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Palynological study on vegetation and climatic change in the subaqueous Changjiang (Yangtze River) delta, China, during the past about 1600 years

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ABSTRACT: The well-defined pollen record in massive marine clay deposits from the subaqueous Changjiang (Yangtze River) delta reveals changes in vegetation and inferred climate during the last about 1600 years. Climatic periods inferred from the pollen record include (1) a basal cool/dry period (AD 385–910), (2) a relatively warm/wet conditions comparable to Medieval Warm Period (AD 910–1085) with a strengthen summer monsoon, (3) a relatively cool and wet conditions possibly corresponding to Little Ice Age (LIA; AD 1085–1815) with a weaken summer monsoon, and finally (4) the present warm period, since AD 1815. The pollen aridity index based on variations in humidity suggests that three subperiods within the LIA can be identified: wet LIA-1 (AD 1085–1170), dry LIA-2 (AD 1170–1330), and wet LIA-3 (AD 1330–1815).

Key words: pollen, medieval warm period, little ice age, subaqueous changjiang (Yangtze River) delta

1. INTRODUCTION

The Changjiang (Yangtze River) delta in eastern China is characterized by the East Asian monsoon that has characteristics of hot, wet conditions during the summer and cool, dry conditions during the winter. In summer, a subtropical high pressure system occupies the region, and the monthly mean of the daily maximum temperature is up to 28.9 °C, whereas in winter, the region is under the influence of the Siberian high pressure system, and the minimum temperature is about 2 °C (Jiang 1991). Climatologically, the region is sensitive to environmental change because it lies along the boundary between subtropical and temperate climatic regions where seasonal frontal zones separate highly contrasting air masses.

Today, the mouth of the Changjiang is 120 km long and 90 km wide at its outer limit. The inner continental shelf on which the Changjiang delta is built has a gradient of <1‰ (Yang et al. 2003). About half of the sediment carried by the Changjiang is deposited in the river-mouth area (Chen et al. 1985), with the result that the delta has prograded at a rate of 10 cm/yr in recent centuries (Yang et al. 2001). Approximately 12 000 km^2 of new land has been created in the river-mouth area during the past 2000–3000 years by the deposition of riverine sediments (Hori et al. 2001; Yang et al. 2001). The present Changjiang prodelta receives most of the riverine sediment (Chen et al. 1985) and therefore contains a record of the subaqueous delta environment for the past 2000 years. Vibrocore Y8 was drilled into the prodelta about 50 km off the coast (Fig. 1) and hence is strategically situated in an area where records of both river sediments and vegetation cover in the region near the river are preserved. The radiocarbon-dated, high-resolution pollen record from Y8 is presented to fill a gap in the reconstruction of the late Holocene climate of eastern China.

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2. MATERIALS AND METHODS

Sediment core Y8 was obtained from the Changjiang prodelta (Chen et al. 2000) at a water depth of 29.5 m (latitude 31°01.1'N, longitude 122°47.0'E) and consists of light- to dark-gray silty clay and clayey silt. Thirty-nine dried samples of about 10 g each were collected at 10-cm interval for pollen analysis. Pretreatment for pollen analyses followed the standard method of Moore et al. (1991). The percentages of arboreal pollen (AP), nonarboreal pollen (NAP), and spores were calculated from the total palynomorph sum. Raw data were converted into percentages using TILIA v2.0 (Grimm 1993). TILIAGRAPH v1.25 (Grimm 1991) was used to generate the pollen diagram, which was subdivided into pollen zones by using constrained cluster analysis (Grimm 1987) (Fig. 2). Pollen taxa used to generate the zonation dendrogram included AP and NAP with values of at 2% in two intervals. Six radiocarbon dates were obtained from Y8 (Table 1).

3. PALYNOLOGICAL RECORD AND INTERPRETATION

Five pollen zones were established with ages presented in calibrated calendar years by using Calib 4.3 with the INTCAL 98 reference curve of Stuiver et al. (1998) (Fig. 2). The pol-

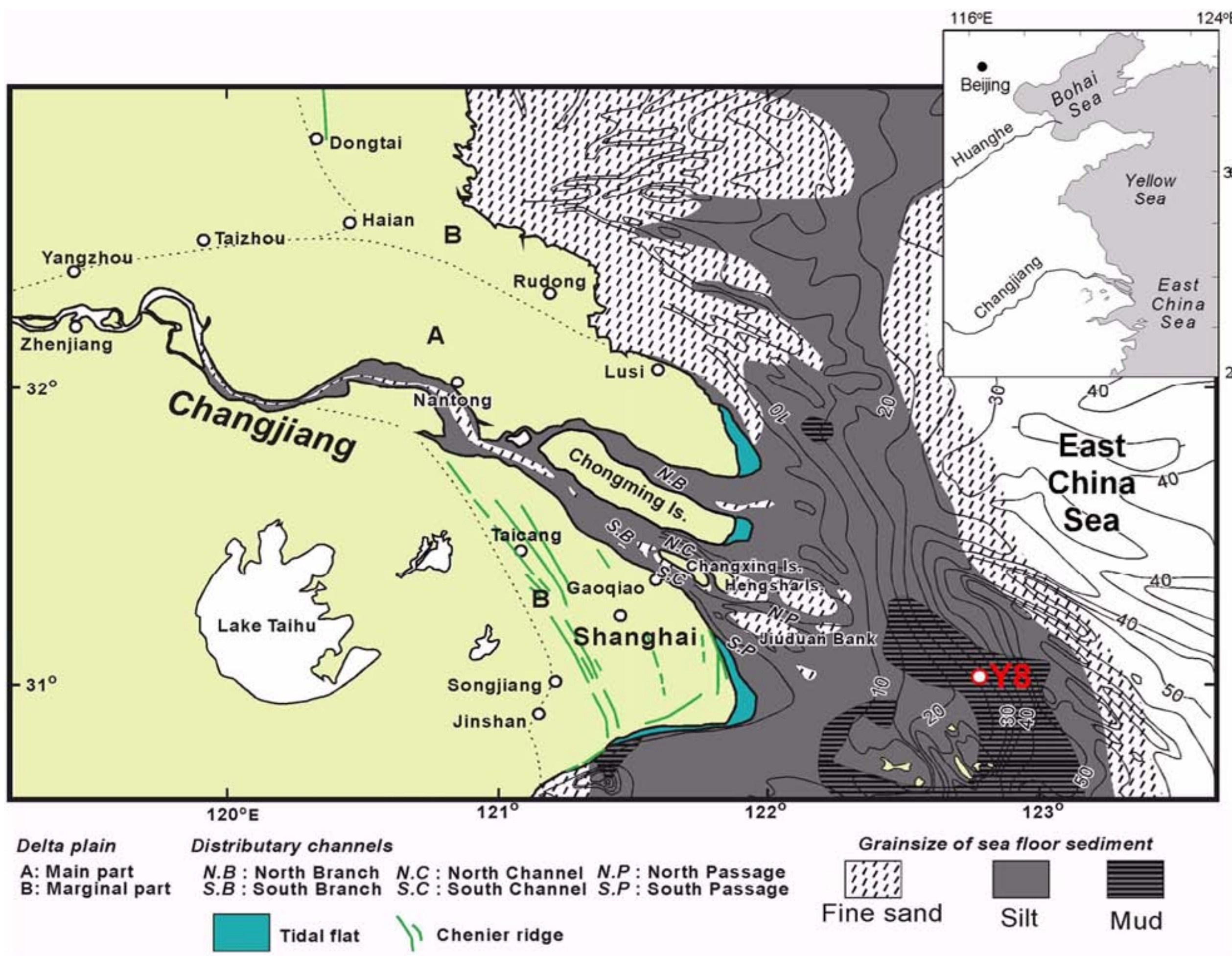

Fig. 1. Location map showing the study area in the Changjiang subaqueous delta (modified from Hori et al., 2001).

len records of Y8 reveal changes in the vegetation composition and inferred climate during the past about 1600 years. Conifers, *Pinus* (*Diploxylon*), predominate among the AP, along with common tropical monsoonal evergreen and broad-leaved deciduous trees such as *Quercus* (*Cyclobalanopsis*), *Q. (Lepidobalanus), Pterocarya, Salix* and Taxodiaceae. Herbs, including Cyperaceae and Gramineae, with common Chenopodiaceae dominate among the NAP (Figs. 2 and 4). In general, the palynofloral assemblages of Y8 are closely comparable to those of previous studies (Wang et al. 1981, 1984) from the Changjiang subaqueous delta and continental shelf of the East China Sea.

In eastern China today, Chenopodiaceae and *Artemisia* are high pollen producers in cool and arid regions, whereas Cyperaceae and Gramineae exhibit low pollen production under those conditions. Here, we adopted the semiquantitative aridity index of Fowell et al. (2003), calculated by dividing the sum of Chenopodiaceae plus *Artemisia* pollen by the percentage of Gramineae pollen. High values of the index are indicative of relatively dry conditions, whereas low values are associated with relatively humid intervals (Fig. 4).

During the basal period (AD 385–910; Pollen Zone Y8-I), cool, dry climatic conditions are indicated by the possibly mixed coniferous and broad-leaved deciduous forest consisting mainly of pine, *Pinus* (*Diploxylon*) and hardwood trees, including oak [*Quercus* (*Lepidobalanus*)], birch (*Betula*) and Taxodiaceae, and cool-loving grasses. Relatively high values of the aridity index (Fig. 4) indicate that the prevailing climate was drier than at present. This interpretation can be supported by the phenological data indicating cooler at AD 490s with temperature reached about 1 °C lower than that of today, for eastern China region (Ge et al. 2003).

The possibly Medieval Warm Period (MWP; AD 910–1085), which corresponds to Pollen Zone Y8-II, was warm with high humidity, as reflected by the sudden increase in the subtropical monsoonal evergreen oak, *Quercus* (*Cyclobalanopsis*), which is present along with diverse broad-leaved deciduous trees such as *Q*. (*Lepidobalanus*), *Salix*, *Pterocarya*, *Corylus/Ostrya, Liquidambar,* and *Castanopsis/Lithocarpus* (Fig. 2). Although *Liquidambar* is a broad-leaved deciduous tree, it is a common subtropical element in the forests of south China (Li et al. 1995). The low val-

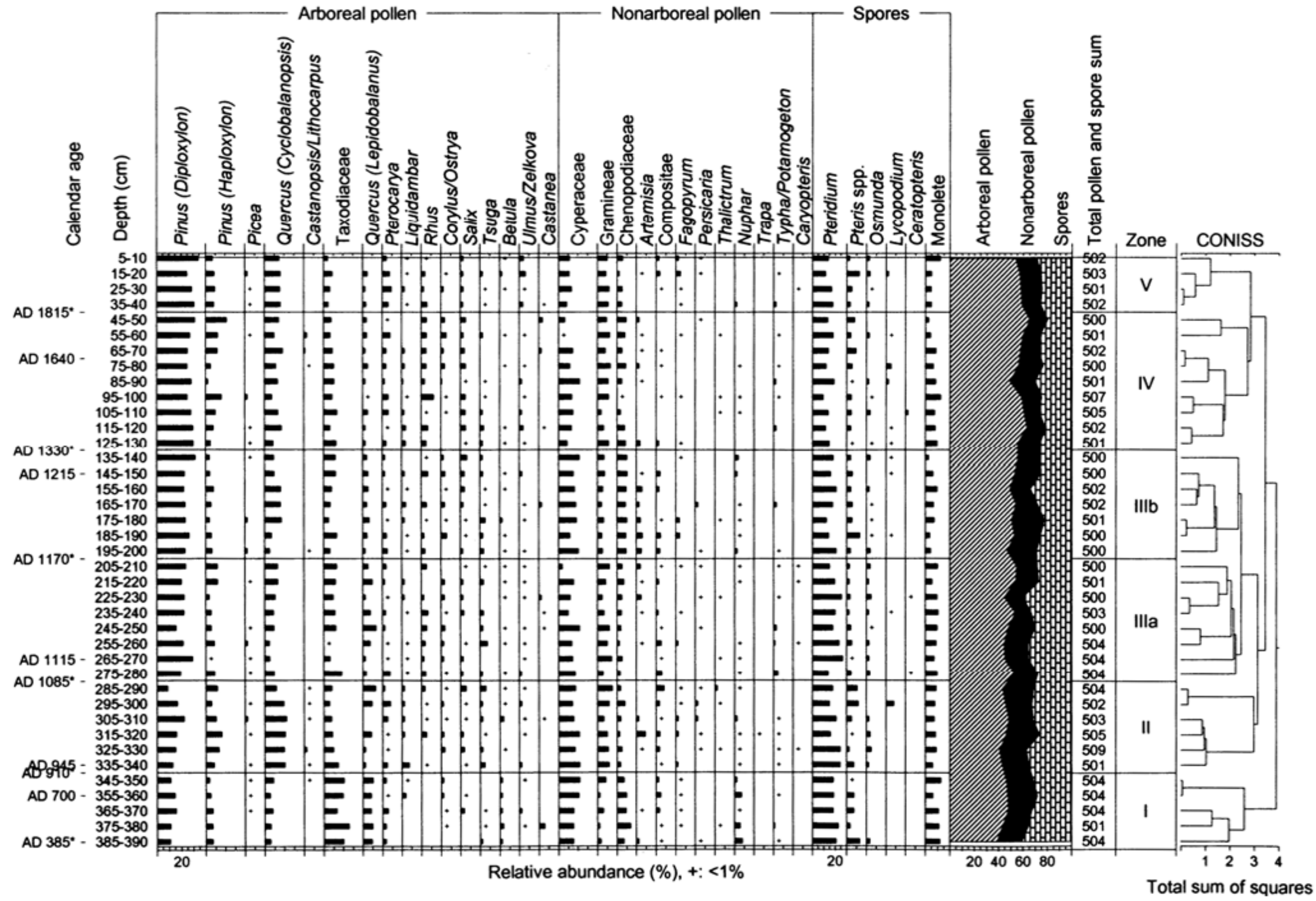

Fig. 2. Diagram showing selected pollen profiles for Y8 from the Changjiang subaqueous delta. Calibrated radiocarbon dates are shown on the left side of the diagram. The dendrogram on the right side was generated by constrained cluster analysis with CONISS software (Grimm, 1987). AP: arboreal pollen; NAP: nonarboreal pollen. * indicates an age estimated from the age–depth diagram in Figure 3.

Table 1. List of ^{14}C ages used for chronology from Y8. Calendar years were recalculated on the basis of Stuiver et al. (1998)

Depth (cm)	Materials	^{14}C age yr BP	Conventional ^{14}C age (yr BP)	Calendar age	Calendar yr BP	Code no. Beta-
72	*Scapharca subcrenata* (Lischke)	230±40	650±40	AD 1640	310	140917
147	*Moerella iridescens* (Benson)	740±40	1130±40	AD 1215	735	140918
266	*Nitidotellina minuta* (Lischke)	790±40	1180±40	AD 1115	835	140919
334	*Nitidotellina* sp., Moerella rutila (Dunker), shell fragments	1180±40	1580±40	AD 770	1180	140920
334	*Scapharca broughtonii* (Schrenck)	1020±40	1410±40	AD 945	1005	140921
356	*Saccella (Saccella) gordonis* (Yokoyama), *Cadella delta* (Yokoyama)	1240±50	1650±50	AD 700	1250	140922

ues of the aridity index (Fig. 4) and the coincident increase in the abundance of Cyperaceae pollen suggest that the climate had become wetter. Our interpretation is also supported by the Beijing stalagmite record (Qian and Zhu 2002), which indicates that precipitation increased as the monsoon became stronger between AD 960 and AD 1180 in China. As demonstrated by both phenologic data (Chu 1973; Ge et al. 2003) and multiple paleoclimate proxy records of ice core, tree ring, lake C/N, lake TOC and peat (Yang et al. 2002) from China, the mean temperature during this period was 1–2 °C warmer than that of today.

The possibly Little Ice Age (LIA; AD 1085–1815), which comprehends Pollen Zones Y8-III and Y8-IV, is characterized by generally cool and wet conditions, as reflected by abrupt reductions in the subtropical monsoonal evergreen *Quercus* (*Cyclobalanopsis*) and broad-leaved deciduous trees and, in contrast, the increasing frequency of pine (*Pinus*) (Figs. 2 and 4). Moisture-loving grassland herbs such as Chenopodiaceae, Cyperaceae and *Artemisia* are well represented, whereas grassland taxon preferring relatively arid conditions (Gramineae) is somewhat low in frequency (Fig. 4). The cool and wet climatic conditions caused the contraction

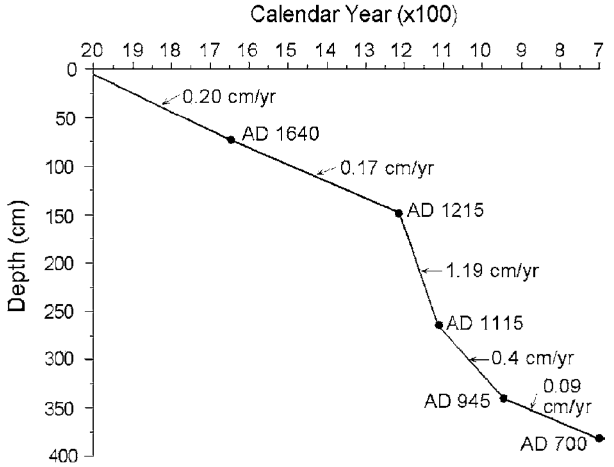

Fig. 3. Age–depth relationship for Y8. Sedimentation rates were calculated by linear interpolation between calibrated ^{14}C ages.

of the thermophilous hardwood forest and the expansion of coniferous forests and grassland. Multiple paleoclimate proxy datasets (e.g., Chu 1973; Shi et al. 1999; Qian and Zhu 2002; Yang et al. 2002; Ge et al. 2003) record cool conditions in eastern China beginning about 780 BP (AD 1170) followed by a warmer and wetter MWP. In this study, the Little Ice Age from AD 1085 to AD 1815 can be subdivided into three events, LIA-1 (AD 1085–1170), LIA-2 (AD 1170–1330), and LIA-3 (AD 1330–1815), on the basis of the pollen assemblages and the aridity index (Figs. 2 and 4).

During LIA-1 (AD 1085–1170) is almost same humidity as MWP, as reflected by the aridity index. The apparent decline in the subtropical monsoonal evergreen and broad-leaved deciduous mixed forest and the increase in conifers reflect the climatic cooling that occurred during the early LIA. LIA-2 (AD 1170–1330) was possibly a brief arid interval recorded by a spike in the aridity index and remarkable

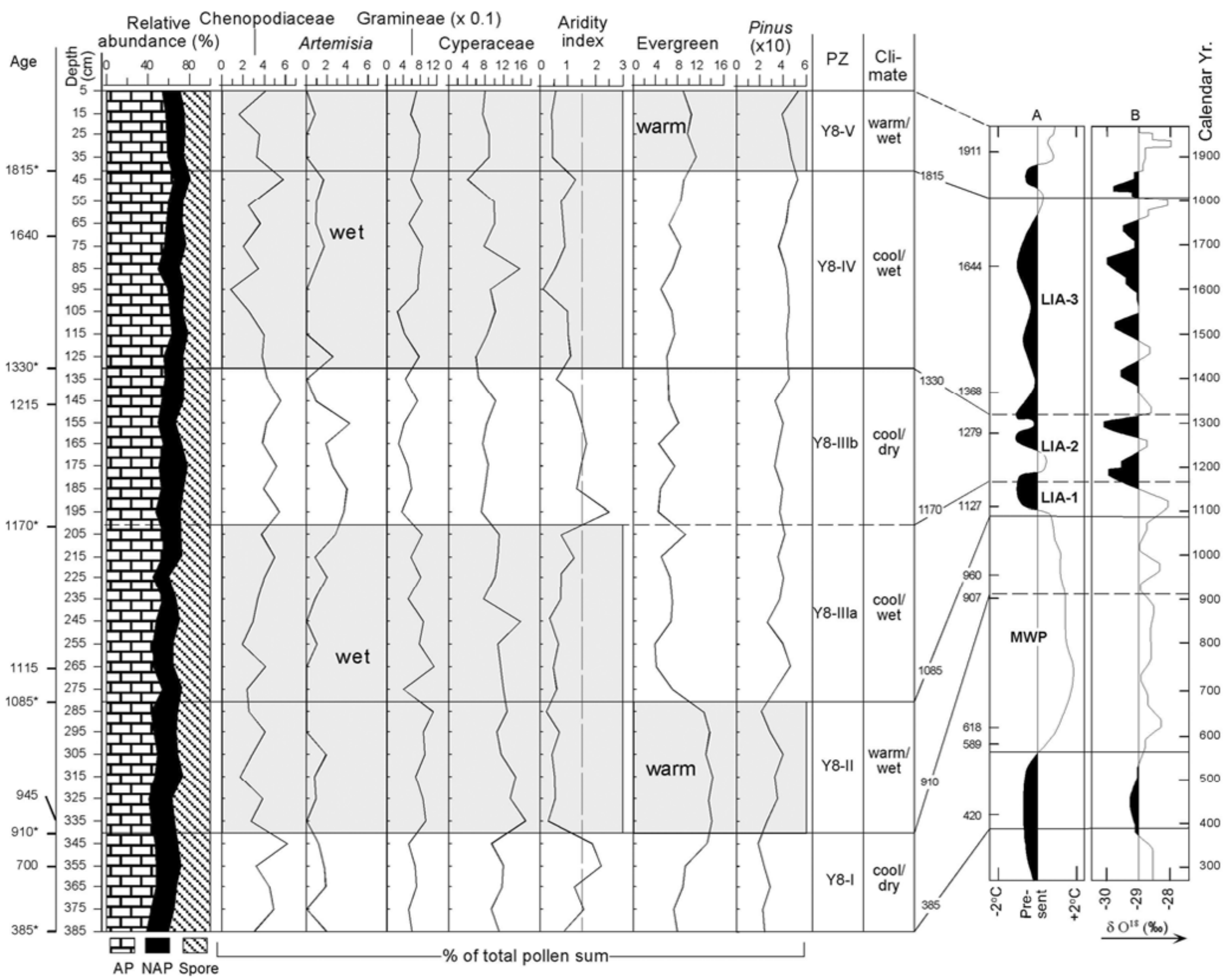

Fig. 4. Schematic diagram showing the pollen zones with climatic changes during the last about 1600 years in the Changjiang delta region. A: Phenologic data for China (from Chu, 1973); B: Greenland ice sheet (GRIP). MWP, Medieval Warm Period; LIA, Little Ice Age. Aridity index=(Chenopodiaceae+*Artemisia*)/Gramineae. *indicates an age estimated from the age–depth diagram in Figure 3.

increases in dry grassland plants, including Gramineae, whereas the decreases in moisture-loving grasses such as Chenopodiaceae and *Artemisia*. LIA-3 (AD 1330–1815) marked a return to relatively humid conditions following the brief arid interlude. The wet conditions are signaled by low values of the aridity index. The Beijing stalagmite record and historical documents (Qian and Zhu 2002) also show that precipitation was greater in northeast China from AD 1400 to AD 1610, which falls within LIA-3.

Pollen Zone Y8-V corresponds to a period of increasing humidity (AD 1815–Present), which is characterized by a climatic shift back to warmer and wetter conditions than had prevailed in the preceding interval. These climatic conditions are also shown by a remarkable decrease in the aridity index, which indicates a gradual increase in moisture availability after AD 1815. The pollen spectrum also indicates relatively more humid conditions compared with the preceding interval (Figs. 2 and 4). Similar changes have been reported in China from multiple paleoclimate proxy dataset: pollen assemblages (Liu et al. 1992; Yi et al. 2003), ice cores (Shi et al. 1999), stalagmites (Paulsen et al. 2003) and phenological data (Ge et al. 2003). Furthermore, an enhanced warming trend during the last hundred years has been observed in eastern coastal regions (Wang and Gong 2000; Ge et al. 2003).

Finally, the general cool/warm trends shown in Figure 4 coincide with the temperature changes reconstructed from other natural proxy dataset: pollen (Xia and Wang 2000), stalagmitic varves (Qin et al. 2000), tree rings (Liu and Shao 2000) and lake sediments (Luo and Chen 1997; Cao et al. 2000). Moreover, the cool/warm trends of eastern China during the past millennium are in correspondence with the temperature variation of the Northern Hemisphere (Mann et al. 1999). However, the contrast in the warming intensity between the twentieth century and the Medieval period is less in China than in the Northern Hemisphere (Ge et al. 2003).

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