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Forecasting fluctuating outbreaks in seasonally driven epidemics

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Seasonality is a driving force that has major impact on the spatio-temporal dynamics of natural systems and their populations. This is especially true for the transmission of common infectious diseases such as influenza, measles, chickenpox, and pertussis. Here we gain new insights into the nonlinear dynamics of recurrent diseases through the analysis of the classical seasonally forced SIR epidemic model. Despite many efforts over the last decades, it has been difficult to gain general analytical insights because of the complex synchronization effects that can evolve between the external forcing and the model's natural oscillations. The analysis advanced here attempts to make progress in this direction by focusing on the dynamics of "skips" where we identify and predict years in which the epidemic is absent rather than outbreak years. Skipping events are intrinsic to the forced SIR model when parameterised in the chaotic regime. In fact, it is difficult if not impossible to locate realistic chaotic parameter regimes in which outbreaks occur regularly each year. This contrasts with the well known Rossler oscillator whose outbreaks recur regularly but whose amplitude vary chaotically in time (Uniform Phase Chaotic Amplitude oscillations). The goal of the present study is to develop a "language of skips" that makes it possible to predict under what conditions the next outbreak is likely to occur, and how many "skips" might be expected after any given outbreak. We identify a new threshold effect and give clear analytical conditions that allow accurate predictions. Moreover, the time of occurrence (i.e., phase) of an outbreak proves to be a useful new parameter that carries important epidemiological information. In forced systems, seasonal changes can prevent late-initiating outbreaks (i.e., having high phase) from running to completion. These principles yield forecasting tools that should have relevance for the study of newly emerging and reemerging diseases.