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When the unpredictable comes: An approach for foreseeing the transition to chaos in wildfire propagation

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Abstract

Inspired by the success of the weather forecast, for improving the prediction of wildfire propagation, we look for uncovering its chaotic nature. Here, we specifically focus on the derivation of a Lorenz-type chaotic system from a prototypical reaction-diffusion equation for the temperature field, which is coupled with an equation of the fuel concentration and also with a Langevin-like equation for the Rate of Spread (ROS). The motion of the fire-front results into a Brownian-like motion where the Gaussian noise is replaced by a combined effect due to the temperature and the fuel concentration. By performing a preliminary study, we show that it is possible to predict under which ”environmental” changes, i.e., a variation in the mean wind or in heat of reaction, a transition to a chaotic propagation occurs for a wildfire that was initially predictable in spite of uncertainties in its initial state. The practical aim of this study is to improve the prediction of wildfire propagation by predicting the arrival of the unpredictable regimes. In fact, in spite of uncertainties in the initial state, there are certain parameter configurations that give predictable trajectories, namely the trajectories evolve closed each other for different initial conditions. Notwithstanding this, if a small change occurs in time in these parameter configurations, e.g., a change in the mean wind or in heat of reaction, then the trajectories, that here-in-before evolved closely, here-in-after turns into diverging trajectories revealing that the process is now unpredictable. Hence, by means of the proposed approach, it is possible to predict for which changes in the system a wildfire, with a predictable configuration, switches from a predictable to an unpredictable propagation. In spite of the fact that the present analysis concerns an oversimplified setting of wildfire propagation, by the proposed approach a systematic analysis of the parameters – including the possible configurations and the possible changes that they may have - leads to establish a quantitative ranking-of-risk by estimating the growth of the error. Then, this approach allows for setting an alternative method for real-time risk assessment.

Keywords: Wildland fire, Lorenz attractor, Lyapunov exponent, Chaos

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