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Nonlinear Processes in Geophysics
Discussions
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Interactive comment on "Brief Communication: Breeding vectors in the phase space reconstructed from time series data" *by* E. Lynch et al.

E. Lynch et al.

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Referee Comment:

The authors proposed a new approach, i.e. the nearest-neighbor breeding, to model and predict sudden transitions in systems represented by time series data. Furthermore, they used the Lorenz-63 model to examine the validity of this method. The results show that the dynamical properties of the standard and nearest-neighbor breeding are similar. This validates the ability of this new approach to predict regime change in a dynamical system using the time series data of one variable. Thus, this has important implications. However, I think that the presentation needs to be improved. Here a

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list of points and questions should be addressed:

Author Comment:

We thank the referee for taking the time to review our manuscript and provide these thoughtful comments. We address each point below. Referee comments are italicized, followed by our comments.

1. *Page 1304, line 15: The authors mentioned "the systems known to exhibit sudden regime changes in their data". In fact, I am especially interested in these systems. In addition to magnetospheric substorms and geospace storms, are there any other systems known to exhibit sudden regime changes? As for the well-known phenomena such as the haze, rainstorm and thunderbolt, could the nearest-neighbor breeding be used to model and predict them?*

   Our focus in the paper is on the demonstration of the breeding technique and the Lorenz63 model is used. Systems in nature that exhibit sudden changes, e. g., magnetospheric substorms (see Vassiliadis et al. GRL 1991 for computation of the largest Lyapunov exponent for substorms), are currently under study and we expect that the technique would be applicable to many natural systems that exhibit regime changes – e.g. transitions from a quiet (near equilibrium) state to a disturbed or active state. The application of the techniques outlined in this article requires the system to have low dimensional underlying dynamics such that phase space trajectories lie onto an attractor. While the application to other systems is outside the scope of this article, we hope that others will follow and look into applying this method to these systems. The applicability of the technique the phenomena such as rainstorm etc. are of interest but requires detailed studies.

2. *Page 1305, lines 11-13: This sentence should be reformulated. It is not clear.*

   Original sentence: Having defined the reconstructed phase space by the time-delayed embedding, the new approach to breeding is in essence a matter of

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selecting the perturbed trajectories that capture the unstable directions along the control.

We will modify the sentence to read: Once the phase space has been reconstructed by the time-delay embedding, the new approach to breeding is in essence a matter of selecting perturbed trajectories that diverge in the unstable direction, relative to the control trajectory.

3. *Page 1306, line 2: The authors said "in order to avoid selecting nearest neighbors that are on the control trajectory". Please explain the reasons.*

   If nearest neighbors along the control trajectory are used to initiate the perturbed trajectory, the growth will be along the orbit and will not represent the nonlinear growth of diverging trajectories. By excluding a segment of the control trajectory near the point at the start of the breeding cycle, we take as our perturbations neighboring trajectories that may tend to diverge exponentially from the control trajectory via the nonlinear dynamics of the system.

4. *Page 1306, lines 1-4: Are there 2l+1 points to be excluded?*

   We excluded the l+1 points centered around the point on the control trajectory.

5. *Page 1306, lines 7-8: "the density of the trajectory points must be high enough". That is to say, the temporal resolution of the time series ïĄĎt should be sufficiently small. Is this right?*

   It is important that the trajectory cover the attractor and that it do so densely enough that suitable analogues for perturbations can be found. The temporal resolution will certainly affect the density of points and the properties of the embedding and breeding, but the more important feature of the time series that contributes to adequate density is the duration of the time series. Given sufficient time, systems like those suitable for this type of analysis will revisit neighborhoods of phase space arbitrarily frequently and within an arbitrarily small neighborhood.

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The radius of the neighborhood, or the size of the perturbation, will be limited in practice by the duration of the time series.

6. *Page 1307, line 1: Is here "m = 3 and τ = 7" determined by the methods described in section 2 (Page 1305, lines 2-9)?*

   Yes, we determined the dimension and time delay by looking at estimates of the correlation dimension and mutual information function respectively.

7. *Page 1307, line 17: The authors used the breeding window size n = 8 with Δt = 0.01 and perturbation size α = 0.10 in all experiments. Then, what about the sensitivity of the results in this paper on n and α?*

   We chose these parameters to make a direct comparison of our work to the results presented by Evans et al.

8. *Page 1307, line 21: The authors said "excluding l = 6 adjacent points". However, I think there should be 2l+1=13 points to be excluded. Am I right?*

   We excluded l=6 points, three on either side of the control point.

9. *Page 1307, line 25: The authors said "The left column of Fig. 1 shows the growth rates along the respective controls in the three experiments", but not mentioned the specific points. Are the points in the left column of Fig. 1 the control trajectory points? That is to say, do these points correspond to the time series data?*

   The points in the left column are the control trajectory points for which bred vector growth rates were computed. They correspond exactly to the time series data. We will modify the text to clarify this point.

10. *Page 1308, line 18: The threshold value "1" seems to be unreasonable. According to Fig. 1(f), there are many red stars corresponding to the absolute value of x1 that is greater than 1. If ignoring all these stars, some information about the regime change may not be noted and used.*

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It is true that sometimes this method will miss a regime change or predict a regime change when none occurs as is indicated by the false alarm rate.

11. *Page 1309, lines 10-11: The first reason should be reformulated. I do not understand what you said.*

    Original sentence: First, unlike the size of a particular variable, breeding can be tested in any dynamical model.

    We will modify the sentence to read: First, unlike threshold values of a particular variable, breeding can be tested in any dynamical model.

12. *Page 1309, lines 17-19: For the time series data of variable x when t is smaller than 10, the longer duration of the high growth rate does not indicate the next longer-lasting regime (Fig. 1d). Please clarify this phenomenon.*

    If the system is continuous, there should be segments along the trajectory that have a high growth rate for bred vectors. Since we have discrete data, the distribution of points for which bred vectors are computed will not always capture the entire segment. We will increase the size of the figure so that it is easier to see that there are often several red stars, or high growth rate bred vectors, preceding a long duration regime change that are very close to one another.

Modifications to the text:

Page 1305, lines 11-13: Once the phase space has been reconstructed by the time-delay embedding, the new approach to breeding is in essence of matter of selecting perturbed trajectories that tend to grow along the unstable directions with respect to the control trajectory.

Page 1307, line 26: Each point along the control trajectory for which a bred vector growth rate was calculated is colored based on the magnitude of the growth rate.

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Page 1309, lines 10-11: First, unlike threshold values of a particular variable, breeding can be tested in any dynamical model. For many systems, there will not be a correspondence between the numerical value of a particular variable and the regime change.

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