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Relaminarization of spatially localized states in plane Couette flow

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Exact localized states in plane Couette flow

Plane Couette flow is a three-dimensional flow confined between two parallel walls moving in opposite directions and is known to possess a linearly stable laminar state for all Reynolds numbers. Transition to turbulence occurs through finite-amplitude perturbations the most dangerous of which often spatially localized (Pringle *et al.*, Phys. Fluids **27**, 064102 (2015)). Exact spatially localized solutions found in plane Couette flow on two intertwined branches in a phenomenon known as snaking (Schneider *et al.*, Phys. Rev. Lett. **104**, 104501 (2010)) have recently been shown to be related to optimal perturbations with respect to the transient energy growth (Olvera *et al.*, Phys. Rev. Fluids **2**, 083902 (2017)). In this study, we use them as initial conditions for time-integration for a range of Reynolds numbers up to $Re = 350$ and investigate their dynamics.

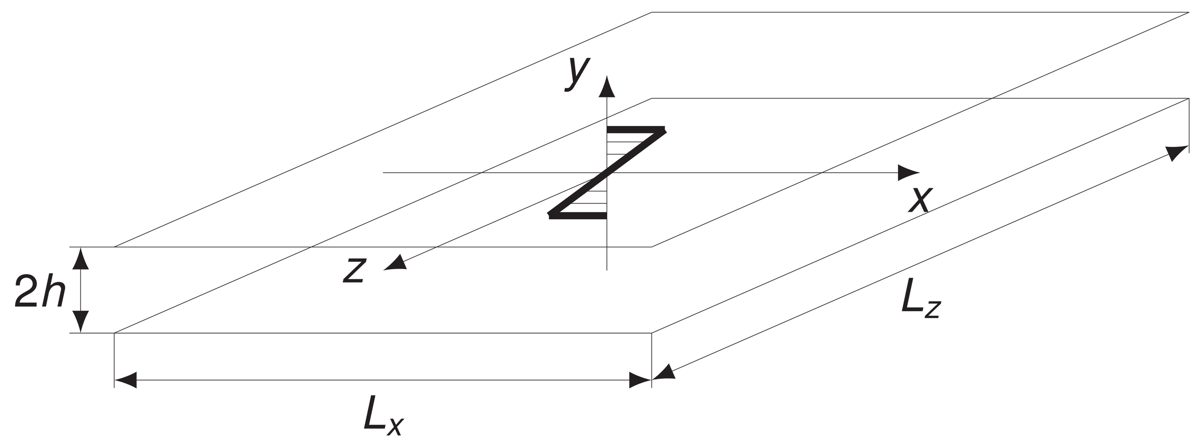

Fig. 1: Sketch of the plane Couette flow configuration and its laminar solution.

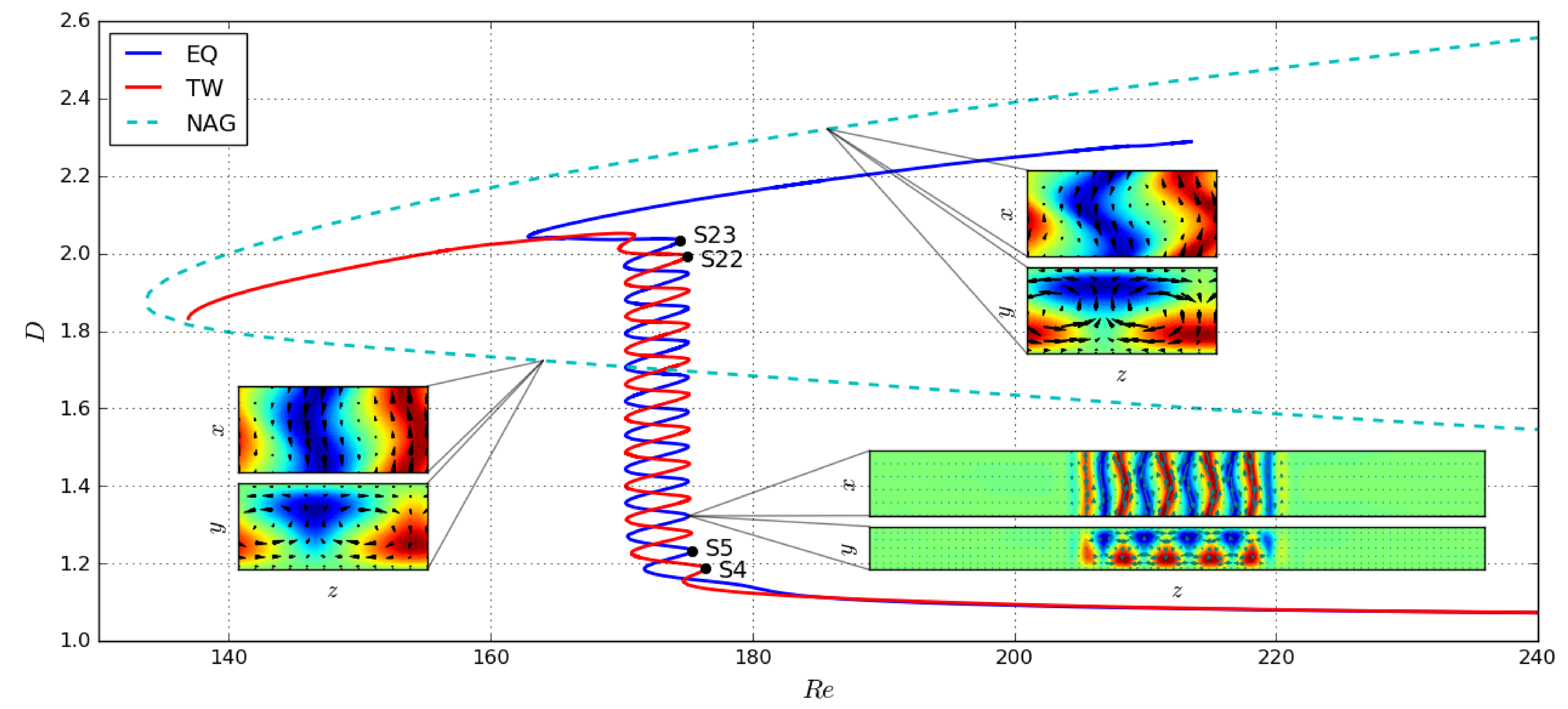

Fig. 2: Bifurcation diagram of the snaking described by the localized equilibria (EQ, blue line) and travelling waves (TW, red line) of plane Couette flow. The saddle-nodes of both branches are labelled Si, where i is the number of rolls the saddle-node state consists of. The spatially periodic Nagata solutions are represented in dash lines.

Map of dynamical regimes

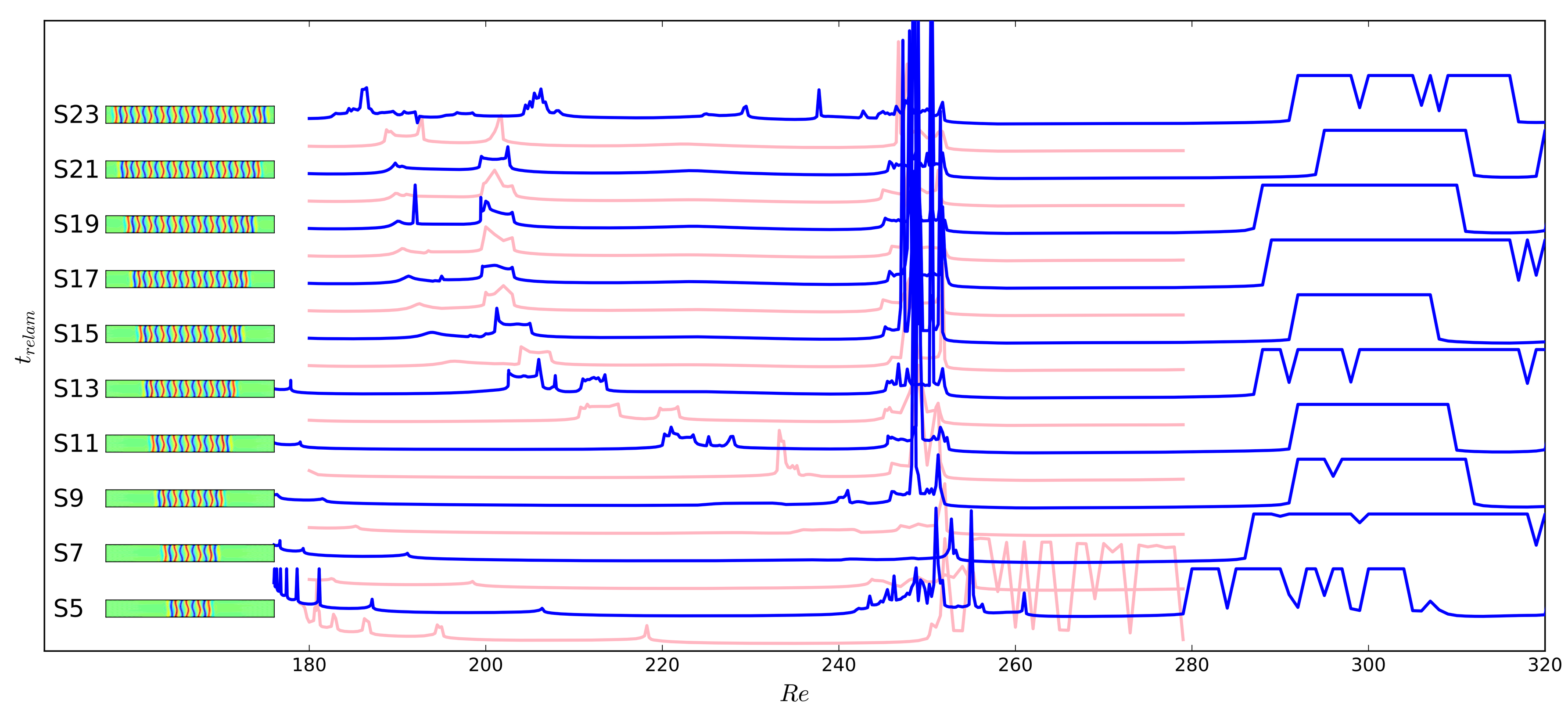

Fig. 3: Relaminarisation times t_{relam} for EQ (blue) and TW (pink) initial conditions for $Re \in [180; 320]$. The curves have been shifted according to the spanwise width of the initial condition.

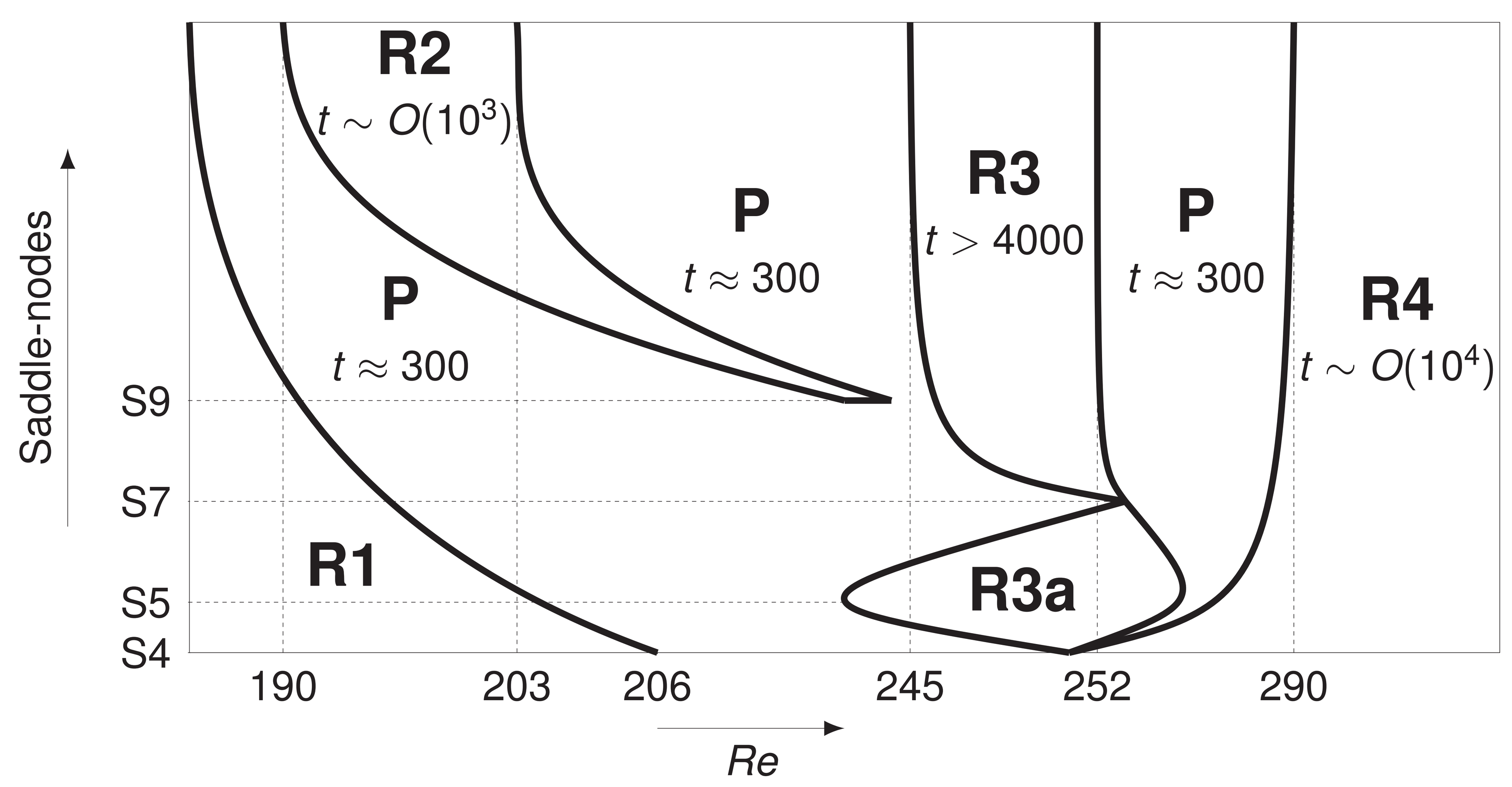

Fig. 4: Map of the parameter space (Re, Si). The regions of non-trivial dynamics labelled R1, R2, R3, R3a and R4 are separated by plateaux (P) of relatively low relaminarisation times. Characteristic relaminarisation times are denoted by t.

Region R1 – peaks

- Peaks: $Re_{n+1} - Re_s = \alpha (Re_n - Re_s)$
- Local minima: $t_n = t_0 + \beta n$

$$\Longrightarrow t_{relam} = \frac{\beta}{\ln \alpha} \ln \left[\frac{2(Re - Re_s)}{(1+\alpha)(Re_0 - Re_s)} \right] + t_0$$

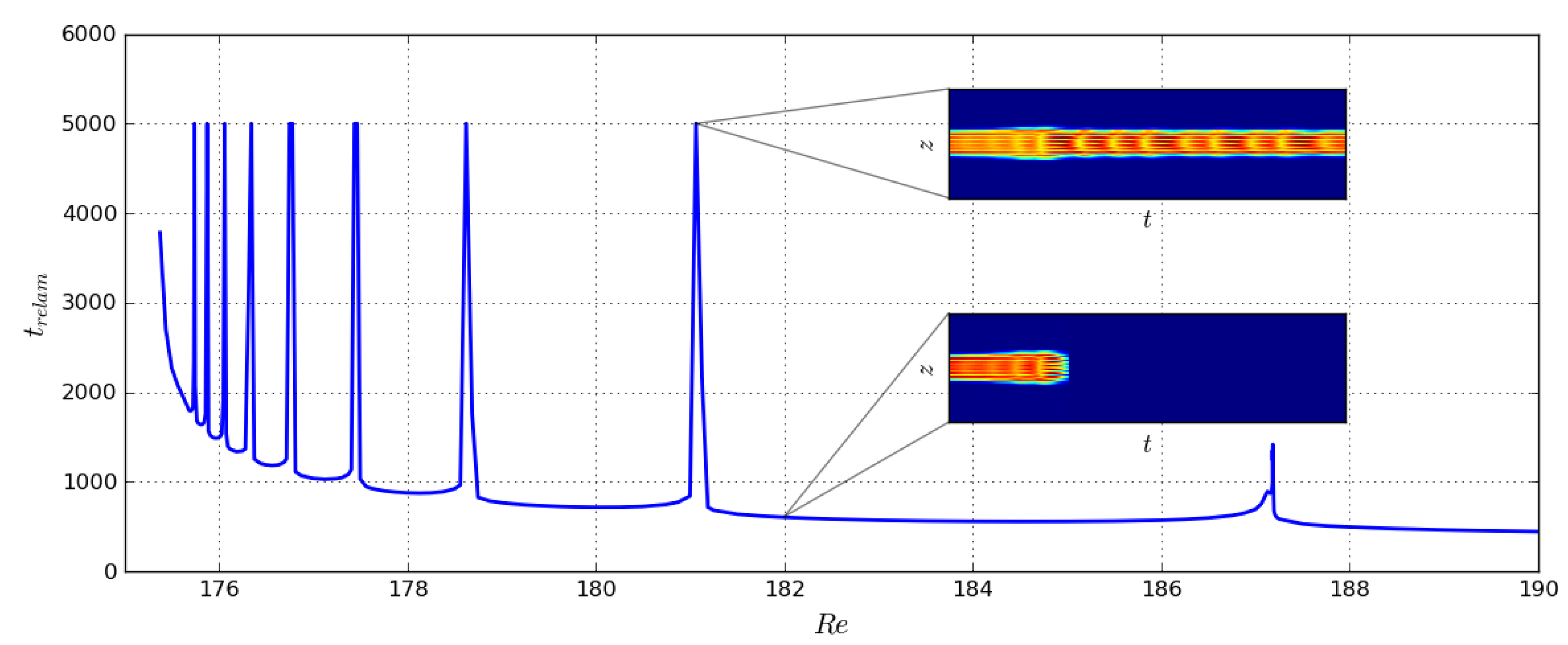

Fig. 5: Relaminarisation times t_{relam} in R1 for initial condition S5.

Region R2 – splitting

- The initial state splits into two spots that start oscillating
- At the boundaries of R2, spots have the same width after splitting for different Si
- The relaminarisation time is $t_{relam} \approx 10^3$

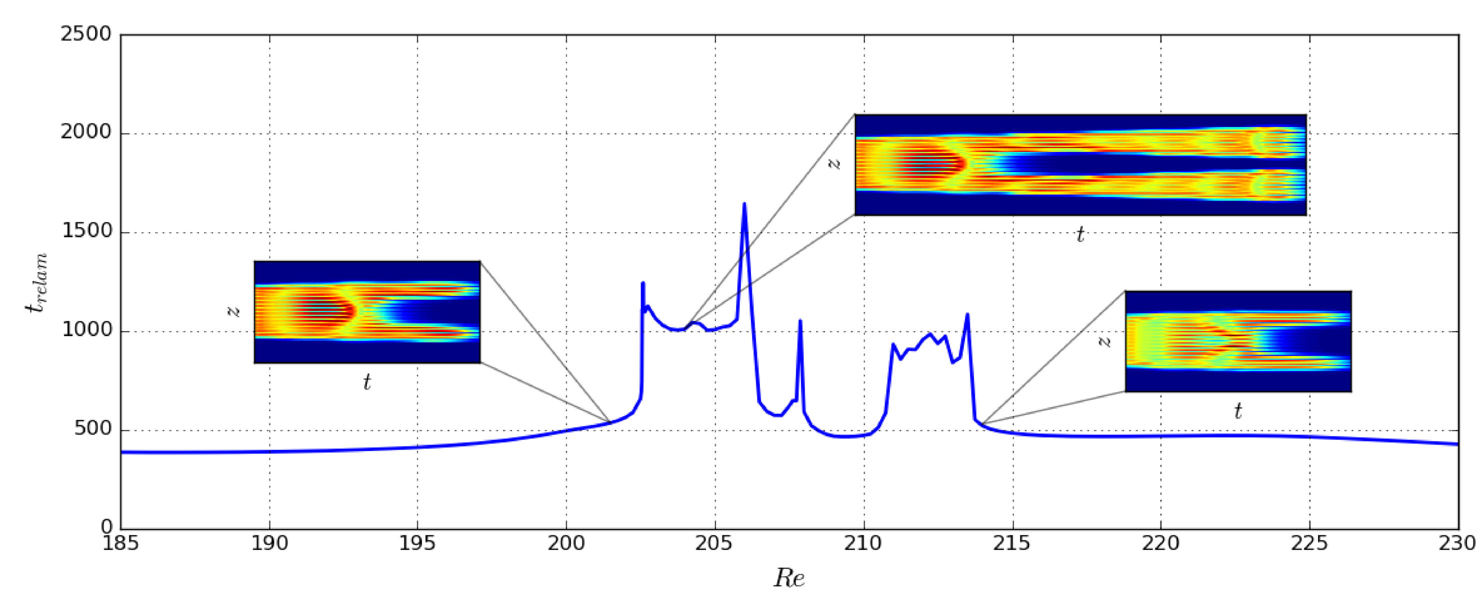

Fig. 6: Relaminarisation times t_{relam} in R2 for initial condition S13.

Region R3 – long-lived chaos

- Spot dynamics may result in long-lasting simulations: $t_{relam} \gg 1000$
- The relaminarisation time is sensitive to changes in Re

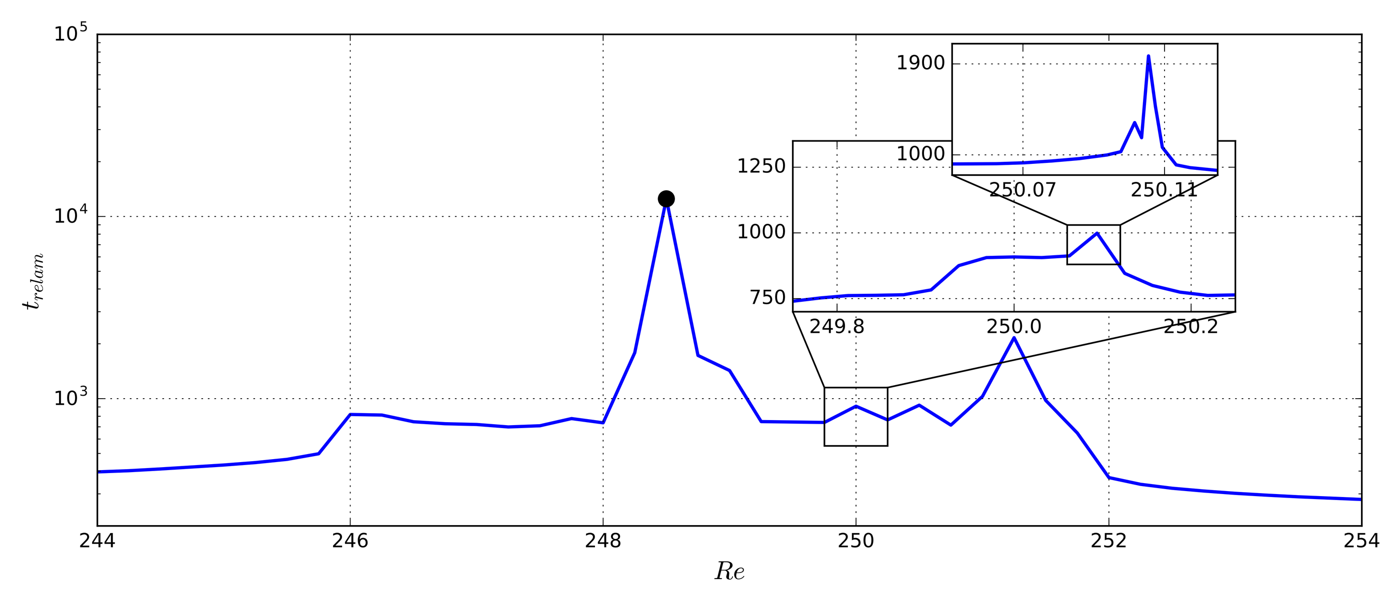

Fig. 7: Relaminarisation times t_{relam} in R3 for initial condition S9.

Region R3 – simulation at $Re = 248.5$

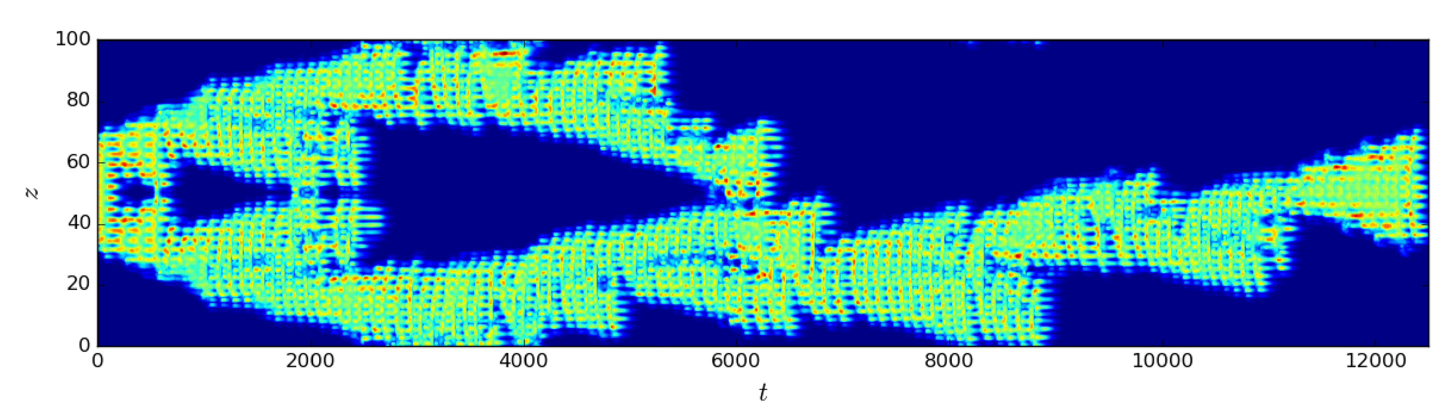

Fig. 8: Spatiotemporal evolution of the streamwise- and wall-normal-averaged kinetic energy at $Re = 248.5$ for initial condition S9 (black dot in figure 7).

Region R4 – transition to turbulence

The majority of simulations are long-lasting with $t_{relam} \gg 1000$.

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