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Climate of the Past

Exploring errors in paleoclimate proxy reconstructions using Monte Carlo simulations: paleotemperature from mollusk and coral geochemistry

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Abstract. Quantitative reconstructions of the past climate statistics from geochemical coral or mollusk records require quantified error bars in order to properly interpret the amplitude of the climate change and to perform meaningful comparisons with climate model outputs. We introduce here a more precise categorization of reconstruction errors, differentiating the error bar due to the proxy calibration uncertainty from the standard error due to sampling and variability in the proxy formation process. Then, we propose a numerical approach based on Monte Carlo simulations with surrogate proxy-derived climate records. These are produced by perturbing a known time series in a way that mimics the uncertainty sources in the proxy climate reconstruction. A freely available algorithm, MoCo, was designed to be parameterized by the user and to calculate realistic systematic and standard errors of the mean and the variance of the annual temperature, and of the mean and the variance of the temperature seasonality reconstructed from marine accretionary archive geochemistry. In this study, the algorithm is used for sensitivity experiments in a case study to characterize and quantitatively evaluate the sensitivity of systematic and standard errors to sampling size, stochastic uncertainty sources, archive-specific biological limitations, and climate non-stationarity. The results of the experiments yield an illustrative example of the range of variations of the standard error and the systematic error in the reconstruction of climate statistics in the Eastern Tropical Pacific. Thus, we show that the sample size and the climate variability are the main sources of the standard error. The experiments allowed the identification and estimation of systematic bias that would not otherwise be detected because of limited modern datasets. Our study demonstrates that numerical simulations based on Monte Carlo analyses are a simple and powerful approach to improve the understanding of the proxy records. We show that the standard error for the climate statistics linearly increases with the climate variability, which means that the accuracy of the error estimated by MoCo is limited by the climate non-stationarity.

1 Introduction

Reconstructions of the past climate from proxy records involve a wide range of uncertainties at every step of the process. These uncertainties and the subsequent error bar in the reconstruction of a paleoclimatic variable need to be understood and quantified in order to properly interpret the reconstructed variability and to perform meaningful comparisons with climate model outputs. In a recent overview of methods used in high resolution paleoclimatology, Hughes and Ammann (2009) concluded that "*the study of the processes by which climate proxy records are formed [...] should be accorded high priority*".

Corals and mollusks are privileged archives for high resolution paleoceanographic studies and especially for El Niño Southern Oscillation (ENSO) reconstructions (Cole and

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