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Universal Covariance Inflation Factors in the Synchronization Approach to Data Assimilation

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A theoretical paradigm that seems appropriate for data assimilation is that of the synchronization of loosely coupled chaotic systems. Two or more chaotic systems, loosely coupled through only a few of many degrees of freedom, fall into synchronized motion along their strange attractors under a surprisingly wide variety of conditons, despite sensitivity to differences in initial conditions. The phenomenon has been used to establish a new framework for data assimilation as the synchronization of two systems, corresponding to “truth” and “model”, respectively. One seeks to introduce coupling between the two systems in a way that minimizes synchronization error.

In previous work, the introduction of observational noise in the coupling channel led to a system of stochastic differential equations that could be analyzed for the optimal value of a coupling coefficient in simple cases. That optimization procedure reproduced the Kalman filter algorithm under certain linearity conditions. In the presence of nonlinearities, if one generalizes the Kalman filter in a way that corresponds to inflating background error, one can derive optimal values for the covariance inflation factor that happen to agree roughly with those used in operational practice. Further, the optimization is robust against the introduction of model error.

Here we generalize these previous results in several ways: First, we show that sampling error can be introduced as multiplicative noise. Optimal inflation factors can then be calculated to take account of this additional source of error. Second, we show that the previous optimization of an idealized one-dimensional system captures the essential effects of nonlinearities in higher dimensions. Lastly, in the optimal synchronization context, we compare covariance inflation to other ways of treating nonlinearities, such as adding noise to elements of the analysis error covariance matrix. The near-universality of the traditional inflation approach is explained, and its limits are explored.