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Using Bayesian regression to construct proxy time series from palaeoclimate archives

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Age-depth observations from palaeoclimatic archives (i.e., peat cores, lake sediments, marine cores, etc.) consist of a set of dating points that comprise of the calibrated radiocarbon-dated ages and corresponding depths measured in the archive. However, the actual understanding of palaeo-climate comes from proxies (such as oxygen isotopes) that are related to various climatic parameters. Due to limitations of measurement, radiocarbon (i.e., ^{14}C) age-depth measurements are far fewer in number than the number of proxy-depth measurements. Thus, the first step in palaeoclimatic studies becomes the construction of an age-depth relationship that transforms the proxy measurements from the depth domain to a time series.

However, it still remains to be resolved as to how the errors of radiocarbon dating be effectively captured in the final proxy time series. Recent advances in this area have shown an emerging consensus favouring the use of Monte Carlo interpolation techniques. These methods typically involve approximate probability distributions that are generated by using thousands of Monte Carlo age-depth models. Despite their relative success and applicability, these methods have one primary drawback: they assume that the calibrated ages have a Gaussian distribution. This is an untenable assumption as the process of calibration - in which the measured ^{14}C age is related to the actual age using a standard ^{14}C calibration curve - converts the simple Gaussian error distribution of the ^{14}C measurement into a complicated multimodal error distribution as a result of the fundamental irregular nature of the calibration curves.

We present a regression based Bayesian approach to this issue. Our method focuses on the ultimate goal of arriving at a meaningful proxy time series and not on the in-between stage of constructing an age-depth model. We suggest to employ the conditional distributions of the measurements (of both the ^{14}C ages as well as the proxies with depth) and thereafter construct an estimator based on regression that provides the distribution of the proxy time series. In this approach, we arrive at meaningful results - such as the mean and standard deviation of the proxy - without having to assume that the calibrated ages have Gaussian errors. The method is validated using simulated data sets where the true values of the age and proxy are known. Moreover, besides radiocarbon dating, the method is applicable to other dating methods as well.

This novel approach based on a perspective of regression can open up newer possibilities of tackling the issue of uncertainties in age-depth relationships and proxy measurements.