Session: C29 Poster: W145A

# On filtering skill for turbulent signals using a suite of nonlinear and linear Extended Kalman Filters

Michal Branicki[†]; Boris Gershgorin; Andrew Majda
[†] New York University, USA
Leading author: branicki@cims.nyu.edu

An important problem in many contemporary scientific applications, including climate change science, lies in developing efficient, computationally cheap and robust filtering techniques for real-time statistical estimation of a state of a natural system based on partial observations and an imperfect model. A major difficulty in accurate filtering of noisy turbulent signals arising in complex multi-scale systems with many degrees of freedom is model error; the fact that the signal from nature is processed through an imperfect model where important physical processes are parameterized due to inadequate numerical resolution or incomplete physical understanding. Virtually all atmosphere, ocean, and climate models with sufficiently high resolution are turbulent dynamical systems with multiple spatio-temporal scales. Various strategies for mitigating model error in nonlinear filtering have been developed and they roughly fall into techniques based on deterministic models and techniques combining stochastic models and sequential Bayesian filters; the unifying feature of these methods in the context of filtering high-dimensional turbulent systems is often an unrealistically large computational overhead necessary for a reliable operation. Filters utilizing stochastic forecast models with 'on the fly' parameter estimation for reducing model error offer a cheap and skillful alternative for filtering turbulent systems with many spatio-temporal scales. Updating the parameters associated with unresolved or unknown processes in the imperfect model 'on the fly' through stochastic parameter estimation is an efficient way to increase filtering skill and model performance. We examine a suite of filters implementing stochastic parameter estimation on a nonlinear, exactly solvable, stochastic test model mimicking turbulent signals in regimes ranging from configurations with strongly intermittent, transient instabilities to laminar behavior. Stochastic Parameterization Extended Kalman Filter (SPEKF) systematically corrects both multiplicative and additive biases in the observed dynamics and it involves exact formulas for propagating the mean and covariance including the unresolved parameters in the test model. The remaining filters use the same nonlinear test model but they introduce additional model error through different moment closure approximations and/or linear tangent approximation used for computing the second-order statistics in the stochastic forecast model. A comprehensive study of filter performance is carried out in the presence of various sources of model error as the observation time and observation noise levels are varied. In particular, regimes of filter divergence for the linear tangent filter are identified. The estimation skill of the unresolved stochastic parameters by various filters is also discussed and it is shown that the linear tangent filter, despite its popularity, is completely unreliable in many dynamical regimes. The presented results provide useful guidelines for filtering turbulent, high-dimensional, spatially extended systems with significant model errors. They also provide unambiguous benchmarks for the capabilities of linear and nonlinear extended Kalman filters on a stringent, exactly solvable test bed.