American Geophysical Union Fall Meeting, New Orleans, LA, Dec 13-17, 2021

Late Oligocene Seasonal Precipitation Based on $\delta^{13}C$ Profiles in Fossil Wood: A Proxy System Model Case Study with Monte Carlo Uncertainty

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Current forecasting models disagree on the direction of hydroclimate change in the East Asian Monsoon (EAM) under anthropogenic climate change due to the offsetting effects of anthropogenic aerosols and CO_2-driven warming. Records of monsoon intensity from deep time may inform the modeling community about EAM characteristics in a warmer world absent the influence of humans, yet most proxies produce hydroclimate estimates averaged over large temporal scales. Here we provide the first annually resolved, quantitative estimates of seasonal precipitation from East Asia during the Oligocene, a time of higher CO_2 and global temperature than the Common Era. The precipitation reconstruction is based on intra-annual variation in carbon isotopes ($\delta^{13}C$) across growth rings of exquisitely preserved fossil wood from Nanning, southern China. A proxy system model trained on a global data set of modern trees was adapted for local application in East Asia and validated using a local weather station and a replicated, intra-ring $\delta^{13}C$ record from two living evergreen trees in Nanning (22 rings, 317 $\delta^{13}C$ samples). We then applied the technique to three late Oligocene fossil wood specimens (20 rings, 518 $\delta^{13}C$ samples). A clear pattern of consistent, summer-dominated precipitation was found, with ~4.5 times more precipitation in summer (P_s) than winter (P_w). Seasonal precipitation estimates were calculated using Monte Carlo resampling, resulting in median P_s = 1042 (95% C.I. = 628-1517) and P_w = 235 (95% C.I. = 50-578), which are indistinguishable from the instrument record at a nearby weather station, where P_s = 977 (95% C.I. = 662-1434) and P_w = 292 (95% C.I. = 165-515), and from proxy application on the two modern trees near the fossil site, where P_s = 1058 (95% C.I. = 617-1558) and P_w = 188 (95% C.I. = 31-583). These data demonstrate that by the late Oligocene, precipitation patterns in East Asia had strength and seasonality as least as strong as modern conditions, which suggests the presence of an East Asian Monsoon-style system prior to the Neogene. These findings also imply that the EAM may intensify if future policy decisions lead to a reduction in anthropogenic aerosol emissions in East Asia.