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A predictability-based characterization of intermittency in turbulence

E. Frogé^{*†}, C. Granero-Belinchón^{*†}, S. G. Roux[‡], N. B. Garnier[‡] and T. Chonavel^{*}

The chaotic nature of the velocity of a turbulent flow, often modeled as a stochastic process, makes the forecast of the future values of velocity from the past ones a complex challenge. Moreover, the intermittency phenomenon implies extreme events at the small scales of the flow velocity, hindering the prediction task. We propose to characterize the predictability of turbulent velocity at time t by using the concept of innovation which is defined as the deviation between the actual value of the flow velocity at time t and its expected value knowing the precedent ones¹. The estimation of innovation is based on analog forecasting techniques, typically employed in meteorology and dynamical systems². In this work, we apply analog forecasting methods on a longitudinal turbulent velocity time series from the Modane wind tunnel³, and propose a characterization of intermittency based on predictability *via* innovation.

The resulting innovation is a non-Gaussian process with heavy-tailed probability density function *i.e.* with extreme events, see figure 1. Despite its white noise structure resulting in a flat second order structure function, higher-order dependencies are significant, as evidenced by the evolution of the flatness. Furthermore, the occurrence of large events in the innovation coincides with the occurrence of large values in the velocity gradient. This highlights the impact of intermittency on the unpredictability of the velocity of a turbulent flow as well as the capacity of innovation to characterize intermittency from a new point of view.

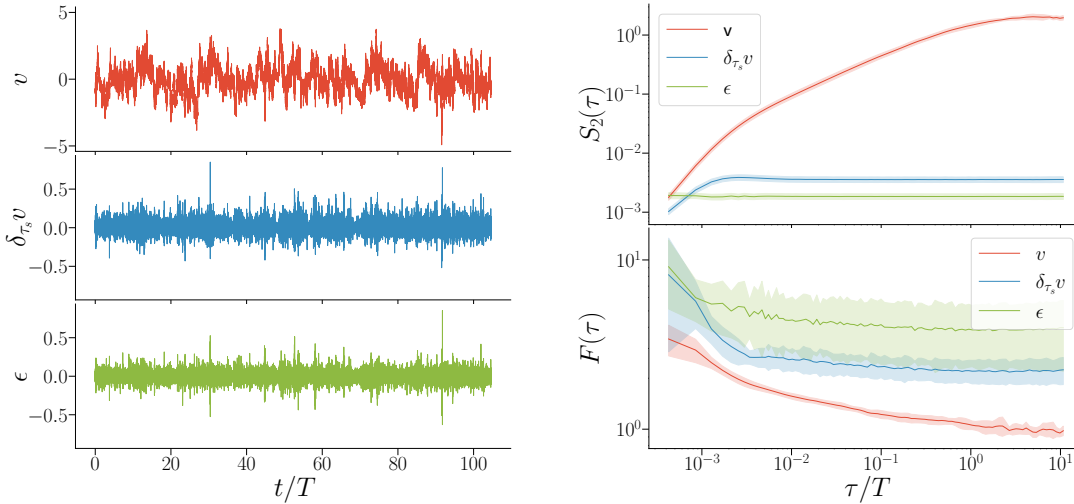


Figure 1: Left) One realization of Modane longitudinal velocity component $v(t)$ (red), its smallest scale increment $\delta_{\tau_s} v(t) = v(t) - v(t - \tau_s)$ (blue) and innovation $\epsilon(t) = v(t) - \mathbb{E}\{v(t)|v(t - \tau_s), \dots, v(t - n\tau_s)\}$ (green). With τ_s being the sampling period of Modane and \mathbb{E} the expected value operator.

Right) Second-order structure function $S_2(\tau) = \mathbb{E}\{(Z(t) - Z(t - \tau))^2\}$ and flatness $F(\tau) = \frac{1}{3} \frac{\mathbb{E}\{(Z(t) - Z(t - \tau))^4\}}{S_2(\tau)^2}$ of Z , with Z being: the Modane velocity v (red) its smallest increment $\delta_{\tau_s} v$ (blue) and innovation ϵ (green). Lines represent the mean and shadows the standard deviation computed on 10 realizations.

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¹Kalman, *Journal of Basic Engineering* **82** (1960).

²Platzer et al., *Journal of the Atmospheric Sciences* **78** (2021).

³Kahalerras et al., *Physics of Fluids* **10** (1998).