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The role of model dynamics in ensemble Kalman filter performance for chaotic systems

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When applied to large chaotic systems such as atmospheric and ocean models, the ensemble Kalman filter (EnKF) is susceptible to divergence (losing track of observations), thereby limiting its predictive capabilities. Past studies have demonstrated the adverse impact of random sampling error during the filter's update step. In this study, we demonstrate how the structure of ensemble, which represents initial condition errors, affects filter divergence. In particular, we examine whether the absence of certain dynamical features of the model in the ensemble plays an important role. The idea is that the EnKF can only correct errors covered by the ensemble, and thus the ensemble must adequately capture important errors that grow during forecast periods. When applied to a simple chaotic model, we found that the EnKF ensemble self aligns strongly with the subspace spanned by unstable Lyapunov vectors, which is associated with linearized long-term error growth. Furthermore, the filter avoids divergence only if the full linearized long-term unstable subspace is spanned. However, short-term dynamics also become important as non-linearity in the system increases. Non-linear movement prevents errors in the long term stable subspace from decaying indefinitely. If these errors then undergo linear intermittent growth, a small ensemble may fail to properly represent all important modes, causing filter divergence. A combination of long and short-term growth dynamics are thus critical to how EnKF stabilizes errors. These findings can help in developing practical robust filters based on model dynamics.