Diurnal to interannual rainfall $\delta^{18}O$ variations in northern Borneo driven by regional hydrology

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A B S T R A C T

The relationship between climate variability and rainfall oxygen isotopic ($\delta^{18}O$) variability is poorly constrained, especially in the tropics, where many key paleoclimate records rely on past rainfall isotopes as proxies for hydroclimate. Here we present a daily-resolved, 5-yr-long timeseries of rainfall $\delta^{18}O$ from Gunung Mulu National Park, located in northern Borneo (4 N, 114 E) in the heart of the West Pacific Warm Pool, and compare it to local and regional climatic variables. Daily rainfall $\delta^{18}O$ values range from $-0.7\%$ to $-18.5\%$ and exhibit a weak but significant inverse relationship with daily local precipitation amount ($R = -0.19, p < 0.05$), consistent with the tropical amount effect. Day-to-day $\delta^{18}O$ variability at Mulu is best correlated to regional precipitation amount averaged over the preceding week ($R = -0.64, p < 0.01$). The inverse relationship between Mulu rainfall $\delta^{18}O$ and local (regional) precipitation amount increases with increased temporal averaging, reaching $R = -0.56$ ($R = -0.72$) on monthly timescales. Large, negative, multi-day rainfall $\delta^{18}O$ anomalies of up to $16\%$ occur every 30–90 days and are closely associated with wet phases of the intraseasonal Madden–Julian Oscillation. A weak, semi-annual seasonal cycle in rainfall $\delta^{18}O$ of 2–3% bears little resemblance to seasonal precipitation variability, pointing to a complex sequence of moisture sources and/or trajectories over the course of the year. Intermittent rainfall $\delta^{18}O$ variations of 6–8% are significantly correlated with indices of the El Niño Southern Oscillation, with increased rainfall $\delta^{18}O$ during relatively dry El Niño conditions, and vice versa during La Niña events. We find that Mulu rainfall $\delta^{18}O$ outperforms Mulu precipitation amount as a tracer of basin-scale climate variability, highlighting the time- and space-integrative nature of rainfall $\delta^{18}O$. Taken together, our results suggest that rainfall $\delta^{18}O$ variability at Mulu is significantly influenced by the strength of regional convective activity. As such, our study provides further empirical support for the interpretation of $\delta^{18}O$-based paleo-reconstructions from northern Borneo stalagmites as robust indicators of regional-scale hydroclimate variability, where higher $\delta^{18}O$ reflects regional drying.

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1. Introduction

The inverse relationship between tropical precipitation amount and rainfall isotopic values, known as the ‘amount effect’ (Dansgaard, 1964; Rozanski et al., 1993; Araguas-Araguas et al., 1998), has provided the basis for numerous reconstructions of tropical paleohydrology from lake deposits (e.g. Sachs et al., 2009; Tierney et al., 2010), alpine ice cores (e.g. Hoffmann et al., 2003; Vimeux et al., 2009) and stalagmite calcite (e.g. Bar-Matthews et al., 1997; Burns et al., 1998; Wang et al., 2001). Such reconstructions play a key role in resolving past tropical climate changes, as continuous, high-resolution paleoclimate archives are relatively rare in the tropics. Stalagmite $\delta^{18}O$ records, in particular, have been used to probe hydroclimate variability over the last hundred years (Treble et al., 2005; Frappier et al., 2007), the last glacial cycle (Dykoski et al., 2005; Partin et al., 2007; Griffiths et al., 2009), and the last million years (Wang et al., 2001; Meckler et al., 2012).

Despite robust observations of the amount effect across tropical latitudes, the climatic controls on rainfall $\delta^{18}O$ at any given site remain highly uncertain as numerous processes contribute to rainfall $\delta^{18}O$ variability. Rayleigh distillation, whereby cumulative fractionation during condensation and rainout leaves the residual