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Climatic change and its influence on human society in western Japan during the Holocene

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A B S T R A C T

A continuous reconstruction of quantitative paleotemperatures in the Holocene was conducted by using alkenone sea surface temperature (SST) measurements from coastal sedimentary cores because of the strong correlation of SST with atmospheric temperature (AT) in the coastal bay area. This analysis enabled us to estimate a record of temperatures in western Japan with high and low time resolution during the last 3000 and 10,000 years, respectively. The reconstructed SSTs were validated by historical documents and records after 600 AD. A long-term trend of declining SSTs can be attributed mainly to changes in solar radiation and sea level and, to a lesser extent, changes in the Asian monsoon. Interestingly, the profile was quite different from those reported from the open ocean. During the last three millennia, the SSTs (ATs) fluctuated by 2.1 °C, with a maximum in 820 AD (24.3 °C [25.9 °C]) and two minima in 760 BC (22.2 °C [23.8 °C]) and 990 AD (22.4 °C [24.0 °C]). Low temperatures were also observed in 220–110 BC, 560–620 AD, and other periods. Historical documents suggest a notable cold period from the late 18th to early 19th centuries. The overall mean value (23.6 °C) was comparable to the average value in the mid-20th century, whereas the top sediments had an SST of 24.6 °C, which is higher than the maximum observed in the previous 3000 years. Although a cold climate was definitely observed in 1440–1730 AD, which almost corresponded to the Little Ice Age, the Medieval Warm Period was not identified in this study. These temperature fluctuations cannot be explained by a single cause but rather by more than one external and internal driver of climate variability (e.g., volcanic forcing, ocean-atmosphere interactions, and solar forcing). With respect to the influence of climate on human activity, major shifts in social systems appeared to coincide with cold periods in western Japan.

1. Introduction

High time-resolution reconstruction of important state variables of the climate system such as temperature and precipitation, in association with the carbon cycle, is currently considered a top priority to better understand climate variability (Jungclaus et al., 2010). There are many processes involved with both the external drivers and the internal variability of climate and carbon cycles. Of these, solar forcing, volcanic forcing, ocean-atmosphere and land–ocean–atmosphere interactions, and greenhouse-gas forcing were selected when the first ensemble simulations including a fully interactive carbon cycle over the last 1200 years were conducted (Jungclaus et al., 2010). These simulations showed that a warming trend of about 0.6 °C in the 20th century can be explained by greenhouse-gas forcing, and internal variability dominates solar forcing. Over the last millennium, land-cover changes have had a minor influence. Large volcanic eruptions may have left a long-lasting imprint on the climate in the Northern Hemisphere

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(Smithsonian National Museum, 2014). A great deal of attention has been paid to changes in total solar irradiance, which are important drivers of the Holocene climate, although modeling studies suggest that multi-century climate swings such as the MWP-LIA (Medieval Warm Period–Little Ice Age) transition may not require particularly strong solar forcing and can be attributed, at least partly, to internal variability on centennial time scales (Jungclaus et al., 2010; Esper et al., 2012). The El Niño–Southern Oscillation (ENSO) and the Asian monsoon also fluctuated during the Holocene (Wu and Liu, 2004; Wang et al., 2005; Hu et al., 2008; Kawahata et al., 2009; He et al., 2015).

In particular, many efforts have been made to collect proxy data for the reconstruction of the environment and climate in past centuries at the local or regional scale. Studies have shown that temperatures both globally and in the Northern Hemisphere have varied over the past 1500 years, including climatic epochs such as the MWP (ca. 950–1250 AD [sometimes 1000–1400]) and the LIA (ca. 1600–1850 AD [sometimes 1350–1850]) (IPCC Assessment Report, 2007; Mann et al., 2009). However, spatial patterns have remained poorly defined and the causal factors behind these changes remain unclear. In addition, a key question in the evaluation of the late Holocene climate is whether or not the 20th century warming is unusual in the context of the past two millennia (Moberg et al., 2005; Christiansen and Ljungqvist, 2011). This issue is important when attempting to distinguish between anthropogenic climate change and natural climate variability and when attempting to predict future climatic change.

Environmental and climatic changes as well as geohazards have been found to have a significant impact on the rise and fall of civilizations (Ishimura and Miyauchi, 2015). Civilization in the Yangtze River area originated in a warm and humid climate in about 4400–4100 BC; the civilization developed until about 3800–3700 BC but then declined as a result of the effects of climate change (Yasuda et al., 2004). The collapse of the Neolithic culture in central China has been inferred to be caused by an abrupt hydrological change in about 2000 BC caused by a reduction in the intensity of the Asian monsoon from 2200–2000 BC, as deduced from the $\delta^{18}O$ values of a Dongge and Heshang Cave stalagmite (Wu and Liu, 2004; Wang et al., 2005; Hu et al., 2008). This event was also in phase with a Mesopotamian dry event in western Asia (2100 BC) (deMenocal, 2001). Sudden abandonment of a settlement after 1700 years of relative prosperity was reported at the Sannai-Maruyama site, Aomori City in northern Japan, as a result of a rapid temperature drop of 2.0 °C in about 2200 BC (Fig. 1a) (Kawahata et al., 2009; Irizuki et al., 2015). These events could all be linked to changes in the Asian monsoon during this time period. Mid-latitude areas are sensitive to climatic change induced by latitudinal shifts of the westerly winds and relevant ocean currents such as the Kuroshio Extension (Kawahata et al., 2000; Kim et al., 2015). Increasing aridity has also had impacts in the 8th and 9th centuries on societies in Central America. A century-scale decline in rainfall put a general strain on the population in and around the Yucatán Peninsula, which was then exacerbated by an abrupt drought event that is presumed to have contributed to the social stresses leading to the demise of the Mayans in the Terminal Classic Period (Haug et al., 2003). Although most of the critical reasons behind the collapse of these civilizations have been identified as a prolonged period of drought or cooling, most of the discussions have been based on qualitative or semiquantitative environmental parameters.

Temperature and rainfall are the most important factors controlling environments and primary industries such as agriculture,

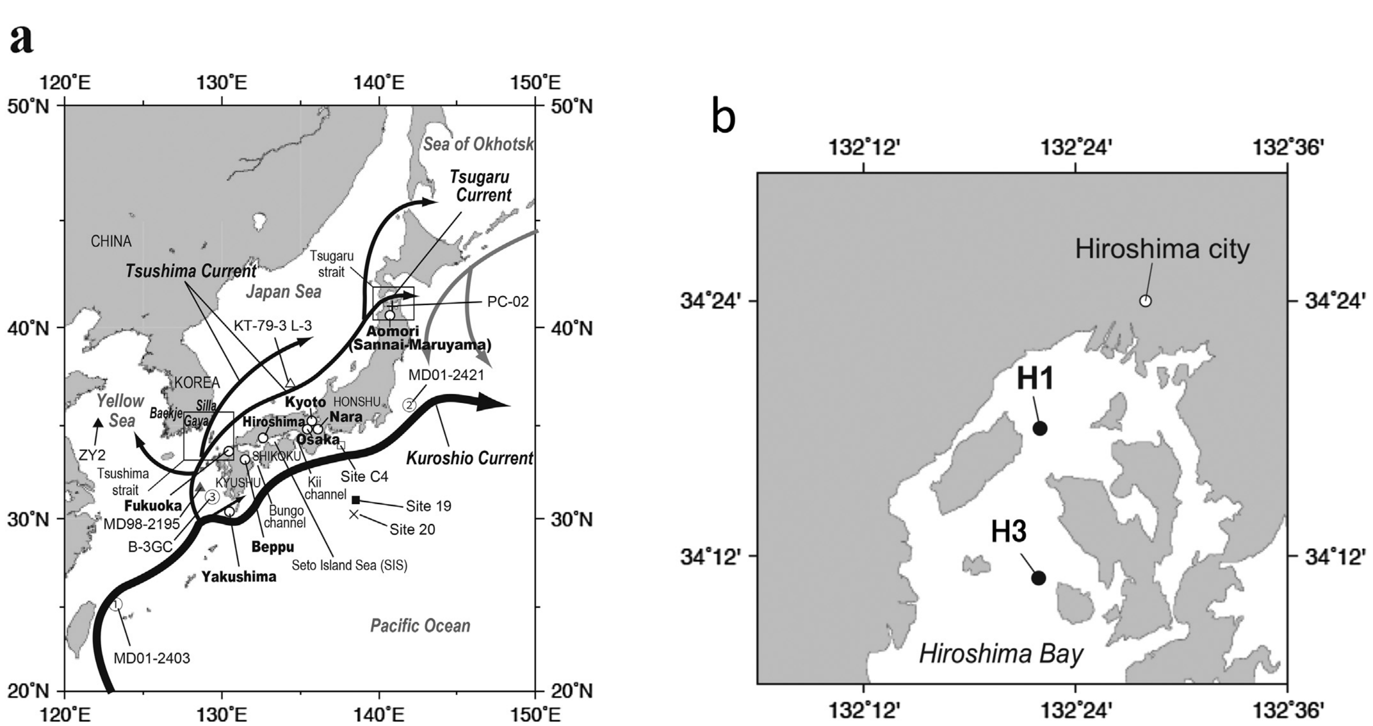

Fig. 1. a. Map of the North Pacific and Japan Sea around the Japanese Islands, including the Seto Inland Sea (SIS). The SIS is 450 km long from east to west and 15–55 km wide from south to north with the area of 23,203 km^2. The paths of the Kuroshio, Tsushima, and Oyashio currents are also shown. The route of the Kuroshio follows the figure by Jian et al. (2000). The location of the cores of PC-02 (+; 41°00′N, 140°46′E); Site C4 (□; 33°9.0′N, 137°41.9′E), Site 19 (■; 31°5.7′N, 138°39.9′E), Site 20 (×; 30°22.6′N, 138°38.9′E), KT-79-3 L-3 (△; 37°04.0′N, 134°42.2′E), ZY2 (▲; 35°31′N, 122°39′E), MD01-2403 (①; 25°36′N, 123°24′E), MD01-2421 (②; 36°02′N, 141°47′E); B-3GC (③; 31°29′N, 128°31′E; ODP Site 1202 (④; 24°48′N, 122°30′E)) (Oba et al., 1995; Sawada and Handa, 1998; Jian et al., 2000; Lin et al., 2006; Fengming et al., 2008; Kawahata et al., 2009; Wang et al., 2011). b. Locations of H1 (34°18.5′N, 132°22′E; water depth, 24 m) and H3 (34°11.5′N, 132°20.5′E; water depth, 44 m) sites and Hiroshima city (34°24′N, 132°28′E). These cores were collected 10 and 23 km from Hiroshima City, respectively.