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Deep Reinforcement Learning for enhancing heat transfer in turbulent convection

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Abstract

Heat-transfer enhancement in turbulent Rayleigh-Bénard (RB) convection holds significant value, spanning diverse applications across both theoretical research and industrial engineering. Controlling turbulent convection through non-uniform wall temperature distributions is not only common but also relatively easy to implement in experiments. Previous studies have also shown that such methods can effectively modulate heat transfer performance. However, current control strategies are mostly based on empirically designed functions, and significant challenges remain in optimizing wall temperature fluctuations and formulating advanced strategies to maximize heat-transfer efficiency. Deep reinforcement learning (DRL) method sheds light on the optimization of control strategies, offering the potential to provide adaptive and data-driven solutions to address these complexities. Inspired by this advantage, our goal is to employ reinforcement learning to develop an effective heat-transfer enhancement strategy for turbulent RB convection.

We consider three-dimensional RB convections, with temperature fluctuations applied to the bottom wall to control heat transfer. The boundary layer temperature signals serve as the basis for these wall temperature fluctuations. For our direct numerical simulations, we utilize the AFiD code, and the reinforcement learning network parameters are trained and updated using the Twin Delayed Deep Deterministic Policy Gradient method, built upon the Actor-Critic framework. We introduce an innovative DRL-driven control strategy for heat-transfer enhancement. Effective at Rayleigh numbers up to 5×10^8, this approach achieves a maximum heat-transfer improvement of 38%, significantly surpassing traditional non-uniform temperature distribution methods. Additionally, inspired by the insights gained from DRL training, we propose a simplified control model that operates independently of DRL while maintaining a comparable level of efficiency

Keywords:

Turbulent convections, turbulent control, deep reinforcement learning