LARGE-SCALE DYNAMICS DETERMINES THE PREDICTABILITY OF EXTREME EVENTS IN TURBULENCE

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Extreme events in geophysical flows have a strong impact in human life and in diverse economical activities, and their prediction is crucial to mitigate their consequences. Particularly now, in the context of climate change, interest has emerged to develop models and indicators that allows for early detection and warning of extreme events. Some of these models have proved successful [1], but it is unclear if they can be improved because the predictability limit of extreme events is unknown: how far in advance can we predict extreme events with a perfect model? This limit is usually determined by the rate at which the uncertainty of the initial conditions is amplified by the chaotic dynamics of the system [2], i.e., by the leading Lyapunov exponent. Its inverse, the Lyapunov time, provides the time scale over which predictions become unfeasible. However, this estimate does not offer direct information on the predictability of particular features of the flow, such as the extreme bursts of a relevant quantity.

In this talk, we show that it is now possible to measure the predictability of extreme events directly by probing phase space with a computationally-intensive approach. This allows to assess the exact potential of predictive models and to determine precisely the conditions under which they may be effective. We analysed the predictability of extreme bursts of the dissipation in a two-dimensional Kolmogorov flow by producing massive ensembles of initial conditions perturbed around independent base flows. We produced millions of realisations to cover the full attractor of the Kolmogorov flow, and used the Kullback—Leibler divergence [3], an information-theoretical tool, to assess predictability. This analysis shows that extreme bursts of the dissipation may be successfully predicted beyond a few Lyapunov times, but that their predictability depends strongly on the phase-space region from which they emerge. Specifically, we reveal that predictable and unpredictable events evolve from two distinctly different large-scale circulation patterns (see figure). These results open the possibility of improving predictive models by tuning them to the large-scale dynamics. Our approach could be adapted with the available compute power to more complex flows, for instance to test the predictability of extreme relaminarisation events in transitional flows or the bursting in near-wall turbulence.

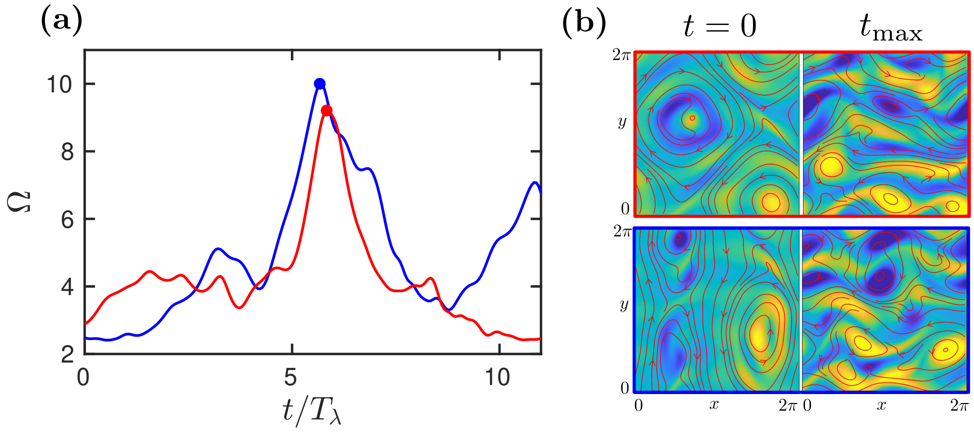

Figure 1. (a) Temporal evolution of the average entrophy, $\Omega = \langle\omega^2\rangle$, in two independent bursts of the dissipation $\varepsilon = \nu\Omega$, where ν is the kinematic viscosity. The red line corresponds to a burst that is unpredictable at $t = 0$, while the blue line corresponds to a predictable burst. $T_\lambda = \lambda^{-1}$ and λ is the leading Lyapunov exponent. (b)Visualisation of the flow in the temporal evolution plotted in (a); red, the unpredictable burst; blue the predictable burst. Panels on the left correspond to $t = 0$, before the burst, and panels on the right to the moment of the burst, $t_{\max} = 5.5T_\lambda$ and $t_{\max} = 5.9T_\lambda$. The colors correspond to the value of the vorticity from -6 (dark blue) to 6 (ligth yellow), and the red lines to the streamlines of the velocity field.

References

[1] Farazmand, M. and Sapsis, T.P., *Science advances* **3**, e1701533 (2017).
[2] Lorenz, Edward N., *Tellus*, **17**, 321–333, (1965).
[3] DelSole, T., *J. Atmos. Sci.*, **61**, 2425–2440 (2004).