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# Marine palynological record for tropical climate variations since the late last glacial maximum in the northern South China Sea

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ABSTRACT

The upper part (191–1439 cm) of the marine sediment core MD05-2906 from the northern South China Sea (SCS) was palynologically investigated. The chronology suggested that it covered the record since ~19 calendar kiloyears before present (cal ka BP) and revealed a detailed environmental change history since the late last glacial maximum (LGM). During the late LGM, due to the lowered sea level (~100 m lower) and the shortened distance from the shore to the study site, the pollen concentration was very high. The pollen assemblages were dominated by non-arboreal taxa, especially *Artemisia* pollen, before ~15 cal ka BP. Abundant subtropical and tropical pollen taxa were still important components and a south subtropical climate prevailed during the late LGM. The coexistent rich *Artemisia* pollen possibly was not derived from near shores, but was derived mainly from the northern exposed continental shelf in the East China Sea (ECS). After ~15 cal ka BP, with the rise in the sea level and enhanced distance from the pollen source areas to the core site, pollen concentrations started to decline gradually. However, during the late deglaciation and early Holocene, the higher concentrations of many pollen taxa reoccurred, which cannot be attributed to the sea level changes. *Pinus* pollen deposited in the core, which is considered to be mostly water-carried based on many modern pollen surveys, also started to dramatically increase at the same time. Therefore, the higher pollen concentration, with more *Pinus* and *Typha* (an aquatic plant) pollen indicated a notably enhanced terrestrial runoff and precipitation during the last deglaciation/Holocene transition (~11.3–9.4 cal ka BP). We inferred that a strong summer monsoon occurred at this time. During the late LGM/deglaciation transition period, the pollen assemblage reflected a gradually warming climate, and the climate fluctuations derived from the high-latitudes were not well-identified. This study suggests that solar insolation played a crucial role in controlling the East Asian monsoon and hydrological cycle in the northern SCS.



## 1. Introduction

The climate since the LGM in the SCS has been dynamic, as in most places in the world. Essentially, it was controlled by varying insolation and the associated changes in the volume of the ice sheets at high latitudes as well as other feedback (Ruddiman, 2008). Moreover, the interactions between the continents and the oceans may have played a crucial role, especially during the transition from the LGM to the Holocene; however, this process has not been well recognized (Clark et al., 2012). In East Asia, the climate of the northern SCS is overwhelmed by the East Asian Monsoon (EAM), which is under the co-influences of both low and high latitude factors (mainly the Intertropical Convergence Zone (ITCZ) vs. Siberia high (SH)) (An, 2000). The variations in the timing and amplitude of the EAMs in the region may provide clues about the effects of the low-latitude climate processes on the global changes (Braconnot and Marti, 2003; Wang et al., 2005, 2014a; Wang, 2006).

To date, the changes in the environment and the variations in the EAMs in this region since the late LGM have been recognized in several paleoclimatic proxies (Wang et al., 1999, 2014b; Pelejero et al., 1999; Oppo, 2005; Wei et al., 2007; Yancheva et al., 2007), including several palynological records from the lacustrine and deltaic sediments (Zheng and Li, 2000; Liew et al., 1998, 2006; Wang et al., 2007; Lee and Liew, 2010). To obtain regional terrestrial climate information, a few marine pollen sequences that covered the late Quaternary were investigated in the northern SCS (Sun and Li, 1999; Sun et al., 2003; Chang et al., 2013), but accurate interpretations of most of the pollen data were restrained due to the limited understanding of the pollen source and extensive pollen dispersions in the region, especially in an ocean setting.

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Recently, many modern palynological investigations showed a tight relationship between marine pollen depositions and dispersal approaches (wind and water currents) (Dai and Weng, 2011; Dai et al., 2014; Luo et al., 2014). This finding is significant for more accurate interpretations of pollen data from the sediments, particularly for paleoclimatic reconstruction with high-resolution.

In this study, we choose a drilling core with a high sedimentation rate (core MD05-2906) in the northern SCS for pollen analysis. Our study investigates the regional climate and associated monsoon variations on a millennial scale by reconstructing epicontinental vegetation and pollen transportation processes, which provides clues for evaluating the relative contribution of high and low latitude climate processes in the regional climate since the late LGM.

## 2. Regional setting

The northern SCS is surrounded by southern mainland China, Hainan Island and Taiwan Island and is connected to the ECS and Pacific Ocean by the Taiwan and Bashi straits in the east. The climate is subtropical and tropical with a high temperature (18–24 °C annually) and heavy precipitation (> 1000 mm annually) on average. In summer, with the northward migration of the ITCZ, the region is under the strong influence of the summer monsoon from the southwest, with high temperatures and heavy rainfalls. During the winter, the SH brings in cold and dry air masses and strong N-NE winds (Zhao et al., 1999).

The surface northern SCS circulations are mostly driven by the EAMs and are also affected by the water exchanges between the SCS and the Kuroshio. A strong Guangdong Coastal Current from NE to SW along the northern coast develops in the winter. In the summer, the Guangdong Coastal current is driven by the summer monsoon and its direction reverses (from SW to NE; Fig. 1).

The continental topography surrounding the northern SCS is characterized by widespread hills (mostly < 1000 m), and only a few large mountains on Taiwan Island reach higher heights, with the highest peak of Yushan Mountain attaining an elevation of 3997 m. The submarine topography of the northern SCS is composed of a broad continental shelf, a continental slope and a deep basin that gradually descends from the northern part to the central basin. The continental shelf of the region is one of the broadest shelves in the world and was widely exposed at the glaciations (Wang et al., 2008). The major rivers include the Pearl River and Hanjiang River, which carry vast amounts of terrigenous materials to the northern SCS (Zhao et al., 1999) (Fig. 1).

In eastern China, tropical and subtropical plants gradually increase southwardly, which have a strong link to north–south gradients in the temperature (Fig. 1). In the south, warm and humid climates allow rich flora, among which subtropical broad-leaved evergreen forest is the most common type and is mainly composed of the families Fagaceae (i.e., *Castanopsis* and *Quercus*), Lauraceae, Theaceae, Hamamelidaceae and Magnoliaceae (Wu, 1980).

## 3. Material and methods

Core MD05-2906 (20° 08.16′N, 117° 21.59′E) was taken from the continental slope near Dongsha Island at a water depth of 1,636 m (Fig. 1). The total length of the core was 36.72 m, but the top 1.90 m was not successfully collected. The sediments were composed of olive and gray clay.

For the current study, 156 samples from 1.90–14.39 m were palynologicaly analyzed. All samples were prepared in the palynology lab at the State Key Laboratory of Marine Geology at Tongji University. A pill of the *Lycopodium* spore tablet with 27,637 ± 593 spores/pill was added to each sample prior to chemical treatments in order to calculate the pollen concentration. Hydrochloric and hydrofluoric acids were used to remove carbonates and silicates, and then the residues were sieved over a 7-μm mesh screen in an ultrasonic water bath sink to remove the tiny impurities. At least 200 pollen grains and many more associated spores were counted under a Leica light microscope (400 × magnifications) for each sample.

Essentially, most pollen taxa were identified to a genus. However, the deciduous and evergreen *Quercus* pollen were separated based on morphology. Generally, pollen grains > 32 μm with a scabrate sculpture were recognized as deciduous taxa; in contrast, the pollen grains < 32 μm with a fine sculpture were evergreens (Liu and Fang, 1986; Liu et al., 2007; Cao and Zhou, 2002). In fact, many pollen taxa of evergreen *Quercus* were characterized by a coarse sculpture with < 32 μm size, such as *Quercus kerrii*, *Quercus championii*, and *Quercus guyavaefolia*, which belonged to *Cyclobalanopsis* subg. (Wang and Pu, 2004). In this core, most evergreen *Quercus* pollen belonged to *Cyclobalanopsis* subg.

The pollen percentage diagrams were made with TILIA software. The pollen zones were divided based on the results of a constrained cluster analysis (CONISS) in which the selected taxa included *Pinus*, alpine conifers, tropical and subtropical conifers, temperate components, tropical and subtropical broad-leaved

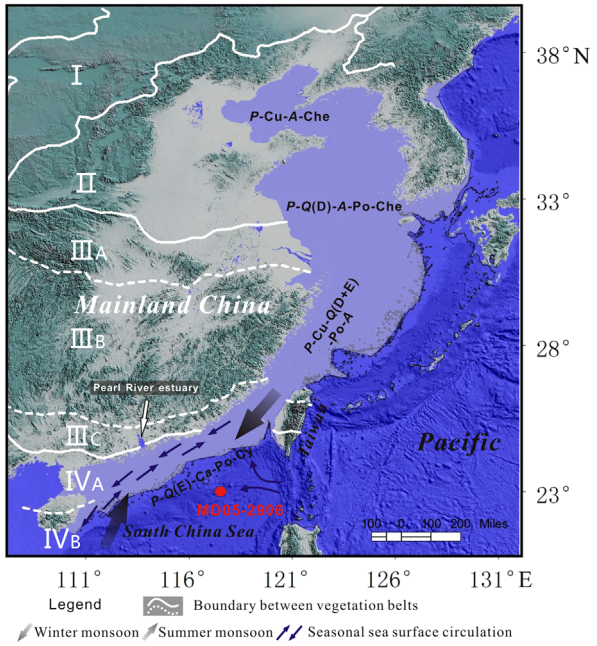


**Fig. 1.** Location of the core MD05-2906, modern vegetation belts (I–V) and combined dominant pollen taxa in adjacent seas.
Note: I, temperate steppe; II, temperate deciduous broad-leaved forest; IIIA, north subtropical evergreen broad-leaved and deciduous mixed forest; IIIB, middle subtropical evergreen broad-leaved forest; IIIC, south subtropical evergreen broad-leaved forest; IVA, north tropical semi-evergreen monsoon forest and tropical moist forest; IVB, south tropical monsoon forest and tropical moist rainforest.
P–Cu–A–Che, *Pinus*-Cupressaceae-*Artemisia*-Chenopodiaceae;
P-Q(D)-A-Po-Che, *Pinus-Quercus* (deciduous)-*Artemisia*-Poaceae-Chenopodiaceae;
P-Cu-Q(D+E)-Po-A, *Pinus*-Cupressaceae-*Quercus*(deciduous and evergreen)-Poaceae- *Artemisia*;
P-Q(E)-Ca-Po-Cy, *Pinus-Quercus* (evergreen)- *Castanopsis*- Poaceae-Cyperaceae.
The vegetation belts are modified from Zhang, 2007. The modern pollen distributions are based on Wang and Yu, 1993; Wang and Zhang, 1987; Wang, 1987; Sun and Li, 1999; Dai et al., 2014; Luo et al., 2013. Surface circulation patterns are based on Hu et al., 2000. The gray shaded areas show the possible exposed continental shelf during the LGM based on −120 m average global Sea level (based on Clark and Mix, 2002).