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Dynamically constrained uncertainty for the Kalman filter covariance in the presence of model error

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The forecasting community has long understood the impact of dynamic instability on the uncertainty of predictions in physical systems and this has led to innovative filtering design to take advantage of the knowledge of process models. The advantages of this combined approach to filtering, including both a dynamic and statistical understanding, have included dimensional reductions and robust feature selection in the observational design of filters. In the context of a perfect models we have shown that the uncertainty in prediction is damped along the directions of stability and the support of the uncertainty conforms to the dominant system instabilities. Our current work likewise demonstrates this constraint on the uncertainty for systems with model error, specifically,

- we produce analytical upper bounds on the uncertainty in the stable, backwards orthogonal Lyapunov vectors in terms of the local Lyapunov exponents and the scale of the additive noise.
- we demonstrate that for systems with model noise, the least upper bound on the uncertainty depends on the inverse relationship of the leading Lyapunov exponent and the observational certainty.
- we numerically compute the invariant scaling factor of the model error which determines the asymptotic uncertainty.

This dynamic scaling of model error is identifiable independently of the noise and is computable directly in terms of the system's dynamic invariants — in this way the physical process itself may mollify the growth of modelling errors. For systems with strongly dissipative behaviour, we demonstrate that the growth of the uncertainty can be confined to the unstable-neutral modes independently of the filtering process, and we connect the observational design to take advantage of a dynamic characteristic of the filtering error.