Geophysical Research Abstracts
Vol. 18, EGU2016-3437, 2016
EGU General Assembly 2016


# Bayesian parameter inference for empirical stochastic models of paleoclimatic records with dating uncertainty

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In the recent past, empirical stochastic models have been successfully applied to model a wide range of climatic phenomena [1,2]. In addition to enhancing our understanding of the geophysical systems under consideration, multilayer stochastic models (MSMs) have been shown to be solidly grounded in the Mori-Zwanzig formalism of statistical physics [3]. They are also well-suited for predictive purposes, e.g., for the El Niño Southern Oscillation [4] and the Madden-Julian Oscillation [5].

In general, these models are trained on a given time series under consideration, and then assumed to reproduce certain dynamical properties of the underlying natural system. Most existing approaches are based on least-squares fitting to determine optimal model parameters, which does not allow for an uncertainty estimation of these parameters. This approach significantly limits the degree to which dynamical characteristics of the time series can be safely inferred from the model.

Here, we are specifically interested in fitting low-dimensional stochastic models to time series obtained from paleoclimatic proxy records, such as the oxygen isotope ratio and dust concentration of the NGRIP record [6]. The time series derived from these records exhibit substantial dating uncertainties, in addition to the proxy measurement errors. In particular, for time series of this kind, it is crucial to obtain uncertainty estimates for the final model parameters.

Following [7], we first propose a statistical procedure to shift dating uncertainties from the time axis to the proxy axis of layer-counted paleoclimatic records. Thereafter, we show how Maximum Likelihood Estimation in combination with Markov Chain Monte Carlo parameter sampling can be employed to translate all uncertainties present in the original proxy time series to uncertainties of the parameter estimates of the stochastic model.

We compare time series simulated by the empirical model to the original time series in terms of standard statistical properties, such as the autocorrelation function and the power spectrum, and analyze how these properties change when we vary the model parameters within ranges suggested by the uncertainty estimates. Finally, we discuss the predictive power of our approach with particular focus on characteristic events in the NGRIP record, namely the Dansgaard-Oeschger events.

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