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Testing for covariance between time-uncertain series: Theory, Monte Carlo results and applications to proxy records of millennial scale climate variations

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Statistical measures of the relationships between time series are generally altered by the presence of errors in timing, i.e. when applied to time-uncertain series. For example, the covariance sampled between two time series which in truth covary will generally be decreased by errors in timing. Previous work has sought to maximize some goodness of fit between time-uncertain series either heuristically or through more quantitative methods. However, there is a danger that unrelated records can be made to appear to covary by time adjustment. Here we propose a statistical test for the presence of covariance between time-uncertain series wherein the probability of obtaining a maximum covariance from randomly realized time-uncertain series is assessed using the theory of order statistics. The results of this analytical method provide insight into the influence of timing errors upon covariance and are shown to be consistent with results derived from a Monte Carlo procedure. As a demonstration, we apply this methodology to evaluate the significance of covariance amongst a globally distributed collection of proxy records that resolve millennial scale variations during the last glacial, and a pattern of significance emerges that appears consistent with hypotheses calling upon millennial scale climate variations to foremost involve changes in atmospheric circulation.