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Novel particle filter approaches to parameter estimation for ecological models

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We present our results on estimating parameters of ecological models using an implicit particle filter. In most data assimilation problems, one estimates the probability density function (PDF) of the state of a stochastic model conditioned upon noisy observations. Traditional approaches, for example the ensemble Kalman filter, are effective only when the model dynamics are weakly nonlinear and its statistics approximately Gaussian. We hope to address a much more general situation, in particular one relevant to the impact of climate change on ecosystems, where the dynamics are strongly nonlinear and the statistics non-Gaussian. In this situation, a common approach is to represent the conditional PDF using a collection of samples, called particles, with associated weights. These weights often become so small that all but a small percentage of the initial samples are eliminated, and an overwhelming large number of particles are required to adequately represent the conditional PDF. We use an implicit particle filter that avoids this problem by first finding large weights, then determining the particles with these weights.

We extend the implicit method to estimate unknown parameters for ecological models. Accurate estimation of model parameters is essential to understanding the relationships among the different trophic levels of local ecosystems. The system parameters determine the interaction among relevant chemical constituents and species that make up the levels, and determine their long-term dynamical evolution. As an example, we consider a classical predator-prey model with a subcritical Hopf bifurcation. We show that even when a bifurcation lies between our initial parameter estimate and the parameters used to generate the reference solution, the particle filter recovers the correct parameters. In more general scenarios, this enables us to detect environmental changes that lead to extinction or survival of a species. The implicit particle filter, appropriately generalized, can produce estimates of any number of parameters optimally, in the sense of root-mean-square (RMS) error. Even when the entire state vector is not observed, the filter is able to recover multiple parameters reliably. Finally, we discuss the application of our method to a more complex marine ecological model with five state variables: nitrate, ammonium, phytoplankton, zooplankton, and detritus. Notably, we demonstrate examples where our approach represents an improvement over augmenting the state vector with the unknown parameters.