Development of a method to reconstruct past winter monsoon variability based on the inter-annual variabilities of river discharges and snowfall in Hokkaido, northern Japan

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Monsoon is seasonally alternating wind due to heat contrast between continents and ocean by solar radiation (Tada, 2005), and one of the most characteristic seasonal variation of climate in east Asia. East Asian winter monsoon (EAWM) is characterized by cold and dry wind blowing from continents, and promotes heavy snowfall along the Japan Sea side of Japanese Islands, while east Asian summer monsoon (EASM) is characterized by wet airmass turning around the north Pacific Ocean flows to Bai-u front and typhoon as well which bring heavy rain along the Japanese Islands in summer. Although past summer monsoon has been successfully reconstructed in many studies, researches on winter paleoclimate including winter monsoon have not been developed well (Ikehara and Itaki, 2005). In this study, we compare climate data (the inter-annual variability of snowfall and river discharge) with winter monsoon index and discuss their interrelationships in order to develop a method to reconstruct past EAWM intensity.

First, we compared the Monsoon Index (MOI; sea level pressure (SST) difference between Nemuro and Irkutsk) by Yasuda and Hanawa (1999) with the inter-annual variability of snowfall of each area in Hokkaido. The inter-annual snowfall is acquired from Japan Meteorological Agency. As a result, MOI and inter-annual snowfall show a positive correlation, and temporal variability of these parameters show similar patterns. Therefore, snowfall could be a good index of EAWM intensity. Furthermore, river discharge during snowmelt season and inter-annual snowfall also show a positive correlation (river discharge data was acquired from Water Information System of Ministry of Land, Infrastructure). Therefore, it was expected to reconstruct past winter monsoon by estimation of river discharge and snowfall.

We collected 10-years river discharge data of 13 class A rivers between 2006-2016 in Hokkaido from Water Information System of Ministry of Land, Infrastructure, Transport and Tourism. Then, we conducted principal component analysis (PCA) using *R*. Missing data was interpolated by the mean values. Out of 13 principle components, we examined Principle Components (PC) 1, 2, and 3. PC1 score represents a common seasonal pattern of discharges in Hokkaido, while PC2 and 3 represent differences of discharge patterns among the areas of Japan Sea, Okhotsk Sea, and Pacific. Based on the PC score that indicates temporal variation of each PC, characteristics of each PC is summarized below.

1. PC1 represents average temporal discharge variation in Hokkaido, where the discharge show maxima depending on precipitation during summer to autumn and snow melt in spring
2. PC2 loadings are significantly positive in the Okhotsk Sea side and negative in the Japan Sea side, where timing of maximum score is associated by summer precipitation in the Okhotsk Sea side and minimum score is associated by spring snow melt in the Japan Sea side
3. PC3 loading shows significantly positive in the Okhotsk Sea side and negative in the Pacific side, where timing of maximum score is associated with spring snow melt in the Okhotsk Sea side, and minimum score occurs at heavy precipitation in summer and autumn in the Pacific Ocean

We also compared scores of PC2 and 3 with inter-annual snowfall or summer precipitation in drainage area of each river, and the results show;

Positive values of PC2 scores correspond to summer precipitation in Takinoue, while the negative scores correspond to snowfall in Iwamizawa
Positive values of PC3 scores correspond to snowfall in Takinoue, while the negative scores correspond to summer precipitation in Noboribetsu

These results suggest that the excess river discharge in Japan Sea side over Okhotsk Sea side or that in Okhotsk Sea side over Pacific side could be an indicator of snowfall and river discharge in snow melt season. These comparison would enable us to develop a method to estimate past snowfall using sediment archives by estimation of sediment flux due to river discharge during snow-melt season, which could be regarded as past EAWM intensity.

Keywords: Winter monsoon, Paleo-environmental reconstruction, Snowfall, River discharge

