Reservoir computing for prediction of intermittent reversals of large-scale vortex in two-dimensional thermal convection

Daigaku Katsumi*, Masanobu Inubushi† and Naoto Yokoyama‡

A large-scale vortex appears in two-dimensional turbulent Rayleigh-Bénard convection, and reverses its rotational direction intermittently. The intermittent reversals of the large-scale vortex is triggered by development of smaller counter-rotating cells near the diagonally opposing corners[1].

A proper orthogonal decomposition[2] suggests that the development of the secondary cells can be captured by time series of shear rates τ and temperatures θ on the side walls. In this work, τ_i and θ_i at four locations shown in Fig. 1(a) are employed as input vector from a direct numerical simulation (DNS) and output vector for multistep (specifically 100 in nondimensional time) ahead prediction by echo state networks with leaky-integrator neurons[3], which is a type of reservoir computing (RC).

The time series display that the global angular momentum L rapidly changes near the intermittent reversals. While τ_2 and τ_3 are almost constant, τ_1 and τ_4 increase 40 before L changes from negative to positive (Figs. 1(b) and (c)). Similarly, τ_2 and τ_3 decrease 40 before L changes from positive to negative. Moreover, the RC successfully can predict τ_i as well as θ_i 100 later (Figs. 1(c) and (d)). Combining the correlation between τ and L and the RC prediction, we can detect the intermittent reversals about 140, which is roughly 1/3 of the mean reversal period, in advance. The success of the prediction where the RC uses the time series at the only four locations on the side walls reveals that similar prediction will be feasible in laboratory experiments.

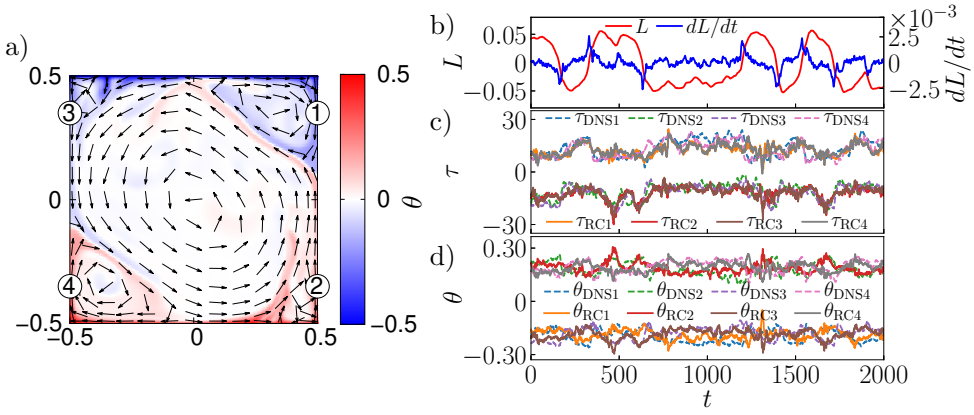

Figure 1: (a) Velocity and temperature field. (b) Time development of L and dL/dt. Time development of τ_i (c) and θ_i (d) obtained by DNS and RC.

*Grad. School of Engineering, Tokyo Denki University, Adachi, Tokyo 120-8551, Japan
†Dep. Applied Mathematics, Tokyo University of Science, Shinjuku, Tokyo 162-8601, Japan
‡Dep. Mechanical Engineering, Tokyo Denki University, Adachi, Tokyo 120-8551, Japan

[1]Sugiyama et al., *Phys. Rev. Lett.* **105**, 034503 (2010).
[2]Podvin and Sergent, *Phys. Rev. E* **95**, 013112 (2017).
[3]Jaeger et al., *Neural Netw.* **20**, 335 (2007)