A Fingerprint of Global Warming Appeared in Winter Precipitation across South Korea[*]

우리나라 겨울철 강수에 나타난 지구온난화의 징후

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Abstract

In this study, changes in precipitation across South Korea during snow seasons (November−April) and their potential are examined. Current (1973/74−2006/07) and future (2081−2100) time series of snow indices including snow season, snow−to−precipitation ratio, and snow impossible day are extracted from observed snow and precipitation data for 61 weather stations as well as observed and modeled daily temperature data. Analyses of linear trends reveal that snow seasons have shortened by 3−13 days/decade; that the snow−to−precipitation ratio (the percentage of snow days relative to precipitation days) has decreased by 4−8 %/decade. These changes are associated with pronounced formations of a positive pressure anomaly core over East Asia during the positive Arctic Oscillation winter years since the late 1980s. A snow−temperature statistical model demonstrates that the warming due to the positive core winter intensifies changes from snow to rain at the rate of 4.7cm/° C. The high pressure anomaly pattern has also contributed to decreases of air−sea thermal gradient which are associated with the reduction of snow could formation. Modeled data predict that a fingerprint of wintertime global warming causing changes from snow to rain will continue to be observed over the 21st century.

Key words: snow season, snow-to-precipitation ratio, global warming, climate change

1. Introduction

Global surface air temperature has increased by 0.7° C/100years over the 20th century (IPCC, 2007). The warming rate is approximately twice in South Korea, partly due to local urbanization as well as increases of greenhouse gas emission in the atmosphere. Seasonally, most significant warming has been observed in winter, which have reduced the frequency of cold days and nights in recent decades. Regarding the signals of wintertime warming over South Korea, it has been documented that thermal winter duration has shortened by approximately 30 days in the 1990s compared with those in the 1920s (Choi&Kwon, 2001); that the frequency of cold days below the lower 5th percentile value of daily minimum temperature has decreased, particularly since the late 1980s. It has been also

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Table 1. Snow indices (Choi&Kwon, 2008)

Snow indices	Definition	Unit
Daily probability of snowfall	Percentages of snow days at daily basis over the study period	%
Snow seasons	Intervals between the first and last snow days	Days
The frequency of snow days	The number of days with snowfall	Days
Snow-to-precipitation day ratio	Ratio between snow and precipitation days	%
Snow intensity	Snowfall averaged by total snow frequency	cm/day
The frequency of heavy snow days	Days with 5mm or more of snowfall	Days
The frequency of snow impossible days	Days below 5 ° C of daily mean temperature	Days

found that the intensity and frequency of Siberian high preassure have decreased in recent decades (Kim *et al.*, 2005). There have been few studies about climate change focusing on winter precipitation compared to summer precipitation including flooding events and typhoons. Several studies (Lee&Choi, 2001; Lee&Ryoo, 2003) investigated recent linear trends of snowfall only for several weather station data, which is not enough to understand the national scale trends. Thus, this study aims at examining whether there have been changes in winter precipitation across South Korea as well as, if any, what their potential causes are. Snow indices summarized in Table 1 are extracted from daily precipitation and snowfall data observed at 61 stations across South Korea.

2. Changes in snow indices and their potential factors

2.1. current linear trends

There is no significant increasing or decreasing trend in snow seasons (November-April) precipitation averaged across 61 weather stations in Korea, but decreasing trends of snow indices such as snowfall, snow days, snow-to-precipitation day ratio indicates that winter precipitation has changed from now to rain in recent decades. The decreasing trends of snowfall, snow-to precipitation day ratio, and snow days are observed at most weather stations across 61 weather stations(Figure 1). In Figure 1, the upper and lower limits of bar graphs indicates the maximum and minimum linear trend values of individual snow indices for 61 weather stations. Precipitation shows both increasing and decreasing trends, while other snow indices show mostly decreasing trends. Most noticeable reduction of snowfall is observed in Uleungdo. Over the 1973/04-2006/07 period, snowfall has decreased by 45.8 cm/decade in Uleungdo. Consistently, the frequency of snow days have decreased by 5.2 days/decade in Uleungdo. In contrast, the maximum reduction of snow-to-precipitation day ratio is observed in Icheon at the rate of 8.3 days/decade.

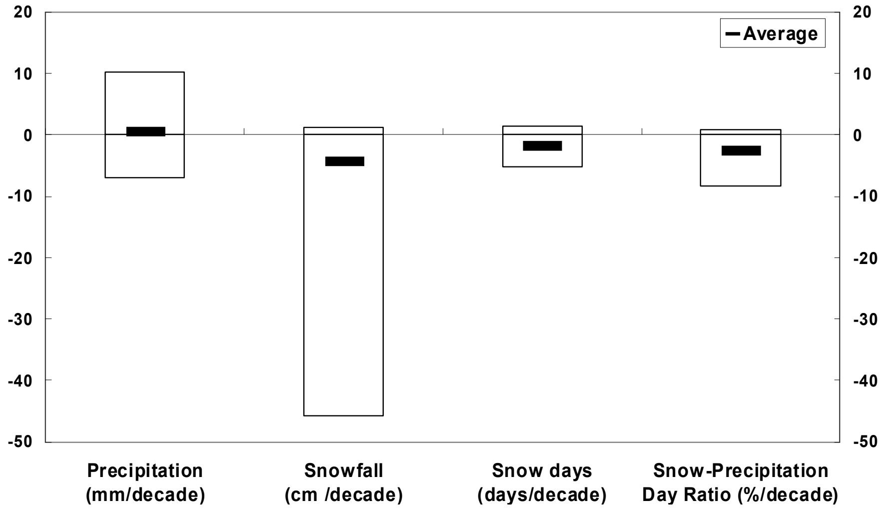

Figure 1. Linear (1973/74-2006/07) trends of snow indices averaged across 61 weather stations in South Korea

2.2 Synoptic patterns

Changes of winter precipitation type are associated with changes in synoptic conditions. Since the late 1980s, a positive pressure anomaly has prevailed over East Asia during the winter period. The winter condition over The Korean Peninsula is affected by the positive pressure anomaly core which allows more solar radiation to reach surface and which subsequently increases winter surface air temperature related to changes from snow to rain. The anomaly system is one of midlatitude positive anomaly cores that are developed by a positive Arctic Oscillation mode.

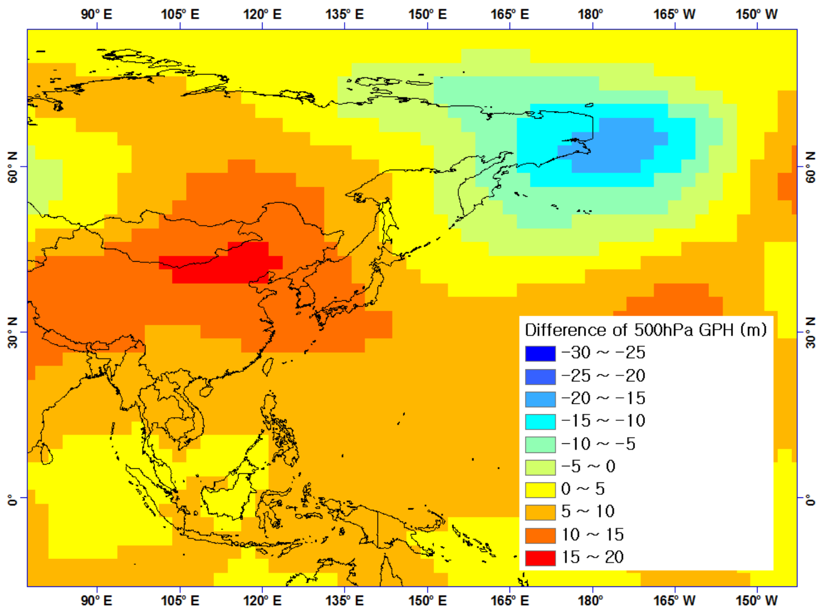

Figure 2. 500hPa geopotential height anomaly differences between the pre-1988 and post-1987 periods along the western Pacific region (Choi&Kwon, 2008)

2.3 Projections of future changes

Frequencies of freezing days (Tmean < 0° C) and snow impossible days (Tmean < 5° C) between November and April between 20 century (1981−2000) and 21 century (2081−2100) are compared(Figure 3). These indicators reflect atmospheric conditions for formation or remaining of snow during winters. Modeled data predict that the cold events related to the favorable condition for snowfall will decrease in the later 21st century in both central and southern regions. The magnitude of changes are greater in the central region compared to those in the southern region.

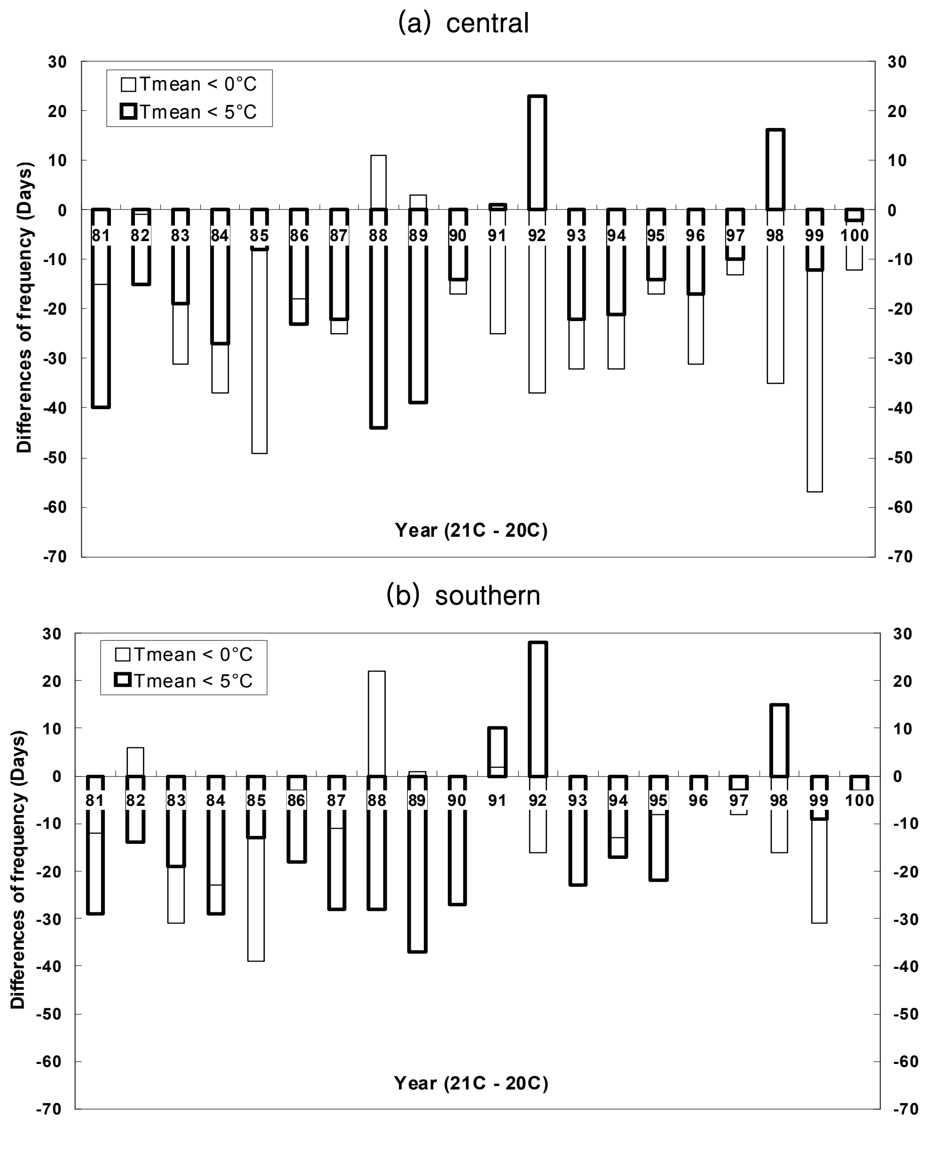

Figure 3. Projections of changes in annual frequency of freezing days (Tmean < 0°C) and snow impossible days (Tmean < 5°C) between 20C (1981–2000) and 21C (2081–2100) derived from modeled (GFDL 2.1 A1B scenario vs. 20C_5run) data for the central (a) and southern (b) regions of the Korean Peninsula.

3. Conclusion and future studies

This study demonstrated that winter precipitation has changed from snow to rain due to regional warming across South Korea in recent decades. Analyses of synoptic conditions in upper atmosphere and oceans show that these changes are attributable to the increases of surface air temperature due to strong atmospheric warming as well as the reduction of air-sea thermal gradient due to differentiated weak oceanic warming. These patterns may lead to less formation of snow clouds and intensify the changes from snow to rain. Modeled data predict that similar trends will intensity over the 21st century in South Korea. Thus, it is needed to examine impacts of reduction of snowfall on socio-economic activities such as skiing industry, agriculture, and transportation in future studies.

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