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Multifractal Intermittency and Ensemble Prediction Systems

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The question of intrinsic predictability limits of atmospheric processes can be traced back to the end of the 1950's and first attempts to assess the potential gain in predictability with an increase of the meteorological network resolution. Thompson (1957) studied the nonlinear uncertainty growth due to errors in the initial conditions resulting from a limited resolution of measurement networks and models, with the help of initial time-derivatives. He estimated the root mean square (RMS) doubling time for small errors to be about two days, whereas Charney and al. (1966), using more elaborate meteorological models, estimated it as five days. The scale dependency of the predictability time was underlined by (Robinson, 1967; Robinson, 1971), who argued that it should be proportional to the "eddy turn over time" that is dimensionally defined as $\tau(\ell) = \ell/\delta u(\ell)$, where $\delta u(\ell)$ is the characteristic shear of an eddy of size ℓ. Indeed, this time should be the characteristic (if unique) of destruction of structures of scale l and therefore of the loss of predictability.

However, the deceptively simple 3-component model of Lorenz (1963) brought a quite different approach of unpredictability that is very generic with the help of the concept of Lyapunov exponent (Lyapunov, 1907) and the Multiplicative Ergodic Theorem (MET, Oseledets, 1968). The "butterfly effect" and "chaos revolution" were so convincing that earlier approches seem to have been forgotten. Unfortunately, the fundamental importance of the large number of (spatial) degrees of freedom could not be ignored as emphasised by Lorenz (1969), who studied the spectral space-time decorrelation with a quasi-normal model of turbulence. Results obtained with somewhat more refined quasi-normal models (Leith, 1971; Leith and Kraichnan, 1972; Métais and Lesieur, 1986) converged to those obtained with straightforward phenomenological arguments (Schertzer and Lovejoy, 2004a), whereas the role of intermittency is drastic and yields strongly non gaussian statistics with many more frequent extremes, i.e. the loss of predictability is highly inhomogeneous and occurs by puffs (Schertzer and Lovejoy, 2004b).

In this communication, we emphasise that the effect of intermittency is twofold: (i) it generates an infinite hierarchy of scaling predictability times/Lyapunov exponents (ii) which may undergo a first order multifractal phase transition for the extremes events (Chigirinskaia et al., 1995). In the framework of Universal Multifractals (Schertzer and Lovejoy, 1987, 1997), these exponents and their phase transition are analytically determined with the help of a few multifractal parameters that are physically meaningful. Altogether, these results enable to revisit the concept of Ensemble Prediction Systems (EPS) (Toth and Kalnay, 1993; Molteni et al., 1996; Palmer, 2000) that has been funded on the butterfly effect, although dealing with systems of very large degrees of freedom. This suggests that the dispersion of the EPS set of perturbed trajectories is much more intermittent than previously expected and a multifractal analysis is required to track the puffs of predictability loss.