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A New Breeding Method with Adjustable Spatial Structure: Logarithmic Bred Vectors (LBV)

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The breeding method is a conceptually simple and computationally cheap ensemble generation mechanism [1]. Bred vectors (BV) are obtained dynamically from the nonlinear model as finite fluctuations growing in time, but rescaled at fixed time intervals to avoid exponential divergence. Therefore, they characterize the spatial structures with fast-growing fluctuations at each time, so they are finite time and finite amplitude approximations of Lyapunov vectors.

The main advantage of this method is the use of the original nonlinear system, with no need of additional information. However, the spatiotemporal effects of nonlinearities have not been fully understood in this framework, due to the lack of an appropriate theory. So far, spatiotemporal growth of errors has been studied in terms of the exponential divergence of errors. However, it has been recently shown that this growth also depends on the spatial correlation of the system, which also grows in time interacting with the exponential growth of errors [2]. This work was done working in the framework of kinetic rough surfaces theory [3]. For the class of the so-called autoafine systems, the dynamics between these two processes is characterized in terms of precise power-laws, which describe the evolution of fluctuations both in space and time. It has been recently shown that fluctuations in spatiotemporal systems belong to this class [4]. Thus, as shown by [2] kinetic rough surfaces theory provides a sound theory to work with finite fluctuations from a spatiotemporal point of view.

In this paper we apply this study to the generation of BVs, which are also finite fluctuations growing in time, but rescaled at fixed time intervals. As BV are typically very localized in space with only a small number of significant values (the leading fluctuation areas), a logarithmic transformation is required in the breeding framework to work with normal spatial errors. Therefore, we propose a new method that we call ‘‘Logarithmic Breeding” which rescales the variables in the logarithmic space; this is equivalent to rescaling the variables in the original space, but using the geometric mean instead of a norm. This new technique allows us breeding bred vectors with a desired spatial structure, from localized vectors (where a single fast-growing fluctuation area is considered) to more uniform vectors with several fast-growing fluctuation areas (these areas are associated with different Lyapunov vectors, apart from the dominant one). We denote the resulting vectors Logarithmic Bred Vectors (LBV), which depend on a new parameter that controls the spatial structure.

The LBVs tend to be more independent as the parameter is increased or, in other words, as the vectors are less localized and take into account the effect of different Lyapunov exponents. Moreover, we show that the growth of the ensemble spread along time depends on the spatial structure (the correlation) of the BVs used to prepare the ensemble. Thus, the growth of the spread can be tuned into different desired behaviors using the proposed methodology. We illustrate the application of LBV to generate ensembles with a desired short- or medium- range spread; i.e., ensembles generated with the same perturbation amplitude, but attaining a prescribed variance at different lead times.

The concepts are illustrated using a chain of diffusively coupled Lorenz systems. This spatiotemporal toy model displays many of the characteristics of atmospheric numerical weather prediction models [5]. However, we also give some preliminary evidence showing that some of the results also stand in an operative medium-range numerical weather EPS system. Thus, this technique could result in an important advance of operative ensemble forecast methods, although further research in atmospheric models is needed.

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