A statistical framework for integrating non-Gaussian proxy distributions into geological reconstructions of relative sea level

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Robust, proxy-based reconstructions of relative sea-level (RSL) change are critical to discerning the processes that drive variability in RSL; however, these reconstructions rely on the ability of statistical models of RSL to accurately constrain the relationships between the proxies and sea level that are often poorly described by traditional methods assuming Gaussian distributions. We develop a new statistical framework to estimate past sea-level change based on modern distributions of RSL proxy elevations in relation to sea level, using corals as an illustrative example. The new statistical framework is hierarchical and comprises data, process, and parameter levels. In a case study based on coral archives, the data level describes each observed proxy's elevation and geochronological uncertainty from field and laboratory measurements and uses modern depth distributions of individual coral taxa to infer the likelihood of RSL, given the observed proxy elevations. The process level uses the full temporal covariance to model RSL through time. The parameter level dictates prior expectations regarding the correlation structure of RSL. Using Markov Chain Monte Carlo (MCMC) sampling, we approximate the posterior distributions of these parameters and RSL, conditioned on the observed data.

Incorporating the empirical distributions of coral taxa in models of RSL in south Florida produces realistic estimates of RSL and its uncertainty through time. The temporal distribution of the data affects the ability of the model to accurately predict past RSL. Using nonparametric likelihoods of proxy data in multi-proxy models provides robust estimates of RSL and its uncertainty within the new framework.