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Meridional ITCZ shifts modulate tropical/subtropical Asian monsoon rainfall

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The temperature gradient between the northern and southern hemispheres and its influence on the global atmospheric circulations are frontier topics in international climate/paleoclimate studies. Over the past approximately two decades, an important hypothesis in the field of global climate change is that the changes of the Atlantic meridional overturning circulation lead to changes in the temperature gradients between the northern and southern hemispheres, which affect the mean zonal locations of the Intertropical Convergence Zone (ITCZ), as well as the subtropical high and the westerly jet stream of the two hemispheres [1–4]. Such a north-south movement of the planetary atmospheric circulations leads to a redistribution of water vapor and energy in different regions, resulting in significant temporal and spatial differences in the observed hydroclimate [5,6]. In addition, the variation of the interhemispheric temperature contrasts may also lead to southward displacement of the southern hemisphere westerlies [1,7], which might serve as an "on-off" switch for the global glaciation/deglaciation cycles because the southward displacement of the southern hemisphere westerlies may change the upwelling rates in Southern Ocean, resulting in enhanced release of greenhouse gases such as CO_2 from the deep ocean to the atmosphere [8]. This interhemispheric temperature gradient forced meridional shifts of the ITCZ and the subtropical high, together with the El Niño-Southern Oscillation (ENSO), are generally thought to be the two fundamental forcings that drive tropical/subtropical hydroclimatic changes.

In the Asian monsoon region, where more than half of the global population reside, understanding the movement of the ITCZ and the northern subtropical high is crucial for evaluating their influence on water vapor transport, energy transfer, and regional to global climate. However, due to the lack of a full understanding of the history and laws of long-term ITCZ and northern subtropical high behaviors, the causes of rainfall variations in Asian monsoon region, especially those of the regional hydroclimatic differences, are still poorly known.

Recently, Tan et al. [9], for the first time, developed a 2000-a long ITCZ shifting index in the central Indo-Pacific region, based on stalagmite $\delta^{18}O$ differences ($\Delta^{18}O$) between well-dated stalagmites in the Klang Cave (southern Thailand) and those in Indonesia. The most notable feature in Tan et al.'s ITCZ shifting index is that the north-south movement of the ITCZ, on centennial scale, is broadly synchronous with the north-south hemisphere temperature gradient [9,10], which further supports the point that the north-south hemisphere temperature gradient leads to the shifts of the atmospheric circulation, affecting water vapor and heat transfer, and subsequently modulating regional hydroclimatic changes. This is therefore an important contribution to the understanding of hydroclimatic changes, regional differences, and the dynamics in tropical/subtropical Asian monsoon areas.

The $\Delta^{18}O$-based ITCZ shifting index by Tan et al. [9] shows an overall southward movement trend over the past two millennia, a southward displacement during the early Medieval Warm Period (MWP; ~950–1150 CE) and the Current Warm Period (CWP), and a relative northward displacement during the Little Ice Age (LIA) and Dark Ages Cold Period (DACP). Such meridional movements of the ITCZ could have led to changes in precipitation trend, e.g., relatively drier MWP and CWP but wetter LIA and DACP hydroclimatic conditions. The hydroclimatic patterns identified by Tan et al. [9] also support our previous findings [5]. As shown in Fig. 1, the lake level changes inferred from beach evidence at Lake Chenghai, Yunnan Province (dominated by Indian summer monsoon; ISM) physically show that the precipitation was relatively low in the MWP period, but high in the LIA period. In the past 100–200 a, the water level dropped rapidly, which is likely due to a combined effect of both a significant decrease in monsoon precipitation and enhanced human activities at this time. The composited precipitation index based on multi-proxy indices from Lake Erhai and Lake Lugu in the southeastern margin of Tibet Plateau (S-ETP) also shows that the precipitation was relatively low in the MWP period, but relatively high in the LIA period, and decreased again in the past 100–200 a [5]. However, we previously ascribed the observed MWP and LIA hydroclimatic patterns more to changes in sea surface temperature in the tropical Pacific. For example, the tropical/subtropical MWP and CWP droughts are broadly synchronous with El Niño-like conditions inferred from sand fraction in El Junco [11], while the LIA wetting corresponds to a La Niña-like condition (Fig. 1). Whereas Tan et al. [9] provide us a new point that the

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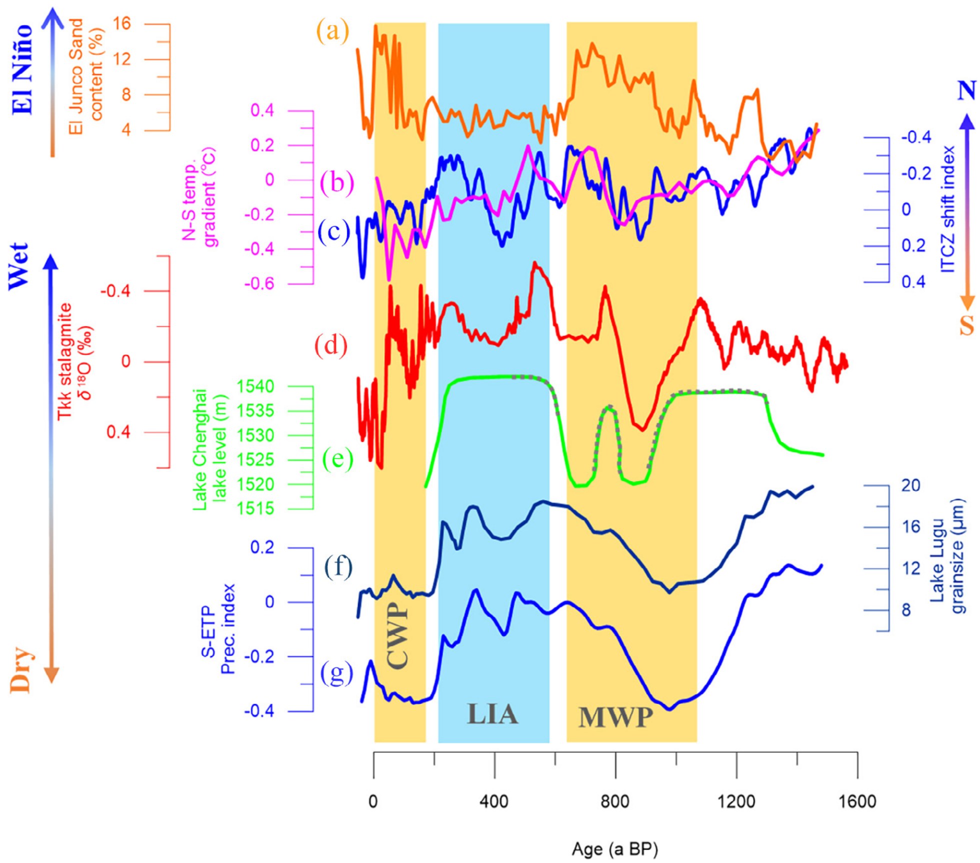

Fig. 1. Comparison between tropical/subtropical precipitation indices, ITCZ shift index, North-South hemisphere temperature gradients, and equatorial Pacific El Niño conditions. (a) El Junco sand fraction (an index of El Niño event) [11]. (b) N-S hemisphere temperature gradients [10]. (c) Reconstructed ITCZ shift index [9]. (d) Klang Cave $\delta^{18}O$ (after removal of linear trend) [9]. (e) Lake levels of Lake Chenghai reconstructed from beach evidence (dotted parts denote lake levels with larger uncertainties; this study). (f) Lake Lugu grainsize [5]. (g) Composited precipitation index over south eastern margin of the Tibetan Plateau (S-ETP) [5]. The orange filled columns represent Medieval Warm Period (MWP) and Current Warm Period (CWP), while the blue filled column represents Little Ice Age (LIA).

meridional ITCZ shift could also have potentially influenced the tropical/subtropical MWP and LIA monsoon precipitation.

It is still quite controversial whether the overall weakening of rainfall in northern hemisphere tropics/subtropics since the 20th century is the result of natural processes or human activities (such as sulfate aerosols and greenhouse gas emissions, etc.). Tan et al. [9] suggest that there is no significant difference between the droughts of the 20th century and historical warm intervals in the northern tropics. The increase of El Niño activity and the southward shift of ITCZ during the last warming century led to variations of atmospheric circulation, causing a redistribution of precipitation. The precipitation in tropical/subtropical monsoon regions is likely to weaken continuously, which is consistent with the conjecture obtained by the author of this paper when studying ISM precipitation in the southeastern margin of the Tibetan Plateau region [5,12]. Overall, under a global warming scenario, the combined effect of ENSO and ITCZ shift tends to generate a "cold/wet-warm/dry" hydroclimatic condition over the tropical/subtropical Asian monsoon region. Yet previous works show that warmer intervals favor "warm/wet-cold/dry" hydroclimatic patterns over the typical East Asian summer monsoon regions [5,13,14]. This implies if global warming continues, regional disparities in precipitation and water availability in Asian monsoon regions are likely to be widened further.

Conflict of interest

The authors declare that they have no conflict of interest.

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