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Reconstruction of seasonal and inter-annual changes in the East Asian monsoon from multi-proxy analysis of Chinese speleothem material

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The East Asian monsoon system is an integral part of the global climate system, exhibiting variability at a wide range of time-scales from Milankovitch to intra-annual. Numerous paleoclimate studies have studied the history of the monsoon over the past several glacial-interglacial cycles, revealing a strong link between monsoon intensity and high-latitude climate. While the general pattern of monsoon variability is largely controlled by Northern Hemisphere insolation, the monsoon is also known to respond to abrupt climate changes such as Dansgaard-Oeschger events and Heinrich events. The relationship between decadal-to-annual monsoon variability and such forcings as ENSO and solar variability is less well understood due to the paucity of well-dated high-resolution paleoarchives in this region. The lack of such records also limits more general understanding of past variability in monsoon intensity, preventing confirmation that recent changes in behaviour are unusual.

An annually banded stalagmite, HS4, collected from Heshang Cave in the central Yangtze River valley, China (30.44 N, 110.42 E), grew during the last 8.8 kyr and exhibits strong seasonal cycles in multiple geochemical proxies. We have performed an ultra-high-resolution study of the stable isotope (δ^{18}O and δ^{13}C) and trace element (Mg/Ca, Sr/Ca, Ba/Ca, U/Ca) composition across 16 annual growth bands to investigate the nature of these geochemical cycles and assess their potential as seasonally resolved proxies of the East Asian monsoon intensity. The bands were microsampled at an average resolution of 44 μm (equivalent to 10 samples per year) using a New Wave Research Micromill. Stable isotope measurements reveal that the speleothem δ^{18}O and δ^{13}C exhibit large seasonal cycles with an amplitude ranging from 0.5 to

2 permil. Interestingly, these cycles are not in phase with each other, indicating that they are responding to different environmental forcings. ICP-MS measurements reveal clear seasonal cycles in the Mg/Ca, Sr/Ca, Ba/Ca, and U/Ca of speleothem calcite. In addition, we have developed methods for *in situ* analysis of Mg/Ca and Sr/Ca, using LA-MC-ICPMS, which also clearly reveal these cycles. In general, δ^{13}C, Mg/Ca, Ba/Ca, and Sr/Ca are positively correlated with each other and anti-correlated with U/Ca. These proxies most likely reflect factors such as precipitation, temperature, growth rate, and vegetation. Speleothem δ^{18}O, which is not significantly related to the other proxies, is controlled mainly by seasonal cycles in cave temperature and drip-water composition. The inter-annual variability observed in the δ^{18}O record may be a useful recorder of monsoon intensity due to the strong negative relationship between rainfall amount and the δ^{18}O of rainfall in this region. The temperature dependence of calcite-water fractionation will amplify this signal, because warmer periods, which tend to exhibit increased monsoon intensity, are also characterized by more negative δ^{18}O values. Through this multi-proxy approach, it may be possible to construct a seasonally resolved history of the East Asian monsoon system for the Holocene and address important questions about monsoon variability, and its relationship to ENSO and solar variability.