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PiecewiseInference.jl: a machine learning framework for inverse ecosystem modelling

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In contrast to purely data-driven statistical models, process-based ecosystem models have the potential to extrapolate beyond observed dynamics and predict their response to global change. Yet, the predictive power of process-based ecosystem models has been limited in practice because of issues with the estimation of the model parameter values and because of model inaccuracies. While inverse modelling techniques can make use of observation data to improve the estimation of parameters and, combined with model selection techniques, improve model inaccuracies, process-based ecosystem models are dependent on numerous parameters, are strongly nonlinear, and their numerical integration is computationally expensive. These characteristics, together with the nature of available observation data that may consist of shallow, incomplete and noisy time series, as well as the difficulty to obtain the model sensitivity to the parameters, have challenged the use of inverse modelling and model selection techniques in ecosystem modelling. Here, we present a machine learning (ML) framework relying on a segmentation method combined with state-of-the-art optimizers and automatic differentiation to perform inverse ecosystem modelling. The segmentation method regularizes the likelihood landscape, while the latter techniques, traditionally used in the field of artificial intelligence, greatly improve the efficiency of the inference process. We introduce PiecewiseInference.jl, a software package written in the Julia programming language that implements the ML framework, and evaluate its performance in recovering the dynamics of simulated chaotic food-webs. We show that it can efficiently estimate parameters and subsequently provide reliable forecasts based on noisy, incomplete and independent time series. Using model selection techniques, we further show that the ML framework can provide accurate statistical support for the true generating model among several candidates. We plan on utilizing PiecewiseInference.jl with long-term fish and invertebrate abundance time series to better understand the dynamical processes regulating marine communities in the Northeast Atlantic and Mediterranean Sea.