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Stochastic emulators for prediction of noisy physical systems with METHO

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Abstract: Efficient and accurate environmental prediction and management require robust stochastic models. Traditional physical models are computationally expensive, while stochastic emulators offer efficient surrogates. However, maintaining high posterior predictive coverage is essential for reliable decision-making. We introduce METHO, a method for training stochastic emulators of stochastic physical models with high posterior predictive coverage, by modifying neural forward predictors to provide stochastic posterior predictions.

The goal of this research is to develop and evaluate METHO for improving the efficiency and reliability of environmental prediction and management.

METHO employs a Bayesian framework, utilizing Gaussian process regression for capturing complex relationships and quantifying uncertainty. A calibration step aligns the emulator's output with the true physical model, ensuring high posterior predictive coverage. METHO modifies neural forward predictors to generate stochastic posterior predictions.

METHO's performance was evaluated using synthetic datasets emulating various computational fluid dynamics problems of relevance to environmental modeling. The results demonstrated that METHO consistently outperforms alternative approaches, providing accurate emulation of stochastic physical models with well-calibrated posterior predictive coverage even in the presence of significant noise and uncertainty.

METHO is potentially applicable when efficient neural forward predictors apply to the domain of interest, which are then modified to provide stochastic posterior predictions. In cases where a suitable neural forward predictor cannot be found or developed, the benefits of METHO may be diminished, potentially limiting its applicability in some environmental contexts.

Despite its limitations, METHO has considerable implications for environmental prediction and management. By maintaining high posterior predictive coverage, it supports more accurate and reliable decision-making in various contexts, such as climate change adaptation, natural resource management, and pollution control. The increased computational efficiency enables real-time decision support and adaptive management.

METHO is an innovative method for training stochastic emulators, offering high posterior predictive coverage and robust performance when suitable neural forward predictors are available and can be modified for stochastic posterior predictions. Incorporating METHO into current frameworks allows stakeholders to make more informed decisions and better manage environmental risks and uncertainties.

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