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Spatiotemporal temperature variations in the East China Sea shelf during the Holocene in response to surface circulation evolution

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ABSTRACT

The Holocene environment evolution in the East China Sea (ECS) is characterized by the gradual establishment and strengthening of its shelf circulation system, but knowledge about temperature responses in temporal and spatial scales is limited due to the lack of continuous high-resolution records. Here, we compare $U^{K'}_{37}$ and TEX_{86} temperature records for three cores from the ECS shelf, which provide the temporal and spatial patterns of Holocene temperature structure variations. These temperature records revealed broadly consistent temporal trends with three intervals characterized by two distinct shifts. During the early Holocene (10.0–6.0 ka), the modern-type circulation system was not established, which resulted in strong water column stratification; and the higher sea surface temperature (SST) might be associated with the Holocene Thermal Maximum (HTM). The interval of 6.0 to 1.0/2.0 ka displayed a weaker stratification caused by the intrusion of the Yellow Sea Warm Current (YSWC) and the initiation of the circulation system. A decreasing SST trend was related to the formation of the cold eddy generated by the circulation system in the ECS. During 1.0/2.0 to 0 ka, temperatures were characterized by much weaker stratification and an abrupt decrease of SST caused by the enhanced circulation system and stronger cold eddy, respectively. Thus, the temperature structure in the shelf of ECS was closely related with circulation system changes during the mid-late Holocene, which was most likely driven by the intrusion of Kuroshio Current (KC). The significant asynchrony of temperature decreases in the three locations during the late Holocene was likely caused by the gradual expansion of the ECS cold eddy area.

1. Introduction

Temperature is an important component of marine ecosystems, and its variations in vertical and horizontal structures are coupled with climate changes, and consequently influence the structure and function of marine ecosystems. It is generally accepted that the overall global temperature during the Holocene had a cooling trend of ca. 0.5 °C following the Holocene Thermal Maximum (HTM) towards the late Holocene (Marcott et al., 2013). However, the range and timing of the temperature decrease varied substantially between different regions, due to additional forcings and feedbacks (Huang et al., 2011; Jennings et al., 2011; Moossen et al., 2015; Trommer et al., 2010; Warden et al., 2016). Many pieces of evidence demonstrated that the evolution of ocean circulation was an important additional driver for regional temperature variations (Giraudeau et al., 2010; Trommer et al., 2010). Thus, better constraints on temperature response to ocean circulation and global climate forcing are needed to get insight to the regional environment change mechanisms and to understand their ecological influences on marine ecosystems.

The East China Sea (ECS) has received increasing attentions for environmental and ecosystem studies recently (Hu et al., 2014; Xing et al., 2016), because of its unique geographic location and complex hydrography. Located between the world's largest continent and the largest ocean, the ECS is influenced by climatic forcing from both the high-latitude Northern Hemisphere (East Asian Monsoon System) and the tropic ocean (Kuroshio Current, KC), generating distinct seasonal

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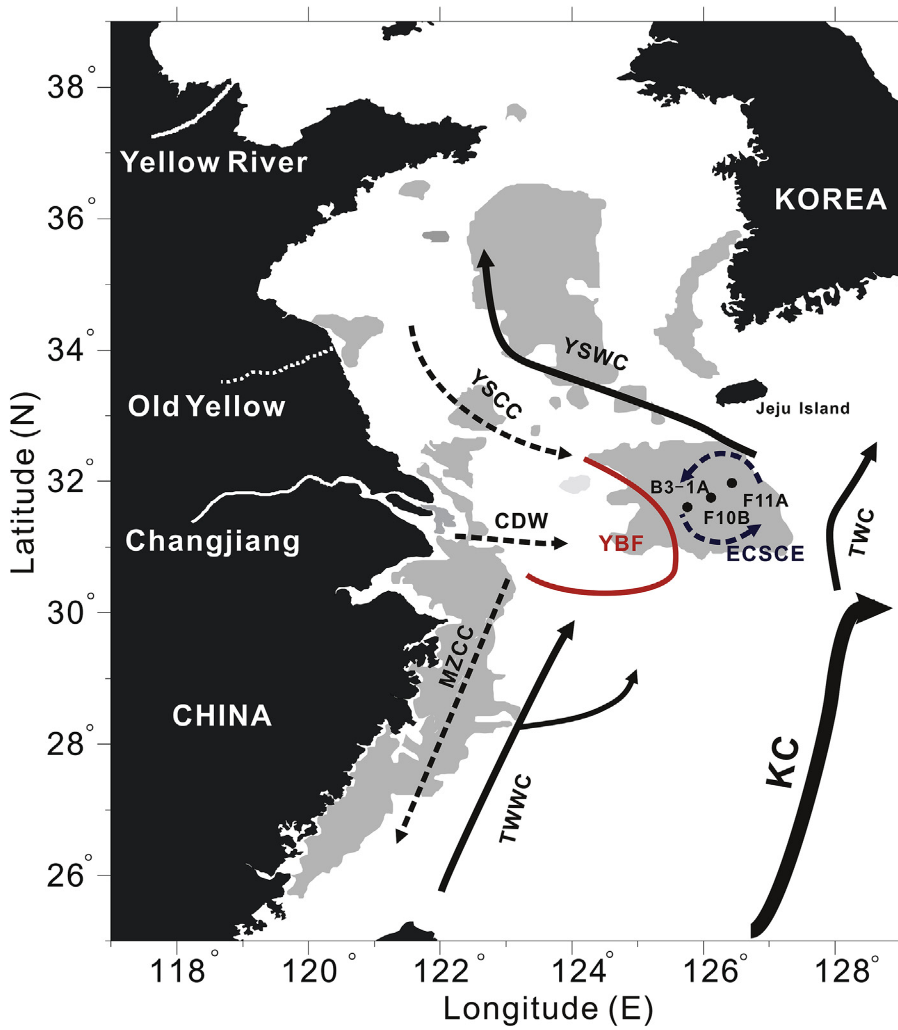

Fig. 1. A schematic map showing B3-1A, F10B and F11A site (●), the distribution of mud sediment areas, and the regional circulation system in the ECS and the YS during winter. Dark grey represents mud areas. KC: Kuroshio Current; YSWC: Yellow Sea Warm Current; TWC: Tsushima Warm Current; TWWC: Taiwan Warm Current; YSCC: Yellow Sea Coastal Current; CDW: Changjiang Diluted Water; MZCC: Minzhe Coastal Current; YBF: Yangtze Bank Front; ECSCE: East China Sea Cold Eddy.

circulation patterns, with strong horizontal and vertical temperature gradients (Chen, 2009; Lie and Cho, 2016). In winter, coastal currents including the Yellow Sea Coastal Current (YSCC) and the Minzhe Coastal Current (MZCC) carry cold and low salinity water southward (Fig. 1). Conversely, the offshore currents including the Yellow Sea Warm Current (YSWC) and the Taiwan Warm Current (TWWC) carry warm and high salinity water northward (Fig. 1). Cold coastal waters and the warm Kuroshio water meet at the shelf of the ECS, contributing to various hydrographic features such as oceanic fronts and cold eddies (Fig. 1). In summer, the circulation system in ECS is relatively weak as the coastal currents are not evident due to the reversed monsoon. In addition, the Changjiang Diluted Water (CDW) flows northeastward which also affects the surface circulation. Temperature is quite uniform in surface waters of the entire ECS shelf, while showing strong stratification in the thermal structure due to higher solar radiation heating of surface waters.

Paleoclimate records from the ECS could provide important evidence to understand the influence of ocean circulation on temperature changes over the Holocene. Previous reconstructions showed that the basic structure of the modern circulation system in the ECS was first established at 6.0–7.0 ka (Li et al., 2009b; Xiang et al., 2008), and probably reached the present level since the late Holocene (Xing et al., 2013; Zhao et al., 2013). However, our knowledge was still very limited on the temporal and spatial temperature patterns in the Holocene, as well as the vertical temperature structure, in response to the evolution of circulation system in the ECS, because existing temperature records were either short time scale or low temporal resolution (Badejo et al., 2014; Li et al., 2009a; Zhao et al., 2014). In addition, most published studies mainly focused on SST variations, but did not consider vertical temperature structure changes. The latter is very important, as the seasonal shift of modern circulation system can result in significant changes in stratification (Chen, 2009). A preliminary study using Holocene temperature records (Xing et al., 2013) observed opposite trends of surface and subsurface temperature changes, suggesting different forcing mechanisms. Therefore, better assessments of the Holocene circulation system changes are important for quantifying and explaining both horizontal and vertical temperature patterns in the ECS.

Surface and subsurface temperature records can be obtained using the $U_{37}^{K'}$ and TEX_{86} indices, respectively. They are widely used temperature proxies and have been applied successfully for Holocene temperature reconstructions in the China marginal seas (Ge et al., 2014; Nan et al., 2017; Wang et al., 2011; Xing et al., 2013). The $U_{37}^{K'}$ values in surface sediments of the Yellow Sea (YS) and the ECS display a good linear correlation with the instrumental annual SST, confirming that the $U_{37}^{K'}$-derived SST represents annual mean SST (Tao et al., 2012). While the TEX_{86} values in surface sediments displayed a good linear