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# Initiation of East Asia monsoon failure at the climate transition from the Medieval Climate Anomaly to the Little Ice Age

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ABSTRACT

We have reconstructed decadally-resolved continuous sea surface temperature and seawater $\delta^{18}O$ (hence salinity) records over the last 1300 yr from alkenone and planktonic foraminiferal oxygen isotope ratio analyses of the East Sea/Japan Sea marine sediments to investigate East Asia monsoon variability. Comparisons of the records with other paleoclimate records indicate a possible connection between changes in the mid-latitude East Asia monsoon and Pacific Decadal Oscillation (PDO) over this period. The results show that during the Medieval Climate Anomaly (MCA) when the PDO index was negative, East Asia was characterized by surface warming with a strengthened summer monsoon. Summer monsoon-related precipitation increased and pluvials possibly dominated in the region at that time. Onset of Asia monsoon failure and severe drought occurred at the end of the MCA and extended to the Little Ice Age (LIA) when the PDO became positive.



## 1. Introduction

There have been a number of studies concerned with the dynamical mechanisms of the East Asia monsoon system on various timescales (e.g., Wang et al., 2005). Interannual to decadal variability in the modern monsoon system has been identified based on the analysis of the last century's records. These studies have tried to explore the relation between the East Asia monsoon and modes of climate variability such as the Arctic Oscillation (AO), North Atlantic Oscillation (NAO) and Pacific Decadal Oscillation (PDO) (e.g. Gong and Ho, 2003; Li et al., 2010). However, a scarcity of instrumental climate records prior to the last century impedes further progress toward resolving these issues. Recently past millennium climate variability records have been reconstructed based on various proxies including tree rings, ice cores, corals, sediments, and others from the ocean and land regions of both hemispheres (e.g. Jansen et al., 2007). These records make it possible to reconstruct the large-scale climate changes over the period including the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA). The MCA has been defined as a period extending from AD 950 to AD 1250, while the LIA extended from AD 1400 to AD 1700 (Mann et al., 2009; cf. Graham et al., 2010 for other possible definitions). Investigation of significant changes in major elements of the climate system and their linkages at the MCA–LIA transition may help to understand climate dynamical mechanisms.

The East Sea is strongly influenced by the East Asia monsoon system. During the winter monsoon season, the Siberian high pressure system centered over the Eurasian continent energizes a cold and dry northwesterly wind to blow over the East Asia. During the summer monsoon, the enhanced North Pacific high pressure system leads to a warm and humid southwesterly wind to blow over land and the sea. This period is characterized by a large amount of rainfall. Hence, the sea surface temperature (SST) and salinity (SSS) of the East Sea are strongly affected by the seasonal changes of monsoon systems. In this study, new SST and seawater $\delta^{18}O$ (and SSS) records over the past millennium were reconstructed from the marine sediments of the East Sea located on the western margin of the subtropical North Pacific (Fig. 1). $C_{37}$ alkenone content of marine sediments was measured in order to reconstruct past SST changes. The oxygen isotopic composition of the planktonic foraminifer *Globigerinoides ruber* from the same sediment core materials was measured to reconstruct past seawater $\delta^{18}O$ and SSS changes. The alkenone temperature and planktonic foraminiferal oxygen isotopic values are robust and well-known proxies. They provide a continuous record enabling to investigate temporal variations. Quantification of these paleo-temperature and seawater $\delta^{18}O$ changes helps to understand climate and hydrological changes in the mid-latitude Northwestern Pacific margin. More importantly, comparisons of these records with other paleoclimate records can provide connections between major elements of the climate system over the past millennium.

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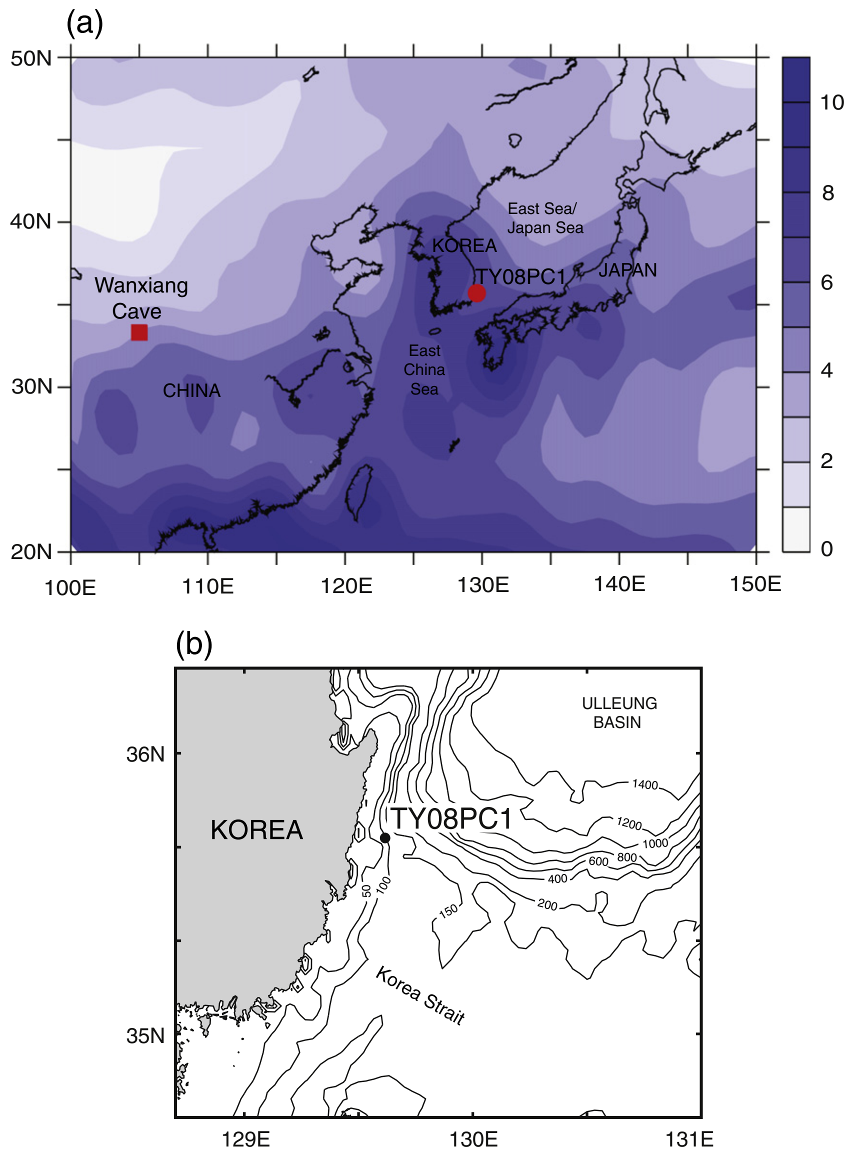


**Fig. 1.** (a) Locations of core TY08PC1 in the East Sea (red circle) and Wanxiang Cave (Zhang et al., 2008) (red square). Color shading represents summer (JJA) mean precipitation [mm/day] from Xie and Arkin's (1997) 1°-gridded data for the period 1979–2002. (b) Bathymetry of the study area (contours in meters).

## 2. Study site and methods

This study used marine sediments from a piston core TY08PC1 (129° 37′E, 35° 42′N) recovered from a water depth of 118 m in the southwestern part of the East Sea (Fig. 1). Monthly mean SST and SSS of the study area were examined using in situ observational data obtained by the National Fisheries Research and Development Institute (NFRDI), Korea, during the period 1999–2008 (Table 1). For this period, the data show cold SST from December to April, with minimum in February (13.2 °C), and warm SST from June to October, with maximum in August (23.5 °C). The annual averaged value of observed SST is 18 °C. Mean values of water salinity are 34.1–34.4 psu in winter, and 32.3–32.9 psu in summer. The low salinity in summer is due to dilution by river discharge from the adjacent land, which is associated with the East Asia summer monsoon precipitation. Fig. 2 shows the spatial distribution patterns of SST and SSS surrounding the study area. Temperature and salinity data are monthly mean values for the period of 1955 and 2012 from the dataset of World Ocean Atlas 2013. It is notable that low salinity occurs at the Korea Strait between Korea and Japan in August, indicating influence of diluted seawater by river discharge in summer (see also Fig. 3). The core location is just south of the northern limit of the summer monsoon-related rain belt (Fig. 1, Sampe and Xie, 2010).

**Table 1**
Modern SST and SSS and seasonal concentration of alkenones near core TY08PC1 site (129° 37′E, 35° 42′N).

| Month | Feb | Apr | Jun | Aug | Oct | Dec | Annual average |
|---|---|---|---|---|---|---|---|
| SST (°C)[a] | 13.2 | 14.7 | 19.6 | 23.5 | 20.7 | 16.2 | 18.0 |
| SSS (psu)[a] | 34.4 | 34.4 | 33.7 | 32.3 | 32.9 | 34.1 | 33.6 |
| Alk. conc. (ng $L^{-1}$)[b] | – | 0.2 | 0.1 | 1.3 | 0.9 | 0.4 | |

[a] Data from National Fisheries Research and Development Institute in Korea were obtained from 1999 to 2008 at location 129° 38′E, 35° 45′N.
[b] Total $C_{37}$ alkenone concentration in suspended particles from surface waters near the core site. Seawater samples were collected in 2009 (Lee et al., 2014).

The marine sediment core TY08PC1 consists of 2.46-m-thick fine-grained sediments. The absence of large rivers along the eastern coast of Korea results in low fluvial sediment input to the East Sea. However, the shelf mud deposit accumulated along the coast is considered to contain terrigenous sediments possibly from nearby Nakdong River and/or