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A new theory on predictability: Nonlinear error growth dynamics

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For a chaotic system, there exists a limit to how far ahead we can predict, which is very difficult to be determined by the existing global or local Lyapunov exponents. In this paper, through investigating nonlinear error growth of nonlinear dynamical systems we introduce a new concept, the nonlinear local Lyapunov exponent (NLLE), to study predictability. The NLLE is a nonlinear generalization to the existing local or finite-time Lyapunov exponents, and can measure the growth rate of initial errors of nonlinear dynamical models without linearizing the governing equations. A saturation theorem of the ensemble mean relative growth of initial error (RGIE) is obtained by use the chaotic dynamical system theory and probability theory. Once the RGIE reaches the saturation, at the moment almost all predictability of chaotic dynamic systems is lost. Therefore, the predictability limit can be defined as the time at which the RGIE reaches its saturation level. With the NLLE and its derivatives, the limit of dynamic predictability in large classes of chaotic systems can be efficiently and quantitatively determined. Moreover, it is also very efficient and convenient to quantify the predictability limits of the atmosphere and climate systems on various scales and their spatial- temporal structure.