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

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ABSTRACT

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. Interannual 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 Nina 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.



## 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

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