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The Application of Nonlinear Local Lyapunov Vectors to Ensemble Predictions in the Lorenz Systems

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Nonlinear local Lyapunov vectors (NLLVs) are developed to indicate orthogonal directions in phase space with different perturbation growth rates. In particular, the first few NLLVs are considered to be an appropriate orthogonal basis for the fast-growing subspace. In this paper, the NLLV method is used to generate initial perturbations and implement ensemble forecasts in simple nonlinear models (the Lorenz63 and Lorenz96 models) to explore the validity of the NLLV method.

The performance of the NLLV method is compared comprehensively and systematically with other methods such as the bred vector (BV) and the random perturbation (Monte Carlo) methods. In experiments using the Lorenz63 model, the leading NLLV (LNLLV) captured a more precise direction, and with a faster growth rate, than any individual bred vector. It may be the larger projection on fastest-growing analysis errors that causes the improved performance of the new method. Regarding the Lorenz96 model, two practical measures, namely the spread/skill relationship and the Brier score, were used to assess the reliability and resolution of these ensemble schemes. Overall, the ensemble spread of NLLVs is more consistent with the errors of the ensemble mean, which indicates the better performance of NLLVs in simulating the evolution of analysis errors. In addition, the NLLVs perform significantly better than the BVs in terms of reliability and the random perturbations in resolution.