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Holocene East Asian winter monsoon changes reconstructed by sensitive grain size of sediments from Chinese coastal seas: A review

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ABSTRACT

While mean grain size of sensitive component in muddy sediments from Chinese coastal seas was widely used as a proxy for reconstruction of the East Asian winter monsoon (EAWM) strength, many intractable problems still remain concerning the discrepancies in different studies. This paper provides a comprehensive overview of recent researches on the reconstruction of Holocene EAWM strength using sensitive grain size (SGS) in muddy sediments from the Chinese coastal seas. In the present study, 15 time-series of SGS in sediments from six mud areas are included. These records are summarized and compared during the last 8000 years, 3000 years and 150 years, respectively. The results show that trends of SGS time-series are inconsistent at millennial, multi-centennial and decadal time scales. The inconsistencies could be partly caused by age uncertainties and chosen SGSs. More important, grain size characteristics in sediments from some mud areas could be influenced by factors other than coastal currents driven by EAWM, such as sedimentary environments, riverine runoff and storms. Thus SGS of muddy sediments should be used with caution when reconstructing winter monsoon strength, especially those in the northern Yellow Sea and near the Yangtze River estuary.

1. Introduction

The East Asian winter monsoon (EAWM) is an important part of the Asian climate system, which is formed as a result of the thermal contrast between the Asian landmass and the Pacific Ocean (An et al., 2000). It transports cold air from the Siberian–Mongolian Highs southeastward to the mid and low latitudes, and eventually crosses the equator to the Southern hemisphere, strongly influencing about one third of the global population (Ding et al., 1995; Qiao et al., 2011b). Over the past a few decades, many studies were conducted on the issues of paleoenvironmental and global climate changes since the Holocene (Mayewski et al., 2004), in which one of the outstanding aspects is the evolution, forcing mechanisms of EAWM and its links with other climate systems. A profound understanding of the history, nature and causes of EAWM in the Holocene, particularly those post-dating the Northern Hemisphere deglaciation, will be of considerable importance to the modeling and prediction of present and future climates.

Long-term EAWM records derived mainly from loess–paleosol profiles on the Loess Plateau in northern China, spanning a time-series of ~25 million years (Guo et al., 2002; Qiang et al., 2011), and grain size was widely utilized as a proxy to reconstruct variations in the EAWM strength at orbital to millennial time scales (Ding et al., 1995; Hao et al., 2012; Sun et al., 2012). However, it's difficult to obtain high-resolution paleoclimate records during the Holocene from loess–paleosol deposits because of its low sediment rates and pedogenic disturbances (Xiao et al., 1992). High-resolution records of Holocene EAWM strength were reconstructed using other proxies from lacustrine sediments (Yancheva et al., 2007; Wang et al., 2008a; Jia et al., 2015) and marine sediments (Steinke et al., 2010, 2011; Huang et al., 2011).

In recent years, numerous paleo-environmental studies expanded from terrestrial materials and deep-sea materials to

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marginal sea materials due to their unique settings and superiority conditions (An et al., 2000; Xiao et al., 2006; Xu et al., 2009a; Shi et al., 2010; Zheng et al., 2010; Liu et al., 2010a, 2010b). Chinese epicontinental seas, including the Yellow Sea, the East China Sea, the South China Sea, are located in the dynamical zone between the largest landmass (Asia) and the largest ocean (Pacific), and they occupy the broadest continental shelves and receive river inputs from large and small rivers from China, Korean Peninsula and other regions (Milliman et al., 1989; Alexander et al., 1991). Two of the largest rivers worldwide, the Yellow River and the Yangtze River, transport about 1×10^9 tons yr^{-1} and 480 million tons yr^{-1} of sediments annually to the sea, respectively, thus contributing about 10% of the world's annual sediment discharge (1.6×10^9 tons yr^{-1}) (Milliman and Meade, 1983; Milliman and Syvitski, 1992). The huge terrigenous sediment discharge from both rivers is considered as the dominant contributor to suspended sediments in the Chinese coastal seas (Xu et al., 2009b). Moreover, sediments delivered by middle and small rivers from Chinese mainland (e.g., the Qiantang River, the Min River, the Pearl River), western Taiwan (e.g., the Choshui River) and the Korean Peninsula (e.g., Han River, Keum River) are also significant contributors (Park et al., 2000; Lim et al., 2006; Liu et al., 2009; Xu et al., 2009a, 2009b, 2009c). The distribution and transport of suspended sediments in the inner-shelf seas are under the influence of marine hydrodynamic factors and regional oceanic circulation systems, which show obvious seasonality (Yuan et al., 2008; Xu et al., 2009b; Bian et al., 2013).

During the postglacial Holocene transgression and mainly after the rise of sea level to the mid-Holocene highstand, several mud areas formed offshore on the continental shelves in low-energy and relatively stable depositional regions (Xu et al., 2009b; Wang et al., 2014b). Geological characteristics of the coastal muddy deposits, such as the provenance (Yang et al., 2003; Lim et al., 2006; Xu et al., 2009b, 2009c), spatial and temporal dispersal patterns (Yang and Liu, 2007; Liu et al., 2014), forming mechanisms (Qiao et al., 2011a; Wang et al., 2014c), have been extensively studied, and they provide a significant amount of information for further relative researches in Chinese coastal seas. Large numbers of paleoclimate and paleoceanographic studies were carried on mud deposits considering their relatively continuous deposition, high sedimentary rates and retained abundant archives for high-resolution reconstructions of paleoclimate changes at millennial-centennial and even decadal scales (Park et al., 2000; Xu et al., 2009a, 2009b; Hu et al., 2012; Liu et al., 2014; Wang et al., 2014b).

In winter, Chinese coastal seas are exposed to the prevailing EAWM (Liu et al., 2006; Qiao et al., 2011a). Intensified coastal currents (Fig. 1), driven by the winter monsoon, resuspend and transport sediments to mud areas. These sediments are high-concentration river-delivered and mainly confined near the river mouths in summer (Qiao et al., 2011a). The fine-grained fractions of the muddy sediments become coarser in response to stronger EAWM (Xiao et al., 2006; Yang et al., 2007). In this case, a number of proxy-based studies have utilized sensitive grain size (SGS) of muddy sediments in the Yellow Sea and the East China Sea to reconstruct EAWM variation at different time scales (Xiang et al., 2006; Xiao et al., 2006; Xu et al., 2009a; Liu et al., 2010a, 2010b; Hu et al., 2012; Wang et al., 2014b; Zhou et al., 2014b).

However, doubt was cast on the indication of SGS in sediments from these mud areas. Wang et al., (2008a) found that mean grain size of the fine sediments in Min-Zhe Coast Mud (MZCM) didn't correlate well with the winter monsoon intensity since ~7000 a BP and they argued that summer monsoon intensity could affect the supply, transportation and deposition of the river-derived sediments in the inner shelf. By analyzing sediments in mud area near the Yangtze River estuary (MAYE), Yang and Chen (2007) showed that variations in the distance between historical outfall of the Yangtze River trunk stream and the studied sites should be the main factor controlling the coarse contents during the past 100 years. Furthermore, Zhou et al. (2012) demonstrated that grain-size characteristics in sediments from the Northern Yellow Sea Mud (NYSM) were driven by precipitation changes in the Yellow River drainage basin at a decadal time scale. While there were noticeable discrepancies in different reconstructed results in mud deposits from Chinese coastal seas, more and more studies focused on the synthesis of EASM records derived from SGS of muddy sediments. For example, based on a comprehensive analysis of earlier works on muddy sediments in the East China Sea and the Yellow Sea, Wang and Li (2014) suggested that the indicative significance of SGS for the Asian monsoon may have different meanings in different areas due to complex regional marine hydrodynamics and different source regions of terrestrial materials and river-delivered sediments. Zhou et al. (2014b) compared five sequences of EAWM records from different mud areas, and suggested that influence of the fluvial discharge might be one cause of the discrepancies during the last two millennia. Tu et al. (2015) compared three time-series of SGS with Siberia High records, and concluded that SGS in sediments from some mud areas was not suitable for the reconstruction of EAWM strength.

However, some questions still remain open about the validity of SGS in EAWM strength reconstruction. A comprehensive review on reconstruction of Holocene EAWM strength using SGS at different time scales is essential to decipher and understand 1) the validity of SGS as a proxy of EAWM intensity in different mud areas, and 2) variations in the EAWM strength during the Holocene. In the present study, we provide a synthesis of previously published SGS data – most of which have been used to study EAWM changes during the Holocene in mud areas of the Chinese coastal seas.

2. Study region, data sources and methods

There are large areas of muddy sediments in the Chinese coastal seas. The mud areas mainly include the NYSM, the central Yellow Sea Mud (CYSM), the old Huanghe Deltaic Mud (OHDM), mud area southwest off Cheju Island (MACI), MAYE, MZCM and the north of South China Sea Mud (NSCSM). All of those mud areas are located in the East Asian monsoon region. In winter, most areas of the Chinese coastal seas are influenced by winter monsoon circulation, which influences the strength of coastal currents. During summer months, the northward-blowing EASM brings heat and moisture to land, and would cause more precipitation and thus higher river flows to the seas.

SGS records collected in the present study covered almost all of the above mud areas except the OHDM (Fig. 1). Out of the 15 records as described in Table 1, six dated back to ~8000 years, five were 1500 to 3000 years long, and four records covered the past ~150 years. Among these records, one was from NYSM, four from CYSM, two from MACI, one from MAYE, six from MZCM, and one from NSSM. The selected records were dated with three methods, including AMS ^{14}C dating for 11 cores (of which all the radiocarbon ages were calibrated to calendar ages), ^{210}Pb chronology for 35009 and S1003 cores, and ^{210}Pb and ^{137}Cs chronology for 38002 and T02 cores.