

Zheng et al., 2017, Atmospheric connections with the North Atlantic enhanced the deglacial warming in northeast China: *Geology*, doi:10.1130/G39401.1.

S1. Research region and Materials

The Hani peat deposit (42°13'N, 126°31'E) is situated in Liuhe County in Jilin Province at an elevation of 910 m on the western flank of the Changbai Mountains (Fig. 1; Zhou et al., 2010). The area has a humid monsoon climate, with a long cold winter and short cool summer. The annual mean temperature is 4 to 6 °C, with monthly mean temperatures that range between −18 °C in January and 22 °C in July. The annual mean precipitation is about 750 mm, mostly delivered as rain by the East Asian Summer Monsoon from May to September. The Hani peats formed after infilling of a shallow lake created by volcanic damming of the Hani River during the late Pleistocene Nanping period. Peat presently covers an area of 18 km² in the swampy valley and is about 4.6 m thick on average (9.6m maximum). Our samples are from an 885 cm core collected from near the center of the Hani mire. The core consists of 574 cm of brown to dark brown acid peat containing a large amount of undegraded plant residue, underlain by 11 cm of brown peat with sand and then 262 cm of dark brown peat. Below 847 cm depth, the sediment is grayish-green mud, representing the original lacustrine depositional conditions. The core was transported intact to the laboratory where it was subsampled at 1-cm intervals and stored at −20 °C.

S2. ¹⁴C dating and chronology

Sample pretreatment, AMS-target preparation and AMS measurement were all conducted at the Xi'an AMS Laboratory. The pretreatment of 9 samples for ¹⁴C dating was performed using the method of Zhou et al. (2002): plant fragments with a size ranging between 90 and 300 µm were isolated from peats by wet sieving, and then subjected to an Acid-Alkali-Acid (HCl-NaOH-HCl) treatment. One sample of total organic matter (TOC) from bulk mud sediments at the bottom lacustrine layers was processed using 10% HCl to remove all carbonate content before graphitization (Zhou et

al., 2004). AMS-targets were prepared from the pretreated samples, which were then placed with CuO powder into 9 mm quartz tubes, evacuated to $<10^{-5}$ torr, and then combusted. The CO₂ was converted catalytically to graphite using Zn (Zn powder with added Fe powder as a catalyst) (Slota et al., 1987). The calibrated ages were obtained from the ¹⁴C ages using the northern hemisphere INTCAL13 curve (Stuiver et al., 1993; Reimer et al., 2013). In order to produce the reliable ages for all depths in Hani core, we used Bayesian age-depth modeling software Bacon (Blaauw et al., 2011) to estimate ages and uncertainties for each sample (Fig. DR1 and Table DR1). The model provides a firm chronological framework for the past 16000 years.

S3. Temperature proxies

The mean annual temperature proxy based on the global peat calibration

Separation of 5-and 6-methyl brGDGTs was achieved with two silica columns in tandem (150 mm × 2.1 mm, 1.9 μm, Thermo Finnigan; USA) maintained at 40 °C. GDGTs were ionized in an atmospheric pressure chemical ionization (APCI) chamber with single ion monitoring at *m/z* 1050, 1048, 1046, 1036, 1034, 1032, 1022, 1020 and 1018. The MS conditions followed Hopmans et al. (2000). The brGDGTs were quantified from integrated peak areas of the [M+H]⁺ ions.

To derive air temperature from brGDGT distributions in the peats, we used the global peat calibration of Naafs et al. (2017). This calibration is based on 470 peat samples from 96 different peats from around the world with a broad temperature range from -8–27 °C. The standard (or root mean square) error of the new calibration is 4.7 °C.

$$(1) MBT'_{5ME} = \frac{(Ia + Ib + Ic)}{(Ia + Ib + Ic + IIa + IIb + IIc + IIIa)}$$

$$(2) MAAT_{peat} = 52.18 \times MBT'_{5me} - 23.05$$

Roman numbers represent the different molecular structures of the brGDGTs, reflecting the relative number of methylations or cyclopentane moieties (See Naafs et al.

(2017) for structures). The new peat calibration is predominantly based on peats from the regions between 40°N and 60 °N, which covers the latitude of the Hani region (ca.42 °N). The temperature calibration range is -8 to 27 °C, which also covers the entire range of temperature reconstructed from our core. Due to the error of the peat calibration, Naafs et al. (2017) urged caution in any application to reconstruct late Holocene temperature variability, but demonstrated that MAATpeat yields absolute temperatures and relative temperature changes that are consistent with those reconstructions based on other temperature estimates. Therefore, this peat calibration is well-suited to reconstruct large amplitude and more long-term temperature excursions such as those associated with the last glacial termination and early Holocene. The Hani peat core is 885 cm long and covers the last 16kyr. In addition, the temperature estimates from the core top peat sediments based on the peat calibration agree well with the modern values. Taken together, the new peat calibration is reliable to be applied in quantify the temperature variations in the Hani peats.

Other paleotemperature proxies used for comparison

The mean annual temperature estimates based on the global soil calibrations: We compared our MAATpeat with other MAATs based on the global soil calibrations (MBT(′)/CBT method (Weijers et al., 2007a; Peterse et al., 2012) in the loess-paleosol sequences. The error of the soils calibration for Weijers et al. (2007a) is $\sim\pm 4.8^{\circ}\text{C}$ and for Peterse et al. (2012) is $\pm 5.0^{\circ}\text{C}$. The MAATs based on soil calibrations from previous studies and cited here have been largely reconstructed in soils (including the loess-paleosol sequences) but also in some cases lake and marine sediments (Weijers et al., 2007b; Loomis et al., 2011; Peterse et al., 2014).

The peat cellulose $\delta^{18}\text{O}$ temperature record: Changes in peat plant cellulose $\delta^{18}\text{O}$ mainly reflect changes in $\delta^{18}\text{O}$ of the water that the plants use, i.e., wetland water and by extension precipitation. The $\delta^{18}\text{O}$ changes in precipitation can correspond to air temperature changes but also hydrological changes. Thus, the $\delta^{18}\text{O}$ of peat swamp plant cellulose could serve qualitatively as a proxy indicator for average annual temperature (Hong et al., 2009).

Mean annual temperatures (T_{Ann}) derived from pollen records: The accuracy of the

pollen-based temperature reconstruction in Japan done by the best modern analogues method has been checked using the surface pollen dataset at 285 sites (Nakagawa et al., 2005). The error of the temperature estimates is $\pm 2^{\circ}\text{C}$.

$\delta^{18}\text{O}$ -based NGRIP temperatures: The temperature calibration is $T = 3.05 * \delta^{18}\text{O} + 75.4$, but the error was not shown (Cuffey et al., 1997).

S4. Climate model simulation and its relevant result

In this study we used results from a long-term transient climate simulation spanning 21000 years, from the last glacial maximum to today (TraCE-21ka). The model used is the atmosphere-ocean-sea ice-land surface fully-coupled Community Climate System Model version 3 (CCSM3) with the T31_gx3 resolution (Versteinsten et al., 2004). The TraCE-21ka simulation was forced with transient greenhouse gas concentrations and orbitally-driven insolation changes. Transient boundary conditions include the ICE-5G ice sheets - extent and topography, and changing paleogeography as sea level rises from its Last Glacial Maximum low stand to modern levels. A transient scenario of meltwater forcing to the oceans from the retreating ice sheets was also prescribed. See Liu et al. (2009) and He (2011) for details about the simulation.

In our analysis, the simulated surface air temperature over the last deglaciation were extracted and employed. The reconstructed $\text{MAAT}_{\text{peat}}$ at the Hani region and the modelled temperature time series based on the transient model simulation do not match well over the last deglacial period (Fig. DR2). The $\text{MAAT}_{\text{peat}}$ record shows more rapid shift than the modelled temperatures. The simulated temperature shows a smaller shift but it is within error and still larger than in other sites. This might mainly due to the low resolution of the model. In addition, the modelled temperature shows a gradual Holocene warming while the $\text{MAAT}_{\text{peat}}$ record shows a cooling. This is a common observation between the model and data for the Holocene (See Liu et al., 2014). Overall, a comparison of the $\text{MAAT}_{\text{peat}}$ and modelled temperature records show that there is a consistent warming and large shift from 16 kyr BP to 10 kyr BP. The OD cold is markedly colder than the PB warm stage in NE China. Thus, we chose the simulation years for ca.16.18-14.498 cal kyr BP and 11.5-10.7 cal kyr BP as OD and PB,

respectively, to explore spatial temperature change. The averaged time interval for the OD is ca. 1580 yrs and for the PB is ca.800 yrs. The two time intervals are much larger than 50 years, which coincide with the relevant freshwater forcing applied to the model (Liu et al., 2009). Figure 3 in the main text shows the simulated surface air temperature difference between the OD and PB, and in particular reveals a larger temperature change in NE China including Hani than at more southern and western Asian sites.

Table DR1. Results of ^{14}C AMS dating from Hani Peats in Northeastern China.

Depth(cm)	Date material	^{14}C age (a BP)	Uncertainty (a)	Calibrated age (Cal a BP)
48	Plant fragments	Modern		
155	Plant fragments	1810	28	1629 —1822
260	Plant fragments	3604	35	3832—4065
353	Plant fragments	5260	42	5927—6180
428	Plant fragments	6710	56	7483—7668
492	Plant fragments	7890	49	8588—8977
568	Plant fragments	9080	51	10175—10387
680	Plant fragments	10348	46	12011—12396
755	Plant fragments	11216	48	12993—13175
880	TOC	15802	85	18852—19304

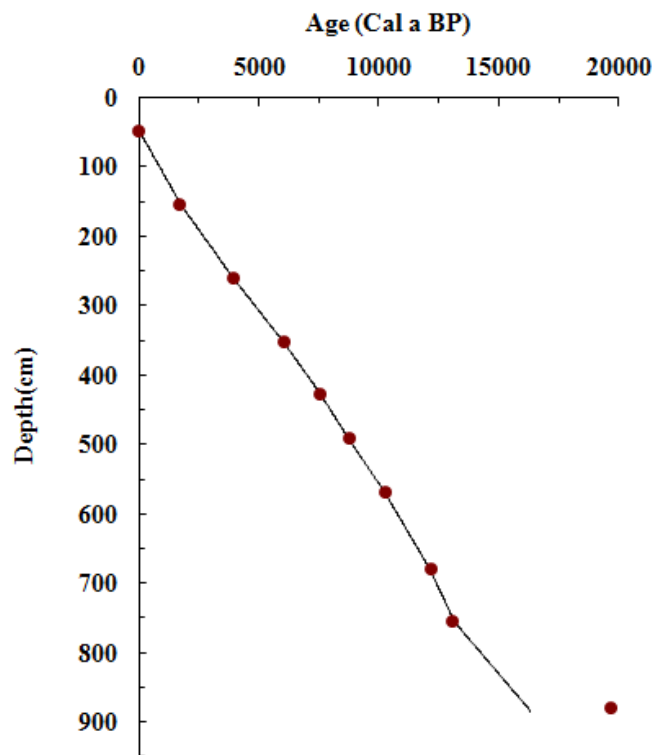


Figure DR1: Calibrated radiocarbon ages plotted against the peat depth. Ages between the measured horizons are obtained by Bacon age model.

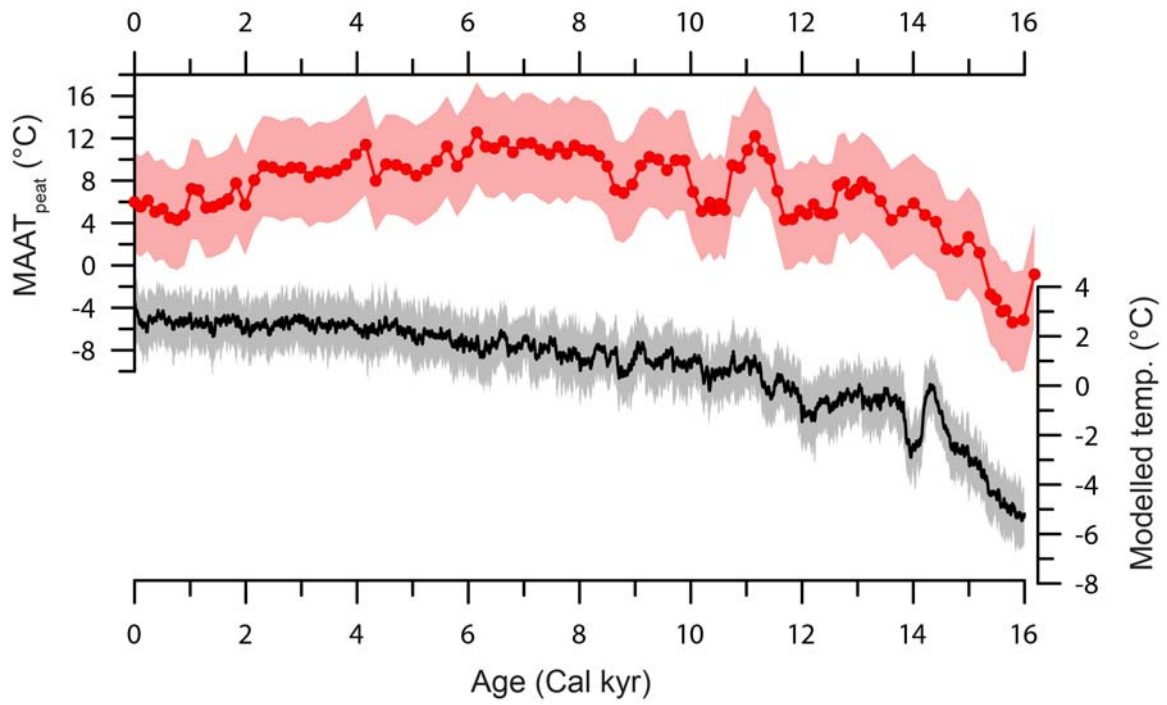


Figure DR2: The temperature series based on MAAT_{peat} and the transient simulation (30pt moving average) over the last deglaciation at the Hani region.

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