Why proxy uncertainty matters and why it is hard to do it right

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The reconstruction of past climates is vital for exploring Earth history and thereby evolutionary processes; for crtically evaluating our understnading of climate dynamics, and therefore future climate; and for examining the interplay of Earth system processes. It is not an isolated endeavour but one that is connected to a range of other disciplines and even the public dialogue around maor policy issues. Given that, it is vital that the uncertainty in our proxy estimates be properly constrained.

Historically, these debates have revolved around the uncertainty in calibrations, which although based on physical, chemical or biological principles are almost always defined by empirical relationships. By extension: i) debates have focused on the assumed mathematical constructions of those relationships; and ii) statistical tools have been at the heart of defining proxy uncertainty. Recent work has applied more sophisticated techniques (such as Bayesian approaches in i.e. the use of glycerol dialkyl glycerol tetraethers as sea surface temperature, SST, proxies). Other advances include more sophisticated treatment of time series.

However, proxy uncertainty is fundamentally entrained in the underlying mechanisms and assumptions on which these calibrations are based, i.e. the role of growth rate in the alkenone-based pCO_2 proxy or of alkalinity in the $\delta^{11}B$-based proxy; or of the Mg/Ca ratio or $\delta^{18}O$ value of seawater for the respective SST proxies. This, however, requires that proxies be based not just on robust empirical calibrations but also robust structural understanding of the relationships as well as the uncertainty in confounding variables. For example, the underlying assumptions of the alkenone pCO_2 proxy (diffusive entry of CO_2 into the haptophyte cell) have been challenged, and this complicates how ancient records are interpreted and questioned. Beyond such 'equation-embedded' uncertainty, there are a range of more complex issues including timing and location of signal origin and diagenetic, taphonomic and mixing effects, requiring understanding of seasonal and interannual production biases and mechanisms of transportation. Such issues are almost always treated in an ad hoc manner. Consequently, one of the key questions going forward will be to what extent we can embed proper quantitative uncertainty in our proxy-based environmental estimates; and at what point do such treatments bring about their own artificial confidence?