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Late Holocene coupled moisture and temperature changes on the northern Tibetan Plateau

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ABSTRACT

The northern Tibetan Plateau involves complex interactions between the mid-latitude westerly circulation and the subtropical Asia monsoon circulation, acting as a bridge communicating high and low latitude climatic processes. Previous studies from the region suggest relatively wet conditions in cold periods during the late Holocene, for instance, the Little Ice Age (LIA). However, the inference of such temperature-moisture association is subject to the large uncertainty in lacustrine ^{14}C chronology, due to the particularly large lake reservoir effect in the region. Here we take a different approach by reconstructing paired temperature and moisture records from the same sediment cores to assess the temperature-moisture association, independent of chronology uncertainty. We use alkenone indices $U^{K'}_{37}$ and $\%C_{37:4}$ to reconstruct high resolution temperature and moisture changes simultaneously from two lakes in the Qaidam Basin, northern Tibetan Plateau, over the last ~2500 years. Characterized by marked climatic variability, our paired records confirm the warm-dry and cold-wet association in arid northwestern China during the late Holocene, opposite to the warm–wet and cold–dry association in subtropical Asian monsoonal regions. Our moisture records further suggest substantially drier conditions during the Medieval Warm Period (MWP) than the current warm period. Lastly, the temperature and moisture changes inferred from our records can be well correlated with solar irradiance changes, suggesting a possible link between solar forcing and natural climate variability during the late Holocene on the northern Tibetan Plateau.

1. Introduction

Understanding of climate variability under natural conditions could help improve projections of future climate change. Numerous high resolution paleoclimatic studies have extended the instrumental data to the past ~2000 years in various parts of the world. Majority of the temperature records show more or less similar patterns around the globe and can be roughly divided into a few warm and cold periods, such as the current warm period after AD 1850, the Little Ice Age (LIA) between AD 1850 and AD 1400, and the Medieval Warm Period (MWP) or Medieval Climate Anomaly (MCA) between AD 1400 and AD 800 (e.g. Esper et al., 2002; Mann and Jones, 2003; Moberg et al., 2005; Mann et al., 2009; Ge et al., 2010). Longer records show another warm/cold oscillation, namely the Dark Ages Cold Period (DACP) and the Roman Warm Period (RWP, Lamb, 1985). On the other hand, moisture records around the globe show strikingly contrasting features, sometimes in opposite directions, among different climatic regimes (Mann et al., 2009; Trouet et al., 2009; Chen et al., 2010; Graham et al., 2011). In this sense, hydrological variability including precipitation vs. evaporation, stream flow and pluvials vs. droughts is perhaps more indicative of regional atmospheric circulation and the associated climatic changes (Holmes et al., 2009). Studies of moisture changes would help decipher climatic processes and forcing mechanisms of natural climatic variability.

The northern Tibetan Plateau is a climatologically important region as it involves complex interactions between the mid-latitude westerly and the subtropical Asia monsoon circulations (Chen et al., 2010; Yang et al., 2011), which may provide a bridge connecting high and low latitude climatic processes (Ding and Wang, 2005). Late Holocene temperature changes on the Tibetan Plateau (Yang et al., 2003, 2009; Liu et al., 2006; He et al., 2013)

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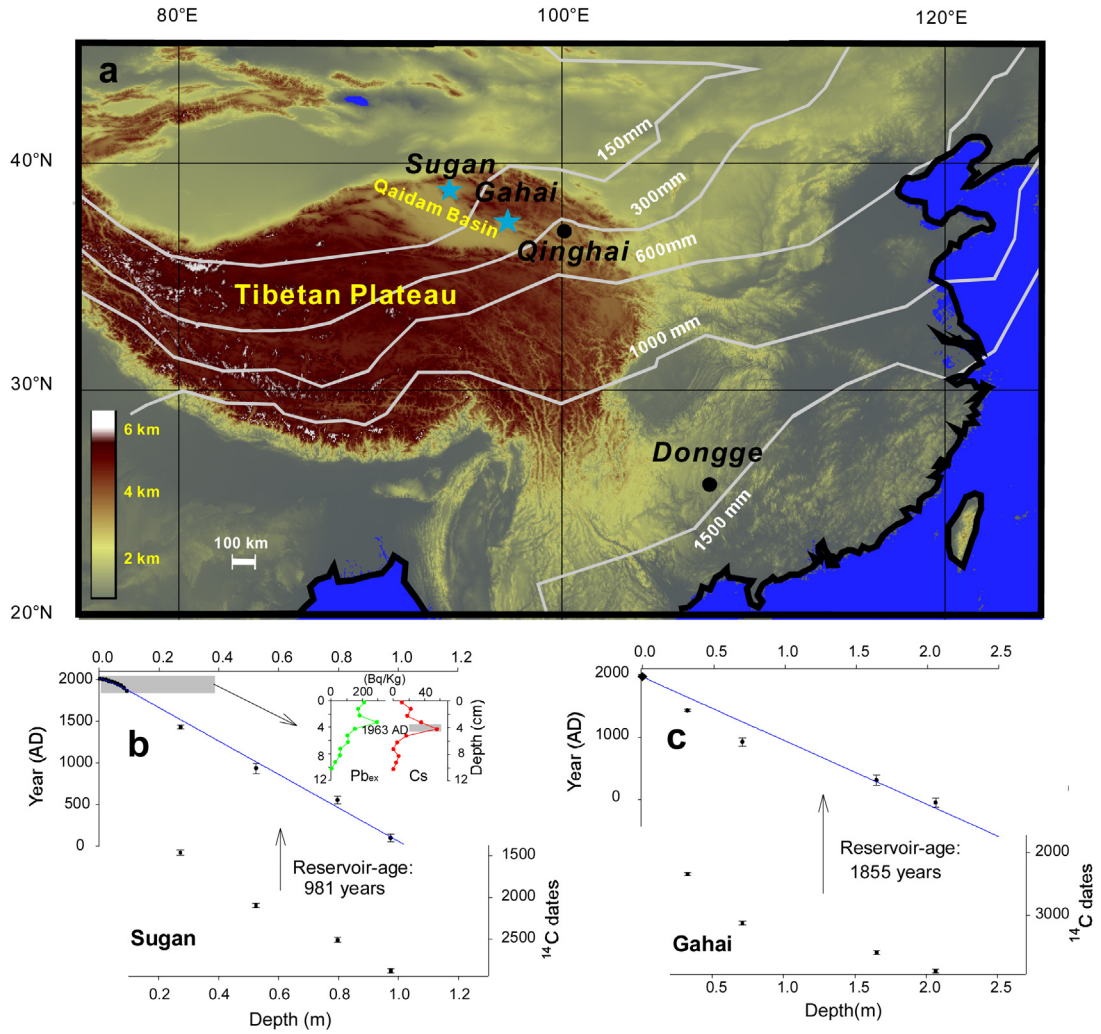

Fig. 1. (a) Location map of the northern Tibetan Plateau. The two study sites, Lake Gahai and Lake Sugan, are shown with stars. Lake Qinghai and Dongge Cave from previous studies are shown with circles. Current precipitation lines based on the global precipitation climatology project precipitation analysis (Adler et al., 2003) are shown. The 300 mm annual precipitation line approximately separates monsoonal regions and arid northwestern China. (b) Age models for Lake Sugan and (c) Lake Gahai, adopted from He et al. (2013).

show oscillating warm and cold periods, in accordance with the northern hemisphere temperature changes (Moberg et al., 2005). Many high resolution moisture records have been obtained from arid northwestern China over the last decades (e.g. Thompson, 1995; Yao et al., 1996; Sheppard et al., 2004; Chen et al., 2008, 2010; Yang et al., 2009; Liu et al., 2011a). In general, these records suggest relatively wet conditions during the LIA period (Chen et al., 2010), although dry LIA conditions have also occasionally been reported (e.g. Zhang et al., 2009b, 2010; Zhao et al., 2010). Many of the moisture studies in this region have also addressed the association of moisture changes with temperature changes, but in an indirect way, by assuming that the interval of AD 1400–1850, derived from ^{14}C chronology, was relatively cold (LIA) whereas AD 800–1400 was a warm period (MWP). The temperature-moisture associations in these studies heavily rely on the accuracy of age model. Actually, large uncertainties in lacustrine ^{14}C chronology (up to a couple of thousand years) on the Tibetan Plateau significantly limit the application of the late Holocene climatic research (Hou et al., 2012). Different studies should not be directly compared without taking the chronological uncertainties into account. In view of that, paired temperature and moisture reconstructions from the same cores are much desired and more convincing to identify the temperature-moisture coupling during the late Holocene, since the association is independent of age uncertainty (although the chronology still needs to be loosely constrained).

Here we adopt the recently developed alkenone indices $U^{K'}_{37}$ and $\%C_{37:4}$ in lacustrine settings for reconstructions of temperature and moisture changes respectively. We present decadally-resolved moisture records ($\%C_{37:4}$) from two lake sediment cores from the Qaidam Basin on the northern Tibetan Plateau (Fig. 1a). The moisture records were compared to the previously reported temperature ($U^{K'}_{37}$) records from the same sediment cores (He et al., 2013) to assess how moisture changes were associated with temperature changes during the late Holocene. We also evaluate the validity of $U^{K'}_{37}$ and $\%C_{37:4}$ as independent temperature and moisture proxies, although they are both based on alkenone compositions. Further, based upon our new data and existing records of hydrological changes from different localities, we discuss the temperature-moisture association in arid and semi-arid regions of northwestern China as well as in the monsoonal East Asia. At last, after carefully evaluating potential age uncertainty, we link temperature and moisture variability in this region to solar irradiance changes during the late Holocene.