Periodical enhancements of multi-decadal hydroclimate variations in central Japan and its implication for the 2600-year East Asian history

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In general, it is not easy to extract low-frequency climate signals from tree rings because they usually overlap with biological age trends. Although oxygen isotope ratio ($\delta^{18}O$) of tree-ring cellulose, a novel proxy of summer hydroclimate in monsoonal Asia, is often free from the age effect, conifer trees sometimes show significant $\delta^{18}O$ age trends. Here, we propose a new method to reconstruct past hydroclimate variations seamlessly from annual to millennial time scales by integrating tree-ring cellulose oxygen and hydrogen ($\delta^{2}H$) isotope ratios (Nakatsuka et al., 2020; https://doi.org/10.5194/cp-2020-6). By analyzing many old conifers, we have found that there are always positive correlations between short-periodicity $\delta^{18}O$ and $\delta^{2}H$ variations and sometimes negative correlations between long-periodicity $\delta^{18}O$ and $\delta^{2}H$ variations, reflecting climatological and physiological factors, respectively. Because the gradual $\delta^{18}O$ decrease and $\delta^{2}H$ increase can be explained by growth-related physiological changes, we can cancel the physiological effect and extract the climatological component ($\Delta\delta^{18}O_{cel(climate)}$) in tree-ring cellulose $\delta^{18}O$ by solving simultaneous equations of $\delta^{18}O$ and $\delta^{2}H$. We apply this procedure to a 2600-year chronology of tree-ring $\delta^{18}O$ and $\delta^{2}H$ made of 67 samples of excavated wooden artifacts, old architectural woods, and naturally buried logs in addition to old living trees in central Japan and demonstrate that long-periodicity variations in $\Delta\delta^{18}O_{cel(climate)}$ agree well with multi-millennial summer hydroclimate variations reconstructed by other global and regional low-frequency proxies. It indicates that the $\Delta\delta^{18}O_{cel(climate)}$ can be a seamless proxy of long- and short-periodicity summer hydroclimate variations in East Asia.

So far, the short-periodicity climate variations in ancient eras have been seldom discussed either from natural or historical viewpoints. Because the $\Delta\delta^{18}O_{cel(climate)}$ chronology may contain many undiscovered information in all frequencies, it is worth analyzing its short-periodicity variations in the distant past. Here, we propose a new analytical framework to identify vulnerability of historical societies against climate changes with special focus on climate periodicity. First, we make a simple model to describe "climate-production-storage-population" dynamics for pre-modern agricultural societies and propose a working hypothesis that multi-decadal climate variations are most critical for human societies because neither crop storage nor demographic adjustment can function for the multi-decadal variations. Second, we investigate periodicity of the 2600-year $\Delta\delta^{18}O_{cel(climate)}$ chronology in central Japan and find that multi-decadal variations are enhanced every 400 years, possibly caused by multi-centennial solar cycles, corresponding to the so-called dynastic cycle in China and the quasi-simultaneous political regime shifts in surrounding countries like Japan and Korea. Third, we compare the chronology with various historical societal parameters in East Asia (yearly data on agricultural productions, famines and peasant uprisings during 16-19th CE centuries in Japan and decadal frequency on internal wars during 3rd BCE –20th CE centuries in China). Statistical analyses on the climate-society relationships clearly demonstrate that crop failures due to large multi-decadal hydroclimate variations actually caused famines and social conflicts and often resulted in political regime shifts in East Asia. There are also substantial exceptions where people could avoid social collapse due to the multi-decadal hydroclimate variations, from which we can extract important lessons, applicable to contemporary global environmental issues, by spatiotemporal comparisons of social vulnerability against hydroclimate variations in the long East Asian history.

Keywords: East Asia, multi-decadal climate variation, tree ring, oxygen isotope ratio, hydrogen isotope ratio, history

