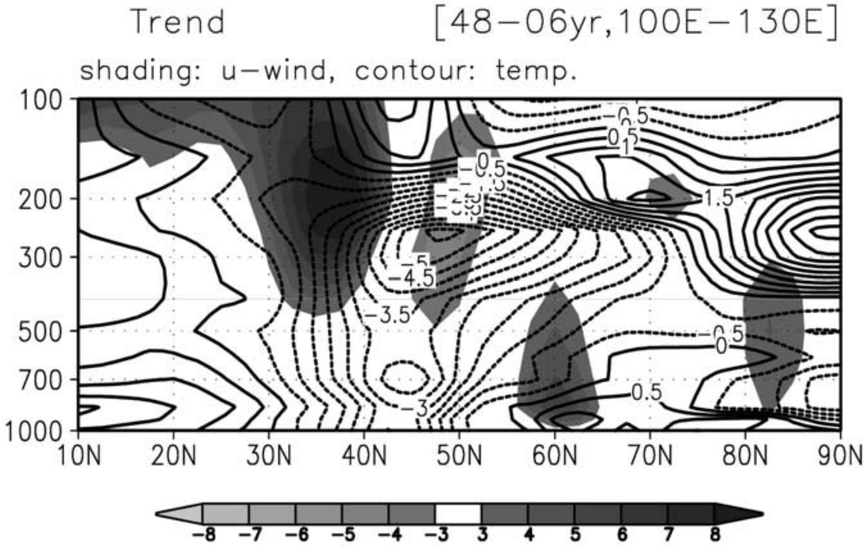


Figure 5. The linear trend of the vertical August air temperature and zonal wind during the period from 1948 to 2006. The shading indicates the trend of the U-wind (ms^{-1}/59 years) and the contour line denotes the temperature trend (°C/59 years).

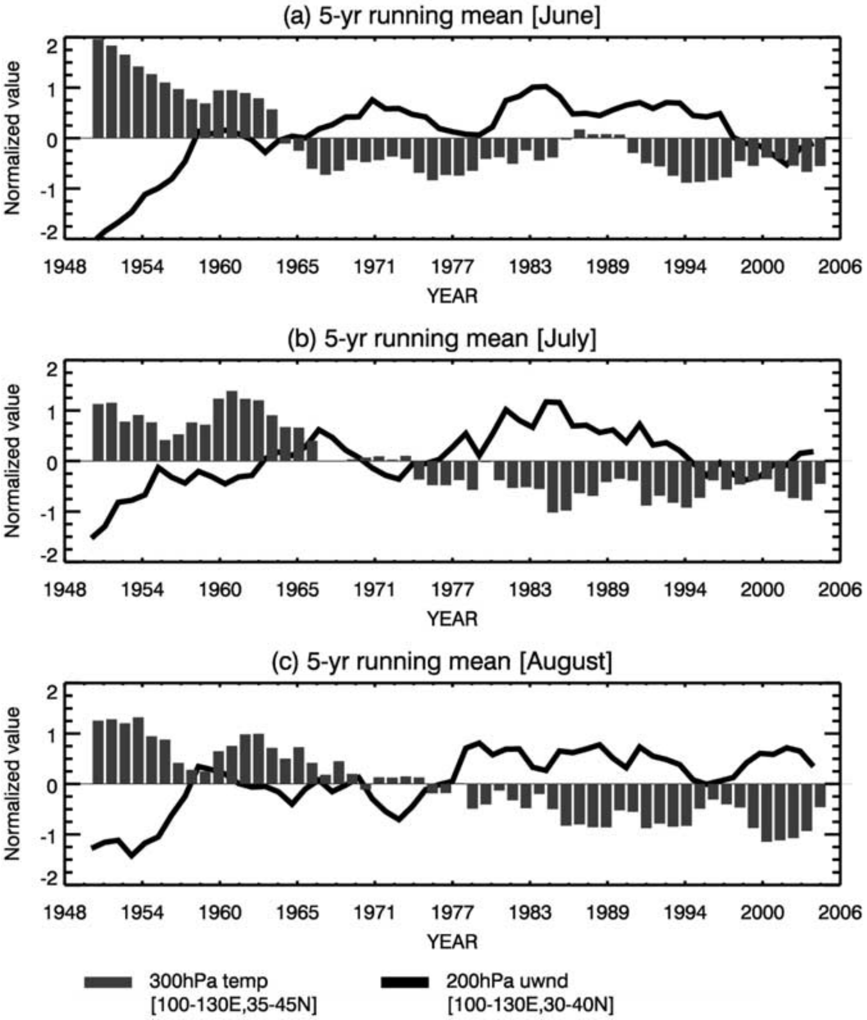


Figure 6. Interannual variability of the 5-year running average for the 300-hPa air temperature (bar graph) and for the 200-hPa U-wind (solid line) anomalies from NCEP reanalysis data during (a) June, (b) July, and (c) August, respectively.

anomalies were averaged over the longitudinal area between 100°E and 130°E. Associated with the strong thermal gradient (i.e., 35°N–45°N), the upper-level zonal wind anomalies from 30°N to 40°N become stronger. The change of intensity and displacement of the EAJS in boreal summer has been observed by *Yu et al.* [2004], *Yu and Zhou* [2007], and others. To examine the interdecadal change in the tropospheric cooling and strengthened EASJ with detail, we display the normalized year-to-year variability (Figure 6) of 300-hPa air temperature (T300) and 200-hPa U-wind (U200) anomalies averaged over the region with large variability as shown in Figure 5. From late 1960s to mid 1970s, the upper air temperature undergoes a significant interdecadal change. The upper troposphere temperature anomalies are evidently cooled after late 1960s, particularly during July and August. The upper zonal wind anomalies also exhibit a clear positive value after this period. The zonal wind anomalies roughly vary in opposite signal of the temperature anomalies. It should be noted that the interdecadal variability of T300 and U200 (Figure 6c) are in phase with that of the August rainfall (Figure 1b). This change is especially obvious during August.

[15] To validate the result obtained from NCEP reanalysis data, we also describe the interannual variability with the use of ERA-40 data (Figure 7). This shows an evident interdecadal change on the upper tropospheric cooling and enhanced EAJS. During all months (i.e., June, July, and August), the two time series in NCEP and ERA-40 data appear in highly correlation coefficients of above 0.93 for both T300 and U200. It reflects that NCEP reanalysis data reasonably represent the interdecadal trend. The interdecadal change in the temperature and circulation seems to happen in the late 1970s as well as in the late 1960s. In order to compare the two change points, we have composited the surface temperature, 500-hPa–200-hPa thickness, and 200-hPa U-wind anomalies between 1948–1978 and 1979–2006 (not shown). The result for the late 1960s (i.e., Figure 3) showed a stronger tropospheric cooling and westerly jet stream than that for the late 1970s, suggesting that the interdecadal change in temperature and zonal wind remarkably occurred in earlier period (i.e., late 1960s).

[16] Although the dynamical circulation change occurs in both July and August, the climate change on the Korean rainfall significantly appears in August, not in July. To

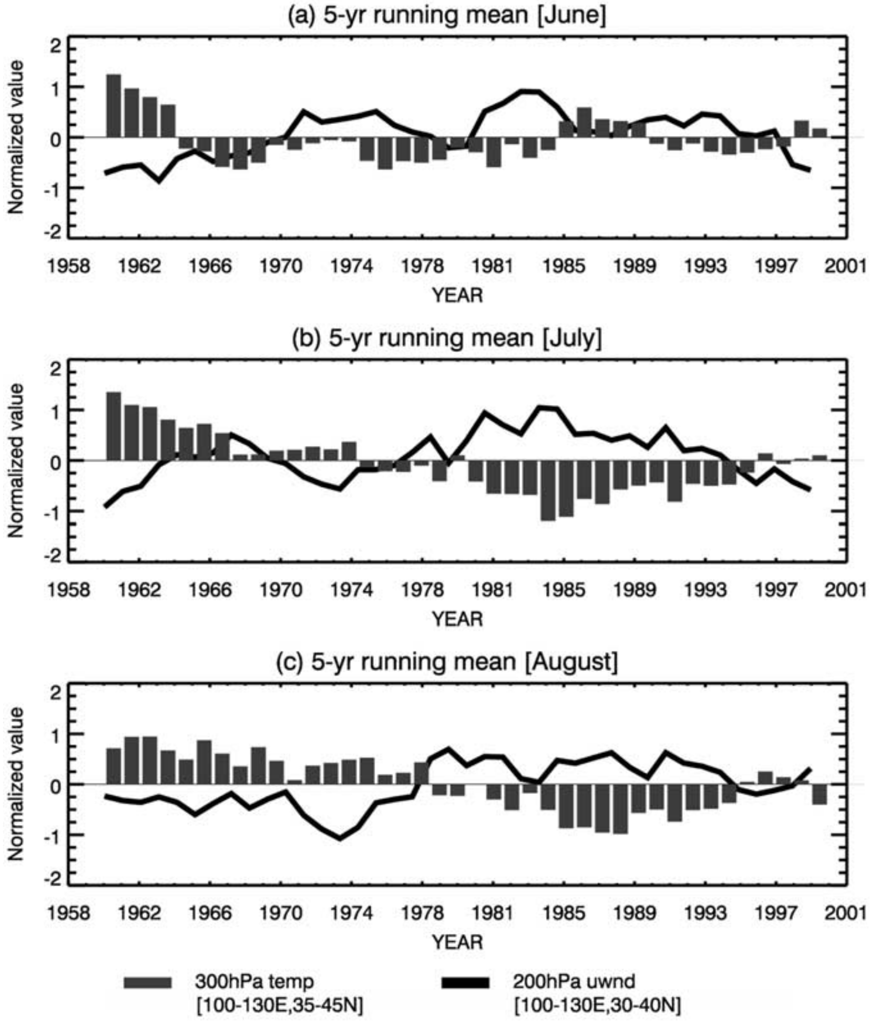


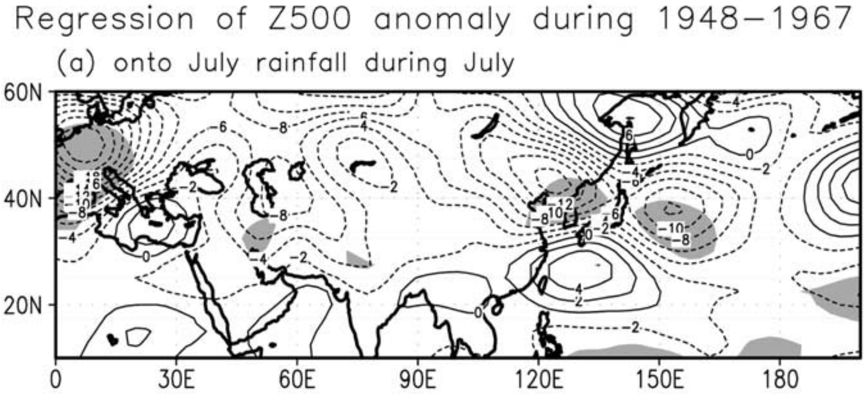
Figure 7. Same as Figure 6, except for the ERA40 data.

explore why the increasing rainfall trend occurs in August, we have separately performed the regression analysis of 500-hPa geopotential height anomalies onto July and August rainfall before and after 1968 (Figures 8 and 9). Before 1968, the regression of instantaneous 500-hPa geopotential height anomalies onto July rainfall shows a distinct wave-like structure, resembling the Pacific-Japan (PJ) pattern [*Nitta*, 1987]. As previously described by many monsoon studies, the EASM rainfall is affected by two standing wave trains [*Hsu and Lin*, 2007]: The former is related to the southwesterly monsoon flow (i.e., PJ pattern); the latter is affected by the upper-level westerly jet stream (i.e., extratropical Eurasian wave-like pattern). The Eurasian wave-like pattern (often referred to "Silk Road pattern") can be identified by using upper-tropospheric meridional wind [e.g., *Lu et al.*, 2002], while the PJ pattern is defined by using 850-hPa geopotential height anomalies [e.g., *Kosaka and Nakamura*, 2006]. Since this study analyzes the combined effect of both PJ pattern and Eurasian wave-like pattern in July and August rainfall, we used the 500-hPa geopotential height anomalies where include information for the two dominate wave-like patterns [*Lee et al.*, 2005]. The regressed patterns onto August rainfall show an insignificant signal with combined characteristics of the two standing wave trains (Figure 8b).

[17] However, as the EAJS is enhanced by the significant tropospheric cooling since 1968, the regressed structure against the August rainfall exhibits a clear Eurasian wave-like train (Figure 9b). In particular, the response of the height anomalies onto the August rainfall is considerably persistent from June to August (not shown). In the regressed those onto the July rainfall, the PJ pattern still has the preponderance over the extratropical Eurasian pattern, although the Eurasian wave-like characteristics after 1968 are somewhat stronger than before 1968. Consequently, the August rainfall may be controlled by the extratropical Eurasian wave-like pattern along the EAJS, while the July rainfall is locally associated with the southwesterly monsoon flow. It can be supported by the work of *Lee et al.* [2005], which showed that the PJ pattern is linked to the migration of EASM system and the Eurasian pattern is related to instability-type localized precipitation.

5. Discussion and Conclusions

[18] The August rainfall in Korea exhibits a significant increasing trend after late 1960s. The ENSO-related dynam-



(b) onto August rainfall during August

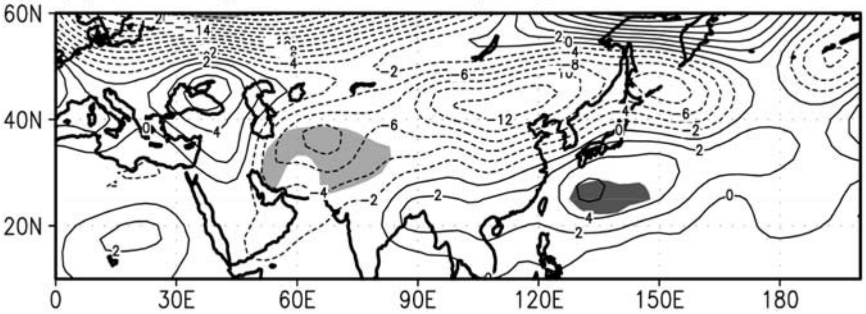
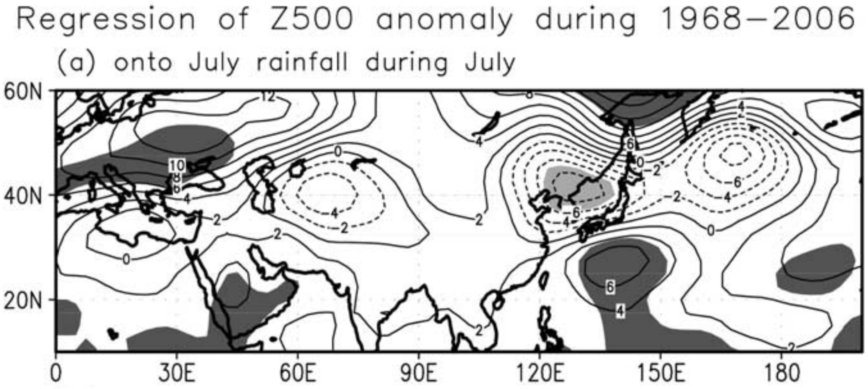


Figure 8. Regression of the (a) July and (b) August 500-hPa geopotential height anomalies against the (a) July rainfall and (b) August rainfall during the period from 1948 to 1967. The heavy (light) shading indicates the positive (negative) values significant at the 95% confidence level.

ical forcing after the mid-1970s, which is related to the Pacific decadal oscillation, is somewhat difficult to explain this interdecadal circulation change. We explore the dynamical circulation changes inducing the increase in August rainfall, using the NCEP/NCAR reanalysis data for 59 years. The August rainfall is strongly associated with the westward expansion of the WNP subtropical high and the position of the Bonin high which has an equivalent



(b) onto August rainfall during August

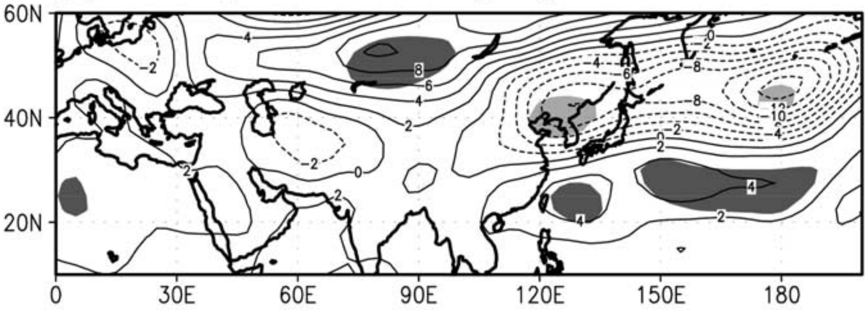


Figure 9. Same as Figure 8 except for the period from 1968 to 2006.

barotropic structure and is induced by the stationary Rossby wave along the upstream Asian jet [e.g., *Enomoto et al.*, 2003]. It was found that a significant interdecadal cooling is revealed in the East Asian region, and then the enhanced north–south thermal gradient induces a strong Asian jet stream.

[19] In the study of the boreal summer circumglobal teleconnection, *Ding and Wang* [2005] showed that the teleconnection patterns vary with calendar month especially over the pacific–North American sector because of changes in the jet stream structure. The July and August rainfall exhibits different dominant wave-like patterns, as well. Unlike July, the August rainfall is significantly affected by the Eurasian wave-like pattern. It is likely that a local air-sea-land interaction induces the distinctly different responses for July and August. That is, both July and August rainfall are affected by the interdecadal variability in the tropospheric cooling and enhanced EAJS. However, their influence on the July rainfall may be counterbalanced by the outstanding PJ pattern. Eventually, the August rainfall exhibits a significant interdecadal change, while the July rainfall has an insignificant interdecadal signal.

[20] The dynamical cause on the interdecadal change in circulations may be related to global climate shift across 1960s. *Quan et al.* [2003] showed that the transition of climate region across 1960s plays an important role in modulating the Walker-Hadley circulation, which in turn develops a strong upper-level cyclonic circulation over Northeast China and Siberia. As another cause inducing the interdecadal change, *Yu and Zhou* [2007] suggested that the troposphere-stratosphere interaction lead the interdecadal change associated with the tropospheric cooling. However, the possible dynamical causes remain questionable. The modeling studies should be followed for further dynamics in advance.

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References

Baines, P. G., and C. K. Folland (2007), Evidence for a rapid global climate shift across the late 1960s, *J. Clim.*, *20*, 2721–2744.

Cha, E. J., M. Kimoto, E. J. Lee, and J.-G. Jhun (2007), The recent increase in the heavy rainfall events in August over the Korean Peninsula, *J. Korean Earth Sci. Soc.*, *28*(5), 585–597.

Ding, Q., and B. Wang (2005), Circumglobal teleconnection in the northern hemisphere summer, *J. Clim.*, *18*, 3483–3505.

Enomoto, T., B. J. Hoskins, and Y. Matsuda (2003), The formation mechanism of the Bonin high in August, *Q. J. R. Meteorol. Soc.*, *129*, 157–178.

Ha, K.-J., and E. Ha (2006), Climatic change and interannual fluctuation in the long-term record of monthly precipitation for Seoul, *Int. J. Climatol.*, *26*, 607–618.

Ha, K.-J., and S.-S. Lee (2007), On the interannual variability of the Bonin high associated with the East Asian summer monsoon rain, *Clim. Dyn.*, *28*, 67–83.

Ha, K.-J., S. K. Park, and K. Y. Kim (2005), On interannual characteristics of climate prediction center merged analysis precipitation over the Korean peninsula during the summer monsoon season, *Int. J. Climatol.*, *25*, 99–116.

Ho, C. H., J. Y. Lee, M. H. Ahn, and H. S. Lee (2003), A sudden change in summer rainfall characteristics in Korea during the late 1970s, *Int. J. Climatol.*, *23*, 117–128.

Hsu, H.-H., and S.-S. Lin (2007), Asymmetry of the tripole rainfall pattern during the East Asian summer, *J. Clim.*, *20*, 4443–4458.

Inoue, T., and J. Matsumoto (2004), Comparison of summer sea level pressure over East Eurasia between NCEP-NCAR reanalysis and ERA-40 for the period 1960–99, *J. Meteorol. Soc. Jpn.*, *82*(3), 951–958.

Kalnay, E., et al. (1996), The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Meteorol. Soc.*, *77*, 437–471.

Kosaka, Y., and H. Nakamura (2006), Structure and dynamics of the summertime Pacific-Japan teleconnection pattern, *Q. J. R. Meteorol. Soc.*, *132*, 2009–2030.

Kwon, M. H., J.-G. Jhun, and K.-J. Ha (2007), Decadal change in east Asian summer monsoon circulation in the mid-1990s, *Geophys. Res. Lett.*, *34*, L21706, doi:10.1029/2007GL031977.

Lee, E.-J., J.-G. Jhun, and C.-K. Park (2005), Remote connection of the northeast Asian summer rainfall variation revealed by a newly defined monsoon index, *J. Clim.*, *18*, 4381–4393.

Lu, R. (2004), Associations among the components of the East Asian summer monsoon systems in the meridional direction, *J. Meteorol. Soc. Jpn.*, *82*(1), 155–165.

Lu, R.-Y., J.-H. Oh, and B. J. Kim (2002), A teleconnection pattern in upper-level meridional wind over the North African and Eurasian continent in summer, *Tellus*, *54A*, 44–55.

Nitta, T. (1987), Convective activities in the tropical western Pacific and their impact on the northern hemisphere summer circulation, *J. Meteorol. Soc. Jpn.*, *65*, 373–390.

Pettitt, A. N. (1980), Some results on estimating a change-point using nonparametric type statistics, *J. Stat. Comput. Simul.*, *11*, 261–272.

Quan, X.-W., H. F. Diaz, and C.-B. Fu (2003), Interdecadal change in the Asia-Africa summer monsoon and its associated changes in global atmospheric circulation, *Global Planet. Change*, *137*(3–4), 171–188.

Trenberth, K. E., and J. W. Hurrell (1994), Decadal atmosphere-ocean variations in the Pacific, *Clim. Dyn.*, *9*, 303–319.

Uppala, S. M., et al. (2005), The ERA-40 re-analysis, *Q. J. R. Meteorol. Soc.*, *131*, 2961–3012.

Wang, B., Q. Ding, and J.-G. Jhun (2006), Trends in Seoul (1778–2004) summer precipitation, *Geophys. Res. Lett.*, *33*, L15803, doi:10.1029/2006GL026418.

Wang, B., J.-G. Jhun, and B.-K. Moon (2007), Variability and singularity of Seoul, South Korea, rainy season (1778–2004), *J. Clim.*, *20*, 2572–2580.

Yu, R., and T. Zhou (2007), Seasonality and three-dimensional structure of interdecadal change in the East Asian monsoon, *J. Clim.*, *20*, 5344–5355.

Yu, R., B. Wang, and T. Zhou (2004), Tropospheric cooling and summer monsoon weakening trend over East Asia, *Geophys. Res. Lett.*, *31*, L22212, doi:10.1029/2004GL021270.

Zhang, Y., J. M. Wallace, and D. S. Battisti (1997), ENSO-like interdecadal variability: 1900–93, *J. Clim.*, *10*, 1004–1020.

Zhang, Y., X. Kuang, W. Guo, and T. Zhou (2006), Seasonal evolution of the upper-tropospheric westerly jet core over East Asia, *Geophys. Res. Lett.*, *33*, L11708, doi:10.1029/2006GL026377.

Zhou, T.-J., and R.-C. Yu (2005), Atmospheric water vapor transport associated with typical anomalous summer rainfall patterns in China, *J. Geophys. Res.*, *110*, D08104, doi:10.1029/2004JD005413.

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