Can kurtosis be an early warning signal for abrupt climate change?

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1.Abstract

The climate system occasionally experiences an abrupt change. However, it is very difficult to predict this change at present. Fortunately, some generic properties have been revealed before several different types of dynamical system near their own critical thresholds. These properties provide a possible way to give an early warning for an impending abrupt climate change. Therefore, it is important to evaluate the applicability of an early warning indicator of an abrupt change. On the basis of several simple fold models, we have systematically investigated the performance of the kurtosis coefficient as an early warning signal for an upcoming abrupt climate change. The testing results indicate that the kurtosis coefficient is a reliable warning indicator in most of cases whether for a critical control parameter or for the strength of an external forcing approaches a critical point. However, the strong noise can greatly shorten the effective warning time, and also can result in the reduction of the magnitude of a kurtosis coefficient when a dynamical system approaches its critical threshold. The missing data has almost no effect on the kurtosis coefficient in all of tests, even it is true when the missing data accounts for 20% of the total sample. We also found that the kurtosis coefficient does not work in some cases, which means that the kurtosis coefficient is not a universal early warning signal for an upcoming abrupt change.

2. Model

The generalized population growth model has been shown as follows (Noy-Meir, 1975; May, 1977; Guttal and Jayaprakash, 2008). The constant r represents the intrinsic growth rate of vegetation biomass and the parameter K characterizes the carrying capacity of ecosystem.The variable V is the vegetation biomass. The control parameter c is the maximum grazing rate which ranges from 1 to 3 .

$$\frac{dV}{dt} = rV\left(1 - \frac{V}{K}\right) - c\,\frac{V^2}{V^2 + V_0^2} + \sigma_V \eta_V(t)$$

$$\left\langle \eta_V(t)\eta_V(t') \right\rangle = \delta(t - t')$$

3.Results

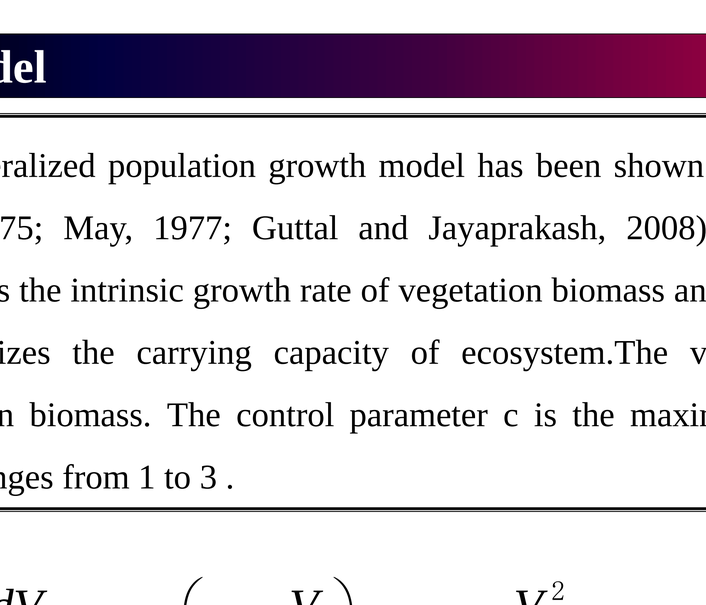

Figure 1. The bifurcation diagram for the univariate population growth model in which the continuous increase in grazing rate c can result in an abrupt change of the biomass density V. The thick solid lines correspond to stable ecological states, and the dotted line indicates the unstable equilibrium states.

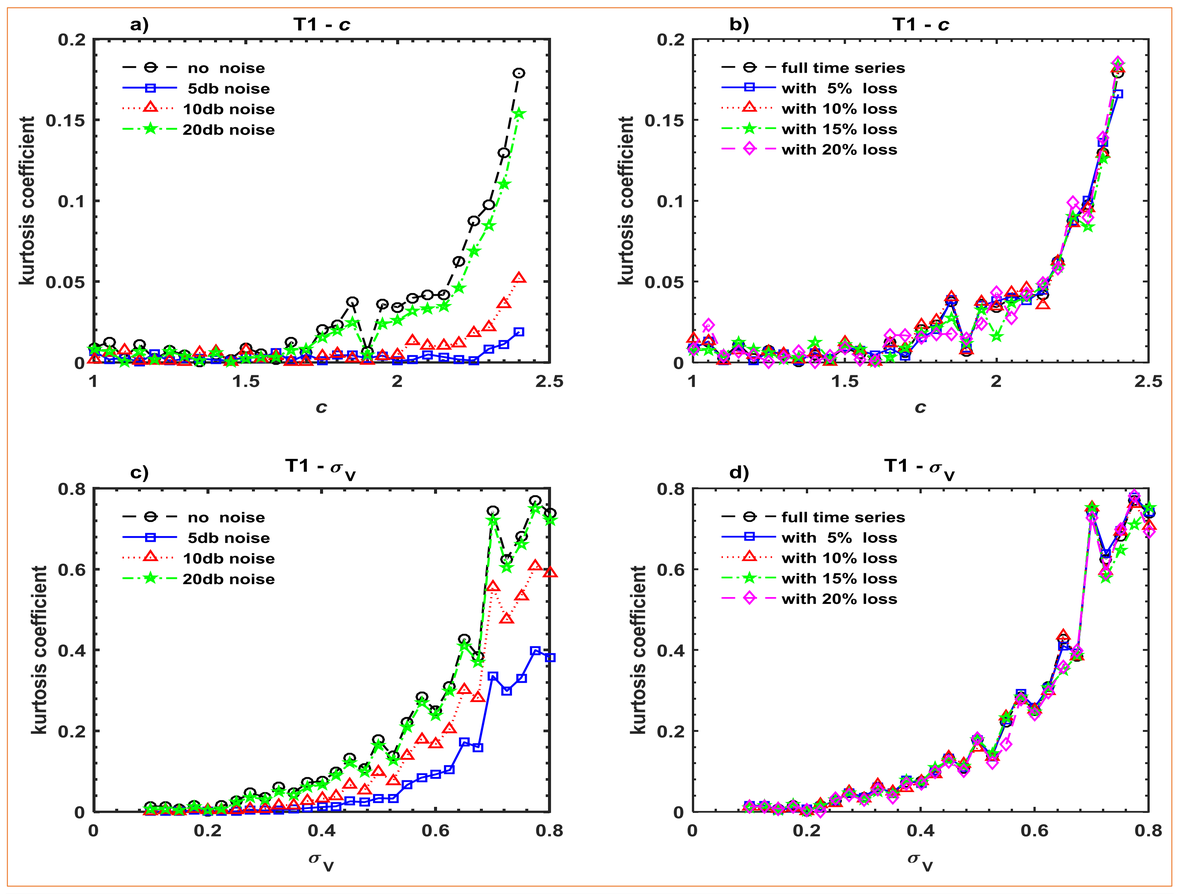

Fig. 2 Influence of the observational error on the kurtosis coefficient (a) for the first route, and (c) for the second route. Influence of the missing data on the kurtosis coefficient (b) for the first route, and (d) for the second route.

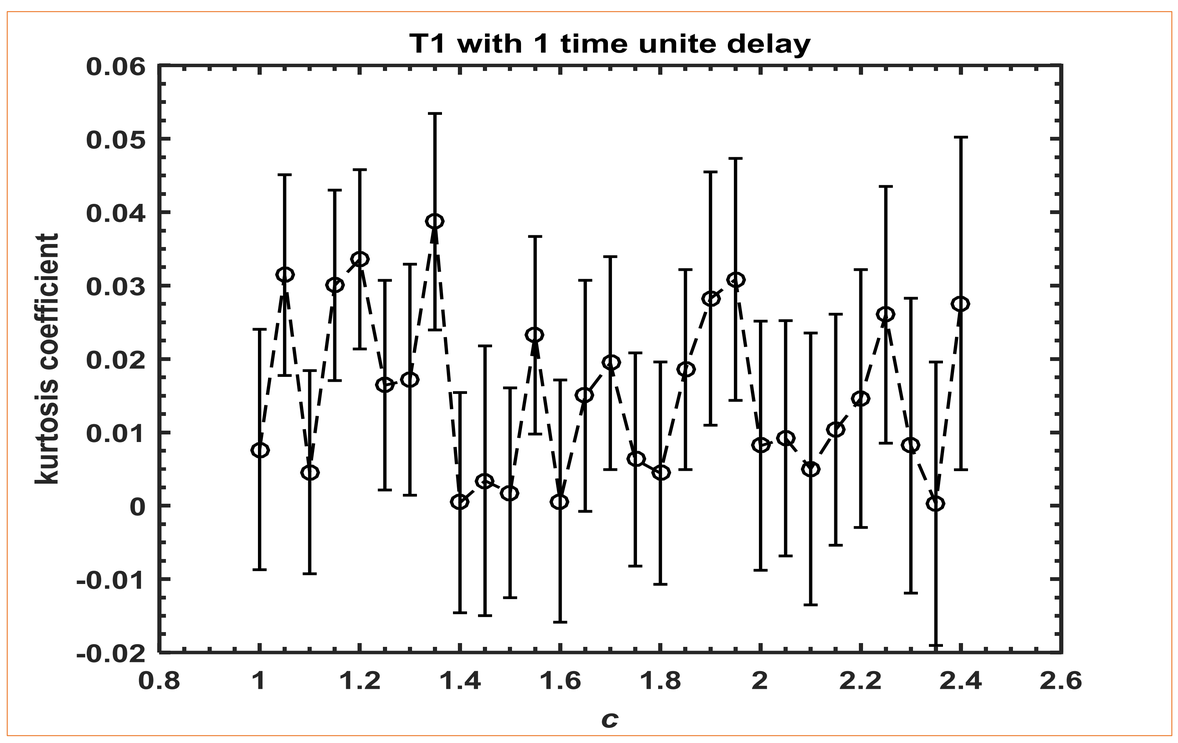

Fig.3 The kurtosis coefficient for the model with a time delay of =1.0. We obtained the kurtosis via the same way as the time delay of 1.7. In this case, kurtosis does not work. The error-bar shows the standard deviation of mean.

4.Conclusion

The strong noise can greatly shorten the effective warning time of the kurtosis coefficient, and also can result in the reduction of the changing magnitude of the kurtosis coefficient when a dynamical system is close to the critical threshold, even the kurtosis coefficient does not work in some cases. The missing data has almost no significant effect on the kurtosis coefficient as an early warning signal in all of tests. The conclusion is still true even when the missing data accounted for 20% of the total sample size in this study.

Moreover, we also found that the kurtosis coefficient did not show significant changes when a dynamical system is close to its critical threshold including delay model and non-delay model. In other words, the kurtosis coefficient does not work in this two cases. The results mean that the kurtosis coefficient has a certain scope of application, and no single early warning indicator can solve all of cases. So, it is very crucial to develop multiple early warning signals for a relatively reliable warning.

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