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Pollen-based temperature reconstructions from Jeju island, South Korea and its implication for coastal climate of East Asia during the late Pleistocene and early Holocene

Jungjae Park [a,b,*], Jina Park [a]

[a] Department of Geography, Seoul National University, Sillim-dong, Gwanak-gu, Seoul 151-742, Republic of Korea
[b] Institute for Korean Regional Studies, Seoul National University, Sillim-dong, Gwanak-gu, Seoul 151-742, Republic of Korea

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ABSTRACT

We derived statistically robust, Weighted Averaging Partial Least Squares (WAPLS) transfer functions using modern surface pollen samples from Mt. Halla in Jeju Island, Korea. Pollen-based temperature reconstructions were performed by applying the best transfer function to lake sediments from Hanon maar paleolake in the southern part of Jeju Island. These quantitatively reconstructed temperatures were thereafter adjusted for the lack of warm analogue with the aid of Japanese and Russian transfer functions. Our temperature reconstructions demonstrated that annual mean temperatures during the Last Glacial Maximum (LGM) were ~8.5 °C, i.e., about 8 °C lower than the present, and that the Younger Dryas (YD) cooling amplitude was ~1.5 °C between Bølling–Allerød (BA) (~11.3 °C) and YD (~9.8 °C). Spectral and wavelet analyses on detrended paleotemperatures identified significant periodicities at 1340 years, primarily after 13,000 cal yr BP. The influence of Antarctic deglacial climate on the western North Pacific probably decreased with increasing northern latitude, as expected. Our results and Borneo oxygen isotope data showed very high correlation, indicating that Jeju Island was substantially influenced by the deglacial variabilities of the western Pacific warm pool via the Kuroshio Current. The climate of the study area seemed to have been mainly controlled by variation in the Atlantic Meridional Overturning Circulation (AMOC) before the beginning of the last deglaciation and subsequently by variation in the Western Tropical Pacific (WTP) Sea Surface Temperature (SST). We present significant information on the correlation of the late Pleistocene climate change with the Greenland oxygen isotope data and western North Pacific SST records. This correlation bridges the gap between terrestrial records, which mostly show AMOC variability, and oceanic records, which show WTP variability. These study results will increase our understanding of regional-scale climate change during the late Pleistocene and Early Holocene.

1. Introduction

Since Imbrie and Kipp's (1971) pioneering study on the use of marine foraminifera to derive sea surface temperature (SST), past quantitative environmental conditions have been intensively reconstructed from biotic indicators (pollen, diatom, and chironomid head capsules) and inorganic chemical and physical markers (stable isotopes and metals). Quantitative paleoclimate information has been considered vital due to its important role in evaluating the reliability of climate model results, which has become increasingly crucial for clarifying the cause of past climate variability and for predicting climate change.

Many regional and local transfer functions for estimating past climate conditions have been successfully developed based on various climate proxy indicators. In particular, modern surface pollen has been extensively used in many regions of the world to quantitatively reconstruct paleoclimate (e.g., Birks, 1995; Nakagawa et al., 2002; Davis et al., 2003; Seppä et al., 2004; Tarasov et al., 2011). However, no quantitative reconstruction of the past climate has been undertaken in Korea, apart from Park's (2011) study using modern pollen. Even Park's (2011) work only covered a short time period after the mid-Holocene and the results suffered from study uncertainties arising mostly from human disturbances. This lack of quantitative data makes it difficult to thoroughly understand the causes and consequences of past climate shifts in the Korean peninsula and thus in coastal East Asia.

Quantitative information on abrupt cold reversals during the last deglaciation will become more important in the near future since similar brief cold events are considered possible in the near future as a result of slowdown of the Atlantic thermohaline circulation triggered by rapid climate warming (Broecker, 1997; Rahmstorf and Ganopolski, 1999). However, there are very few quantitative terrestrial records of the deglacial climate in coastal East Asia (Wang et al., 2001; Nakagawa et al., 2003), although numerous studies on marine sediment have provided quantitative deglacial climate data such as SST and sea surface salinities indicating the

* Corresponding author at: Department of Geography, Seoul National University, Sillim-dong, Gwanak-gu, Seoul 151-742, Republic of Korea. Tel.: +82 62 530 2687; fax: +82 62 530 2689.
E-mail address: jungjaep@snu.ac.kr (J. Park).

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intensity of monsoonal precipitation (Li et al., 2001; Ijiri et al., 2005; Sun et al., 2005; Harada et al., 2006, 2008; Kubota et al., 2010; Shintani et al., 2011; Zhou et al., 2012; Xu et al., 2013). Paleoclimate information reconstructed from terrestrial proxy is obviously more significant because humans live on the land.

Many studies have investigated the mechanisms that determined the past climatic conditions in coastal East Asia, including the Korean peninsula, and thus suggested latitudinal shifts of the westerlies controlled by North Atlantic climate variation (e.g., Porter and An, 1995; Ijiri et al., 2005; Nakagawa et al., 2006) and SST changes in the Western Tropical Pacific (WTP), which Kuroshio warm currents convey (e.g., Sun et al., 2005; Xu et al., 2013), as two major determinants of past climate in this region. However, their relative importance has barely been investigated due to a shortage of appropriate quantitative climate data in this region. Further, the quantitative information gap in coastal East Asia has prevented us from fully comprehending the combined influence of westerlies and warm currents on overall East Asian climate.

The main purposes of this study are to 1) derive pollen-temperature transfer functions using modern pollen data from Mt. Halla in Jeju Island, Korea, 2) apply the best transfer function to the existing fossil pollen record produced from Hanon maar paleolake in the southern part of Jeju Island and obtain quantitative data of late Quaternary paleotemperatures, and 3) investigate the nature and cause of the past climate change in coastal East Asia during the late Quaternary and, especially, the last deglaciation.

2. Study area

South Korea has a distinct, four-season climate, with monthly average temperatures that diverge widely between summer and winter and relatively high rainfall falling mostly in the summer. The summer monsoon brings hot and humid weather to the Korean peninsula, whereas the winter is cold and dry. Stronger seasonal air temperature variation on the continent and weaker oceanic temperature variation lead to seasonal changes of prevailing winds from SE in the summer to SW in winter. Hanon maar paleolake, located on the southern part of Jeju Island (Fig. 1b), has a mild oceanic climate year round with the smallest annual temperature variation range in Korea. The mean monthly temperature at the Seogwipo station near the study site ranges from 6.8 °C in January to 27.1 °C in August, while annual mean rainfall is 1923 mm (Domestic Climate Data). The southern part of the island has one of the highest annual mean rainfalls in Korea. The strength of the winter monsoon is reduced by the maritime influence of the warm Tsushima Current, a branch of the larger Kuroshio Current, leading to relatively mild and humid winter conditions on the island. The slopes of Mt. Halla experience large variation in annual rainfall due to orographic effects. Annual mean rainfall ranges from 1200 mm at the coast to 5000 mm at elevations of 1500–1700 m above sea level (NIMR, 2010).

The vegetation of Jeju Island exhibits considerable altitudinal variation (Cha, 1969; Kong, 1998). The southern and northern slopes of Mt. Halla feature human-induced grasslands and evergreen broadleaved forest between 0–700 m and 0–600 m above sea level, deciduous broadleaved forest between 700–1300 m and 600–1200 m, mixed deciduous broadleaved-coniferous forest between 1300–1500 m and 1200–1300 m, coniferous forest between 1500–1800 m and 1300–1700 m, and subalpine scrub and grassland between 1800–1950 m, and 1700–1950 m, respectively (Cha, 1969; Oh et al., 2007). Dominant weedy species in the range areas are *Trifolium repens*, *Botrychium virginianum*, *Rosa multiflora*, *Miscanthus sinensis*, and *Imperata cylindrical* (Kim et al., 1988). The evergreen broadleaved forest mainly

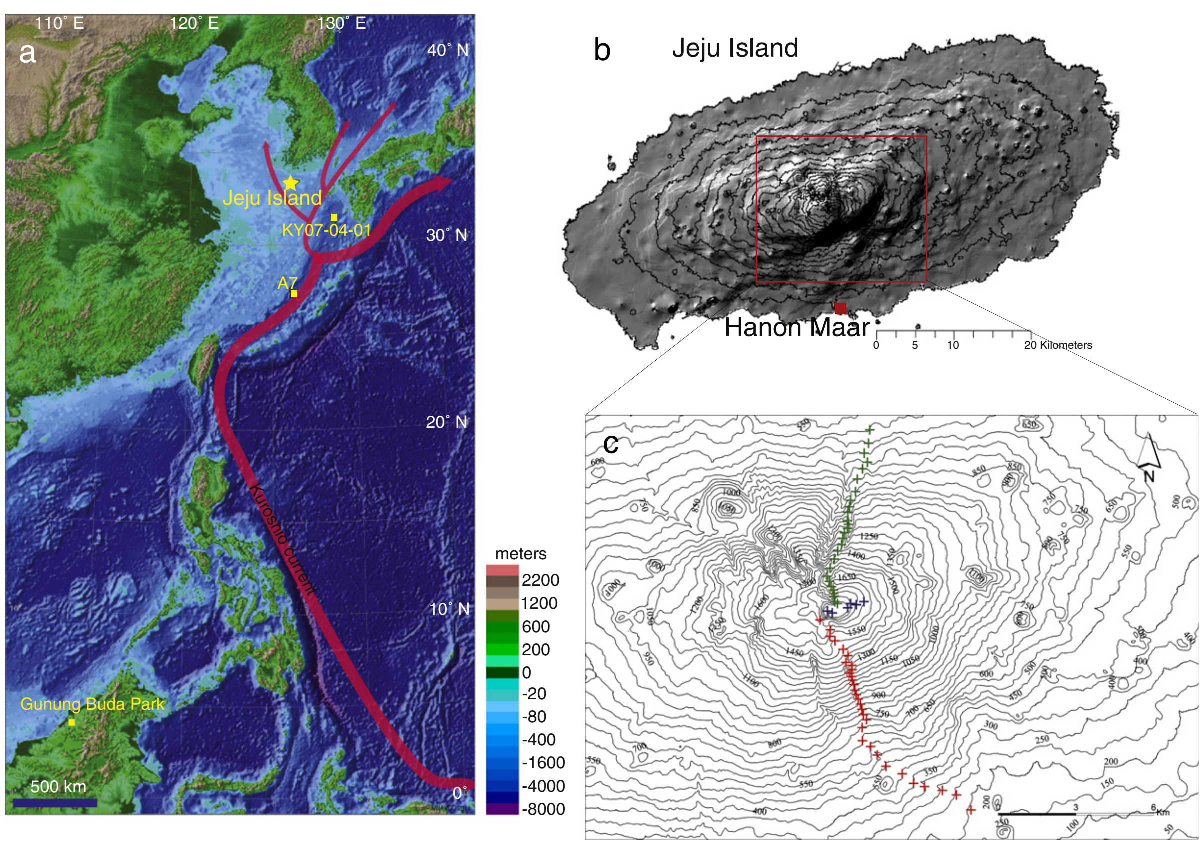

Fig. 1. Map of the study region. (a) Location of Jeju Island and selected paleoclimate sites in western North Pacific: Gunung Buda National Park in Malaysian Borneo (4°N, 114°E) (Partin et al., 2007), marine core A7 in northern East China Sea (27°49′N,126°58′E) (Sun et al., 2005), marine core KY07-04-01 in the Okinawa Trough (31°38′N, 128°56′E) (Kubota et al., 2010). (b) Location of Hanon Maar paleolake in Jeju Island. (c) Map showing the sampling sites (crosses) in Mt. Halla. Sampling sites from the southern, northern, and eastern slopes are indicated by red, green, and blue crosses, respectively.
This map was modified from UNAVCO map tool (UNAVCO Inc., jules.unavco.org).