The characteristics and the causes of extreme rainfall events in August over Korea

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ABSTRACT

We investigate the characteristics of precipitation and its extremes exceeding 80 mm day^{-1} in August over Korea in terms of temporal and spatial variations. In addition, the possible causes of extreme rainfall events in seven years that have the greatest number of heavy rainfall events are suggested. The largest monthly mean rainfall and the greatest frequency of extreme rainfall events appear in August over Korea from 1973 to 2002. The notable increasing trend in both monthly rainfall and the frequency of extreme events is found in August. This increasing trend is mainly attributed by the seven heaviest years, 1987, 1993, 1995, 1998, 1999, 2000, and 2002.

The effects of typhoons and the large-scale circulation as the possible causes of the extreme rainfall in August are suggested. Among the seven heaviest years, in 1995, 1999, 2000, and 2002, the effect of typhoon is important to the occurrence of heavy rainfall events in August. Though the total number of occurrences of typhoons is under the average from the mid-1990s, the effects of typhoons on the August rainfall over Korea are enhanced. The spatial distribution of the frequency of the heavy rainfall events in those years shows that the events are concentrated over the western coast of Korea due to the track of typhoons. In addition, the spatial scale of the events is larger than that of the other heaviest years, 1987, 1993, and 1998.

The large-scale circulation has a more significant role in the extreme events in 1987, 1993, and 1998 rather than typhoons. From the analysis of large-scale circulation, it is found that the heavy rainfall events in August are related to the circulation of both the midlatitudes and the tropics: the Eurasian (EU) pattern and the western North Pacific subtropical high (WNPSH), respectively.

Keyword: extreme rainfall event, August, Korea, typhoons, Eurasian pattern, western North Pacific subtropical high

1. Introduction

In Korea the bulk of the annual precipitation occurs during the Northern Hemisphere (NH) summer (June, July and August, hereafter JJA) when the stationary fronts are the most active and move toward East Asia with time. The stationary fronts are called Changma in Korea and regarded as a regional phenomenon related to the East Asian monsoon system. They also have different names *Meiyu* in China and *Baiu* in Japan. Summer rainfall is mainly contributed to by the stationary fronts that occupy more than half of the annual precipitation in these regions. Therefore, since the water resources strongly depend on the summer rainfall, the time of the onset, evolution, and termination of summer rainfall over the East Asian countries has been one of the main interests of the forecast community.

It is reported that unusual precipitation behavior is more frequent these days and there are long-term changes in frequency, intensity of extreme rainfall events in the world (Folland et al., 2001, and references therein). In particular, we have recently experienced extreme rainfall events and severe flooding during the month of August when the Changma was already terminated, in the climatological aspect from the mid-1990s through the beginning of 2000. Extreme rainfall events have received increasing attention because changes in the variability, intensity and frequency could have a great influence on human resources and socioeconomic activities (e.g., Bernard, 1993, Mearns *et al*., 1997, NDPCH, 2003). However, the mechanisms of the extreme rainfall are not clear, and it is not certain whether the trends are due to the multi-decadal fluctuations, rather the part of a longer-term trend, or regional episodic events.

So far several studies about extreme rainfall have been done. Over the last 50 years, the area affected by the upper 10% of the heaviest precipitation has significantly increased, but there has been a slight decrease in annual precipitation over some areas such as China (Zhai *et al*., 1999a). Zhai *et al*. (1999b) show a significant increase in the precipitation over the middle and lower reaches of the Yangtze River and west China during the latter part of the 20th century, while also detecting a declining trend in precipitation over northern China. The frequency of appearance of extremely heavy daily precipitation clearly shows a long-term increase in Japan for the last 100 years (Iwashima and Yamamoto, 1993). An examination of the relationships between the El Niño Southern Oscillation (ENSO) and extreme rainfall in Korea has been performed (Cha *et al*., 1999), the extreme rainfall events are tending to occur frequently during the El Niño/La Niña

years, although statistically insignificant. However, long-term variations in extreme rainfall events and the associated temporal and spatial distribution patterns have not been studied in detail over Korea. The objective of this study is to investigate the characteristics of precipitation and its extremes in August over Korea in terms of temporal and spatial variations and to suggest the possible causes of extreme rainfall events in the seven years that have the greatest number of heavy rainfall events.

2. The characteristics of the extreme rainfall events

An investigation is carried out to assess the climatology of monthly precipitation and the frequency of extreme rainfall events in Korea. For the period from 1973 to 2002, JJA rainfall occupies more than half of annual total precipitation in most regions over Korea and there appeared the largest monthly mean rainfall in August (269 mm month^{-1}) and the second maximum in July (262 mm/month). The 30-years climatological results show that there are more frequent extreme rainfall events exceeding 80 mm day^{-1} in August than in July, although nearly the same monthly rainfall occurs in both July and August. The rainfall in July is mainly attributed to the stationary front (Changma in Korea), which is the regional component of the East Asian summer monsoon and this monsoon front is fully developed, then moves northward and southward over the whole country in July. On the other hand, the large amounts of rainfall in August are caused by typhoons (including the direct and indirect impacts), cyclones, fronts, instability in the boundary of the North Pacific High, and regional factors.

In order to examine the long-term variability of the rainfall and the frequency of extreme rainfall events in summer over Korea, the time series of the rainfall anomaly and the frequency of rainfall events in August are obtained for the period from 1973 to 2002. An extreme rainfall event at a different weather station in the same day is counted individually. It is not found that any dominate change results either in June or July. The notable increasing trend in both the monthly rainfall and the frequency of extreme rainfall events is found in August. The enhanced summer mean rainfall in recent years is mainly contributed to by the increased precipitation in August.

The increasing trend in August is mainly attributed to the most extreme rainfall events on the historical record in recent summers (1987, 1993, 1995, 1998, 1999, 2000, and 2002, hereafter the seven heaviest years). In the seven heaviest years, the Changma was normal or not fully developed with a relative lack of rainfall and a delay in its onset and termination, whereas the heavy rainfall was reported at most of the stations over

Korea. The record-breaking rainfall caused heavy human resource and property losses through widespread flooding. Since the recent characteristics of the summer rainy season rainfall, especially for August, show a significant difference from the climatological features, we focus on the extreme rainfall episodes in August of the seven heaviest years.

3. The causes of the extreme rainfall events

To investigate the causes of extreme Korea rainfall events in summertime is difficult, because the multiple factors such as typhoons, cyclones, fronts, instability in the boundary of the North Pacific High and regional factors are involved. Though many efforts to reveal the causes of the extreme rainfall events have been made, only a few studies have described how typhoons impact on the extreme rainfalls. Therefore, we try to find out the effect of typhoons on the summer heavy rainfall in Korea, especially in August and we highlight some large-scale features that distinguish a normal August, especially in 1987, 1993, and 1998 among the seven heaviest years, in which the effect of typhoons is relatively weak compared to the other heaviest years. We have examined the number of occurrences of typhoons and their impact on the precipitation over the Korean peninsula. The maximum number of typhoons that influence the heavy rainfall over Korea also appears in August, thus the effect of typhoons is important in the precipitation in August. There is an evidence for the linkage between the extreme rainfall in the six heaviest years except for 1998 and typhoons. No typhoon appeared in August of 1998 over Korea. We note that more than half the extreme rainfall events in August seem to be strongly affected by major typhoons, especially in 1995, 1999, 2000, and 2002. A series of typhoons generated in the western Pacific centered at 20^{o}N and contributed highly to the outbreak of heavy rainfall in 1999. In August 2000, two typhoons occurred consecutively and contributed to the excessive rainfall. From the analysis of large-scale circulation, it is found that the heavy rainfall events are related to the circulation of both the midlatitudes and the tropics: EU and WNPSH. According to Wang et al. (2000), the establishment of the WNP anticyclone is connected to the El Nino event and the high-pressure system persists through the positive feedback between the SST and the wind anomalies over the tropical western Pacific. Therefore, the extreme events in August can occur more frequently, if the above two conditions associated with the midlatitudes and the tropics are satisfied.