Quaternary Science Reviews 83 (2014) 76–82

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Molecular records of continental air temperature and monsoon precipitation variability in East Asia spanning the past 130,000 years

Francien Peterse [a,*], Alfredo Martínez-García [a], Bin Zhou [b], Christiaan J. Beets [c], Maarten A. Prins [c], Hongbo Zheng [d], Timothy I. Eglinton [a]

[a] ETH Zürich, Geological Institute, Sonneggstrasse 5, 8092 Zürich, Switzerland
[b] Nanjing University, School of Earth Sciences and Engineering, Nanjing 210093, China
[c] VU University Amsterdam, Faculty of Earth and Life Sciences, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands
[d] Nanjing Normal University, School of Geography Science, Nanjing 210046, China

ARTICLE INFO

Article history:
Received 14 August 2013
Received in revised form
25 October 2013
Accepted 1 November 2013
Available online 27 November 2013

Keywords:
East Asian monsoon
Organic paleothermometry
Loess
GDGT

ABSTRACT

Our current understanding of past changes in East Asian summer monsoon (EASM) precipitation intensity derives from several loess–paleosol sequences and oxygen isotope ($\delta^{18}O$) records of well-dated stalagmites. Although temperature is generally presumed to have had minimal impact on EASM records, past air temperature dynamics over East Asia are, so far, relatively poorly understood, mainly due to the lack of tools to reconstruct continental paleotemperatures. Here we report a high-resolution record of East Asian air temperature over the past 130,000 years, based on soil bacterial lipid signatures preserved in a loess–paleosol sequence from the Mangshan loess plateau in China. We find that maximum local insolation is the main driver of air temperature, although greenhouse gas concentrations and southern hemisphere climate may influence temperature at times when insolation is weak, causing a decoupling with EASM precipitation intensity. Direct comparison of our temperature record with precipitation-induced changes in past soil pH, derived from the same suite of lipids confirms this decoupling. Subsequent cross-spectral analysis of the two molecular proxy records reveals that variations in monsoon precipitation consistently lag those in air temperature throughout the whole record at the dominant precession band. The length of this lag is variable however, and increases as glaciation develops. This observation is consistent with an increasing influence of northern hemisphere ice sheets on the modulation of EASM response to insolation forcing during ice ages.

1. Introduction

The Asian Monsoon is a fundamental component of the global climate system, and a key factor influencing the sustainable development of densely populated East Asia (An et al., 2000). Our current understanding of past changes in the East Asian Summer Monsoon (EASM) precipitation dynamics is mainly based on a series of precisely dated oxygen isotope ($\delta^{18}O$) records from several caves in China, which so far cover the past four Glacial–Interglacial cycles (Wang et al., 2001, 2008; Yuan et al., 2004). Longer EASM records (i.e. up to 22 Ma) have been derived from various sediment properties (grain size, magnetic susceptibility) of loess–paleosol sequences from the Chinese Loess Plateau (Guo et al., 2002). The loess- and speleothem-based reconstructions show that the intensity of the EASM generally follows the precession-driven pattern of Northern Hemisphere (NH) July insolation. The latter has consequently been proposed as the main driver of the EASM (Yuan et al., 2004; Wang et al., 2008; Cheng et al., 2009), on the basis that modern monsoon precipitation reaches its maximum in July (Wang et al., 2008). However, modelling studies have indicated that seasonal signals can not be directly up-scaled to orbital timescales (Kutzbach et al., 2008; Ziegler et al., 2010), and that maximum monsoon response is actually forced by annual maximum insolation, a parameter that leads reconstructed changes in monsoon precipitation by several thousand years (Kutzbach et al., 2008; Clemens et al., 2010; Ziegler et al., 2010). To explain this mismatch, some authors have suggested that loess- and speleothem-based EASM reconstructions may not reflect a pure precipitation signal, but potentially also contain a temperature component (Clemens et al., 2010), as temperature has an influence on both the calcite/water fractionation of oxygen isotopes and soil forming processes (Jenny, 1941; Wang et al., 2001). However, our

* Corresponding author. Tel.: +41 44 6323358.
E-mail address: Francien.peterse@erdw.ethz.ch (F. Peterse).

0277-3791/$ – see front matter
http://dx.doi.org/10.1016/j.quascirev.2013.11.001

current knowledge on the evolution of continental temperature in East Asia is very limited, mainly due to the lack of suitable proxies to generate the desired high-resolution temperature records.

Promising candidates to fill this gap are the recently developed continental paleoclimate proxies based on branched glycerol dialkyl glycerol tetraether (brGDGT; Appendix A) membrane lipids of soil bacteria. BrGDGT-producing organisms presumably adjust the molecular structure of their cell membranes to the environmental conditions, notably air temperature and soil pH, in their living environment, and these signatures are preserved in soils and sediments (Weijers et al., 2007b). Hence, brGDGTs in sedimentary archives provide a new window on past continental air temperature variability. Paleotemperature can subsequently be quantified using a combination of the MBT (methylation of branched tetraethers) and CBT (cyclisation of branched tetraethers) indices and a transfer function (Weijers et al., 2007b, and recently revised by Peterse et al., 2012). Initial application of the MBT–CBT indices as a 'paleothermometer' to loess–paleosol sequences from the Mangshan, Yuanbao, and Lantian sections of the Chinese loess plateau (Fig. 1) indicates that brGDGTs have recorded changes in continental air temperature spanning at least the past 110 ka (Peterse et al., 2011; Gao et al., 2012; Jia et al., 2013). However, these records are either too short (Peterse et al., 2011; Jia et al., 2013) and/or have insufficient resolution (Gao et al., 2012; Jia et al., 2013) to accurately constrain potential forcing mechanisms of air temperature over a full glacial–interglacial cycle.

To better understand the history of continental air temperature variability in monsoonal Asia, we have applied the MBT–CBT paleothermometer to a ~34 m thick loess–paleosol sequence from the western part of the Mangshan section of the Chinese loess plateau, thereby extending a previous record from this section covering the last deglaciation (Peterse et al., 2011) to the past 130,000 years. In addition to the temperature record, we also derived a record of past soil pH using the CBT index. Soil pH is strongly influenced by precipitation, so that changes in precipitation dynamics in the past can be reconstructed from such paleo-soil pH records (e.g. Weijers et al., 2007a). Since both records are based on the same suite of brGDGTs, this allows us to directly compare the records to evaluate the relative timing and magnitude of changes in continental air temperature and EASM precipitation intensity (soil pH) over the timespan of the Mangshan loess–paleosol sequence while eliminating potential biases associated with age model uncertainties.

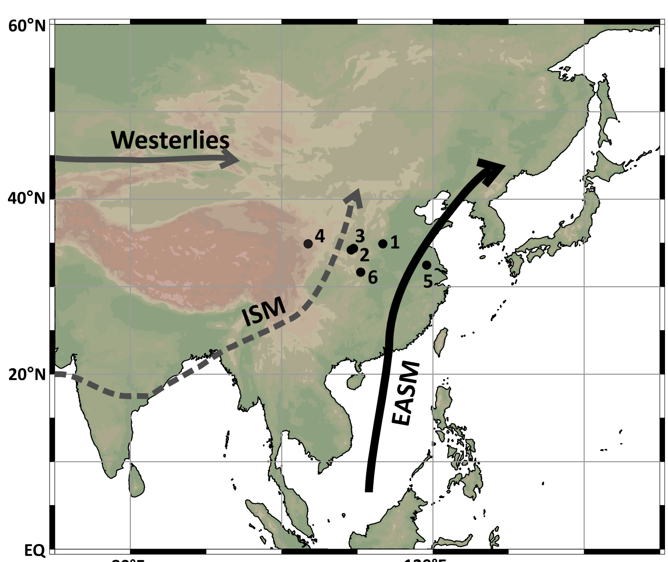

Fig. 1. Overview map of Southeast Asia. The locations of the Mangshan loess plateau (1), the Lantian (2), Weinan (3), and Yuanbao (4) loess sections, and the Hulu (5) and Sanbao (6) caves. Arrows indicate the wind directions of the monsoon systems discussed in the text (adapted from Cheng et al., 2012). EASM is East Asian Summer Monsoon; ISM is Indian Summer Monsoon.

2. Material and methods

2.1. Study site

The Mangshan Loess Plateau is situated 25 km west of Zhengzhou, on the south bank of the Yellow River (Fig. 1). The plateau receives about 645 mm precipitation per year, more than 70% of which falls during the summer monsoon season. Mean air temperatures during the wettest months vary from 15 °C (April, October) to 27 °C (July). Two loess–paleosol sequences were sampled at Mangshan in 2008 in 26 overlapping vertical trenches at 10 cm-resolution and cover the S0 (Holocene paleosol), L1 (Last Glacial loess deposit), S1 (Last Interglacial paleosol), and just reaches the L2 (MIS6 loess deposit). The sampling strategies as well as the source of the loess have been thoroughly described previously (Prins et al., 2009; Peterse et al., 2011). The 14 m thick eastern section (34°56.1′N, 113°22.4′E) covers the S0 and part of the L1, whereas the nearby western section (34°56.4′N, 113°22.2′E) is 34.4 m thick and covers the complete sequence.

2.2. Grain size analysis

Loess samples were prepared for grain size measurements (Konert and Vandenberghe, 1997). In short, organic carbon and carbonates were removed from each loess sample (1–2 g) with solutions of 30% H_2O_2 and 1 N HCl in deionized water, respectively, and additional aliquots of the solutions were added until reaction stopped. Grain size of the siliciclastic loess fraction was measured on a Fritsch Analysette 22 laser particle sizer at the VU University Amsterdam.

2.3. Magnetic susceptibility and $CaCO_3$ analysis

Loess samples were over dried at 50 °C, lightly ground and aliquots of ~8 g were analysed using a Bartington MS2 magnetic susceptibility meter at the School of Ocean and Earth Sciences, Tongji University. The $CaCO_3$ content of the samples was analysed using a Leco TGA 601 at the VU University Amsterdam.

2.4. BrGDGT analysis

BrGDGTs were extracted (3×) from ~20 g homogenized loess with dichloromethane (DCM):methanol (9:1, v/v) using an accelerated solvent extractor (ASE 200, Dionex) at 100 °C and 7.6×10^6 Pa. The extracts were dried under N_2 and a known amount of C_{46} GDGT-standard was added before separation into apolar and polar fractions by passing them over a silica (deactivated with 5 weight% water) column eluting with hexane:DCM (9:1, v/v) and DCM:MeOH (1:1, v/v), respectively. The polar fraction, containing the brGDGTs, was dissolved in hexane:isopropanol (99:1, v/v) and filtered over a 0.45 μm PTFE filter prior to analysis using an Agilent 1260 Infinity series high performance liquid chromatography/atmospheric pressure chemical ionization–mass spectrometry (HPLC/APCI–MS) system at ETH Zürich. The HPLC/APCI–MS settings were according to Schouten et al. (2007), with minor modification. Briefly, compound separation was achieved with a Grace Prevail Cyano column (150 mm × 2.1 mm; 3 μm), preceded by a guard column of the same material. The brGDGTs were eluted isocratically with 90% A and 10% B for 5 min and then with a linear