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South-north dipolar pattern around mid-1990s in Korean summer rainfall variability

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ABSTRACT

From the time series of rainfall in summer (June, July and August) in South and North Koreas for recent 28 years (1981–2008), rainfall has significantly increased in South Korea while it has significantly decreased in North Korea since 1996. In particular, the decreasing trend of summer rainfall in North Korea was more conspicuous during the second Changma (late August – mid-September). This characteristic was also found in the south-north dipolar pattern based on 1996 by empirical orthogonal function analysis using summer rainfall observed in all weather observation stations in South and North Korea.

The decreasing rainfall trend in North Korea was found to be associated with the weakening of convection by anomalous northeasterlies from anomalous anticyclone centered on around Baikal Lake during summer. On the other hand, the increasing rainfall trend of South Korea was associated with the strengthened anomalous cyclone in the southern region of China, which in turn strengthened anomalous southwesterlies.

1. Introduction

Damages from heavy rainfall in summer have led many people to take interest in rainfall, which is a meteorological factor. Summer rainfall is particularly important because human life and industrial activities are greatly affected by the amount of summer rainfall. Furthermore, if rainfall is not sufficient in summer, people suffer from severe drought from the autumn until next spring because winter in Korea is a season with scarce rainfall. Therefore, many efforts have been made to understand the variation characteristics of summer rainfall in South Korea.

Chung and Yoon (2000) and Chung et al. (2004) analyzed South Korea's rainfall data for nearly 100 years and found that the annual rainfall of South Korea had been increasing until recently, and the increasing trend for summer rainfall was most conspicuous among the four seasons. Ko et al. (2005) classified rainfall characteristics during Changma (late August – mid-September) by region and showed that rainfall significantly increased recently in all areas of South Korea compared to the past. They emphasized that the rainfall between late July and early August after the end of Changma also significantly increased recently, and suggested that this change was most conspicuous in the northwestern region of South Korea. Regarding the increased rainfall in the northwestern region of South Korea during the period after Changma, Chang and Kwon (2007) mentioned that it was because the rainfall band during Changma in South Korea has greatly weakened since 1990s. The findings of these four studies about the characteristics of rainfall in South Korea can be summarized as

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follows: the rainfall shows the greatest increasing trend in summer and this increase is most apparent in the northwestern region of South Korea. However, most of these studies focused on analyzing the trend of summer rainfall in South Korea and did not sufficiently explain the causes of the recent increase in summer rainfall.

Several studies investigated the trends of heavy rainfall frequency and rainfall intensity which are closely related to the variations in summer rainfall. Choi and Moon (2000) analyzed rainfall intensity data from 60 weather observation stations in South Korea for recent 28 years (1973–2000) and found that rainfall intensity increased in most regions, and the increase was large especially in the northwestern area and the southern coast area. In particular, Choi (2004) showed that the number of no rain days is decreasing while the summer daily rainfall intensity is increasing.

Meanwhile, studies on climate regime shift are insufficient compared to the studies on the trends of summer rainfall. The period of the climate regime shift can be largely divided into prior to and after 1980s. First, some studies explained the time of climate regime shift as before 1980s. Ha et al. (2009) showed that the August rainfall has increased since 1960s based on the long-term rainfall data for nearly 100 years (1912–2006) observed from five weather observation stations in South Korea. Ho et al. (2003) suggested that the convergence between the cold and dry northeasterlies from the lower-level anticyclone in the East Asian continent and the warm and humid southwesterlies flowing into South Korea was intensified since the late 1970s. Furthermore, Kim et al. (2006) demonstrated that heavy rainfall caused by tropical cyclones landing on South Korea also has increased greatly since the late 1970s. Thus, the change point of the late 1970s seems to be associated with the change point for every climate factor (e.g., North Pacific Oscillation and East Asian summer monsoon) (Niebauer, 1998; Stephens et al., 2001; Wu et al., 2005; Ye and Hsieh, 2006; Cheng et al., 2008).

For studies related to the change point after 1980s, Ha et al. (2005) analyzed that the decreasing point of rainfall during the period between Changma and second Changma (late July to mid-August) was early 1990s. Kim et al. (2002) also claimed that there was a big change at this time. Although not a study on the variation of summer rainfall, Kim and Suh (2008) showed that there were big changes in annual rainfall, rainfall days, and rainfall intensity of South Korea in the mid-1990s.

As shown by the above studies, the big change points of summer rainfall in South Korea are different by study, but the increasing trend is commonly found regardless of the change point. For summer rainfall in North Korea, however, no relevant literature could be found due to the limitation in collectable resources. Therefore, the spatiotemporal characteristics on interdecadal variation of summer rainfall in South and North Korea will be compared together in this study.

2. Data

2.1. Rainfall

This study used the summer (June, July and August) average rainfall data observed in 60 weather observation stations in South Korea excluding Ullungdo between 1981 and 2008 (28 years) and 26 weather observation stations in North Korea for the same period. Ullungdo was excluded from this study because it is an island far from the Korean Peninsula and has unique climate. The number of weather observation stations in North Korea was 12 before 1981, but it increased to 26 from 1981. Thus, the year 1981 was determined as the criterion for analysis. The distributions of weather observation stations in South and North Korea are shown in Fig. 1.

2.2. Reanalysis

This study used the reanalysis data of National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP-NCAR) (Kalnay et al., 1996; Kistler et al., 2001) including zonal and ($m\,s^{-1}$) specific humidity ($g\,kg^{-1}$) and vertical velocity ($hPa\,s^{-1}$) variables. This data provides monthly averages from 1948, and consists of $2.5^\circ \times 2.5^\circ$ units for latitude and longitude and vertical 17 standard levels (8 standard levels for specific humidity).

Furthermore, the monthly mean data of the Climate Prediction Center (CPC) Merged Analysis of Precipitation (hereinafter referred to as 'CMAP') (Xie and Arkin, 1997) which has the same horizontal spatial resolution as the NCEP-NCAR reanalysis data was used. This data is available from 1979 until now.

In addition, the monthly mean data of the National Oceanic and Atmospheric Administration (NOAA) interpolated Outgoing Longwave Radiation (hereinafter referred to as 'OLR') which has the same horizontal spatial resolution as the above two data was used. This data is available from June 1974 until now, but it has missing data between March and December 1978.

This study used the Student's *t* test to determine significance (Wilks, 1995).

3. Empirical orthogonal function analysis

Fig. 2 shows the results of empirical orthogonal function (hereinafter referred to as 'EOF') analysis using the summer mean rainfall data of South and North Korea. First mode and second mode account for about 40% and 20% of the total variance. First, in the spatial variation of first mode, a spatial pattern of south high north low is formed around the border between South and North Korea. In time variation, the principal component shows a generally increasing trend, which is significant at the 90% confidence level. In particular, the principal component after the mid-1990s is larger than before. This can be more clearly seen in the time series with 5-year running average. That is, negative values are clear until 1996 and then positive