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The Application of Nonlinear Local Lyapunov Vectors to Ensemble Prediction in a barotropic quasi-geostrophicmodel

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The breeding method is used extensively as an ensemble generation technique for its simple concept and cheap computing. Bred vectors (BVs) are dynamically obtained from the nonlinear model and represent a set of fastest-growing modes that are globally quasi-orthogonal at each time. However, the BVs have similar local structures that may degrade the global orthogonality to some extent and the natural breeding may not be able to stably capture the fast-growing directions. In this paper, we introduced a new ensemble generation scheme, nonlinear Local Lyapunov Vectors (NLLVs), which is obtained by using the comparison and the Gram-Schmidt reorthonormalization (GSR) methods. The NLLVs are a set of strictly orthogonal vectors that represent the directions from the fastest growing direction to the fastest shrinking direction, and thus the first few of them could be used to provide the subspace of the fastest-growing errors. The performances of the NLLV and the BV schemes are systematically compared in a barotropic quasi-geostrophic model. The results show that the NLLVs perform more stable in capturing the fastest-growing modes and have greater diversity in both local and global regions than the BVs. The NLLVs also have improved performance according to various verification measures, such as the Brier scores and the rank histograms.