Controlling turbulent heat transport by manipulating coherent structures

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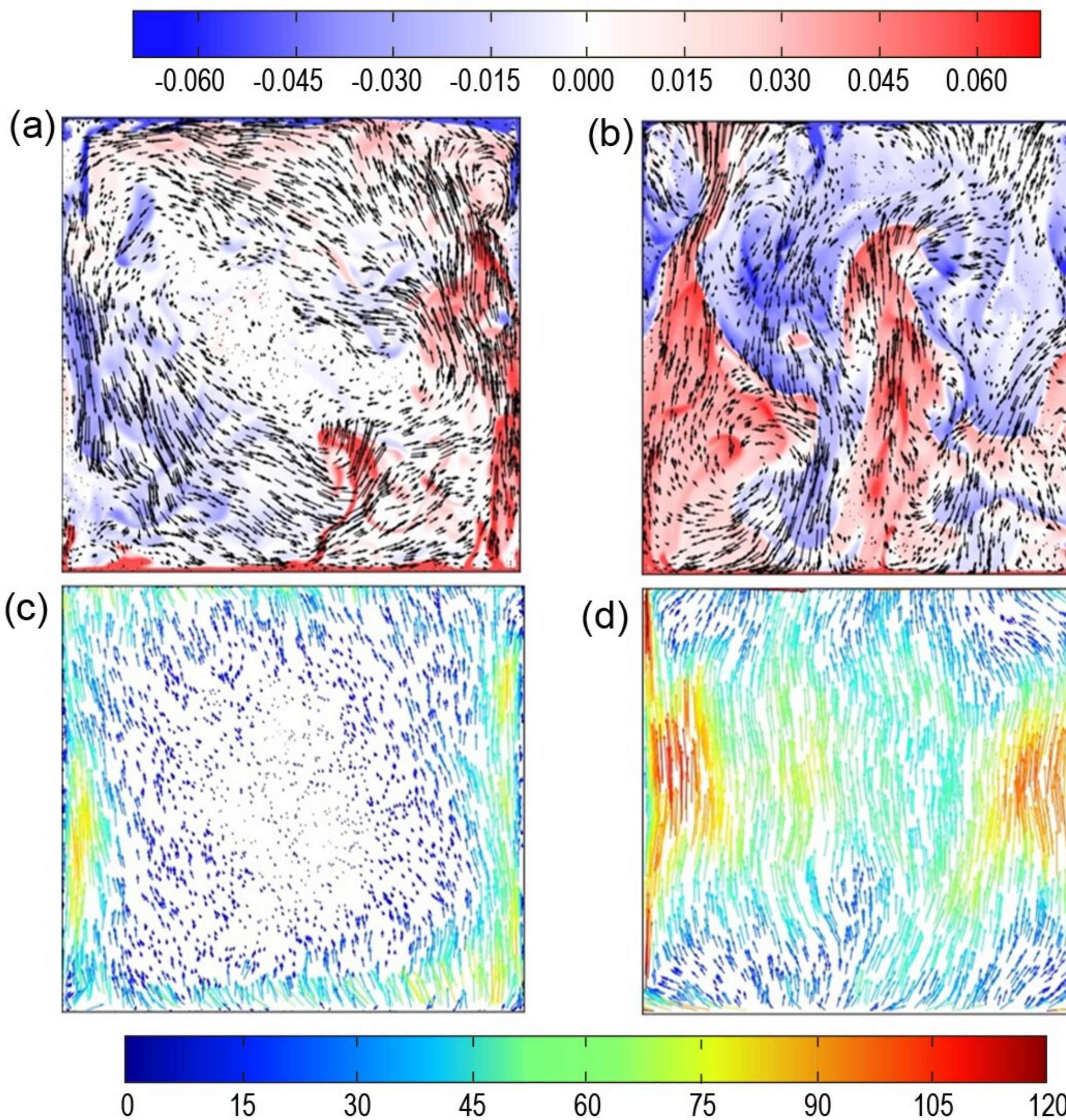

Instantaneous flow fields (a, b) and time-averaged heat flux fields (c, d) in a canonical thermal turbulence system with rectangular geometry. By applying spatial confinement through decreasing the lateral sizes of the system, the domain-sized circulatory flow is replaced by more energetic thermal coherent structures (indicated by the red/blue structures). This manipulation in the coherent structures not only leads to significant change in the global heat transfer, but also alters the spatial distribution pattern of heat flux greatly. Credit: Science China Press

This topic is reviewed by Prof. Ke-Qing Xia (Southern University of Science and Technology, Shenzhen, China) and his collaborators, mainly based on their research work over the past ten years.

Being the last unsolved problem in classical physics, fluid turbulence has attracted much attention from both academic and engineering communities. In contrast to completely disordered systems, one defining feature of turbulent flows is the existence of coherent structures, which are spatial-temporally correlated over a range of scales.

It has long been known that these coherent structures are the primary carriers for mass, momentum, and heat transport in turbulence. However, owing to the inherent characteristics of turbulent flows, such as strong nonlinearity and strong dissipation, how to manipulate coherent structures to control turbulent transport has been a long-standing issue.

In the past decade, Prof. Xia's team have made significant progresses in this issue. By conducting a series of studies in a canonical thermal turbulence system, namely the turbulent Rayleigh-Bénard convection, they discovered a new mechanism of tuning turbulent heat transport via coherent structure manipulation through simple geometrical confinement.

Under this mechanism, the heat transfer efficiency is controlled by the coherency of thermal structures (characterized by their geometrical properties), rather than the turbulence intensity.

As a result, the heat transport efficiency can be significantly enhanced even the resultant flow is much slower. Very importantly, this mechanism is fundamentally different from the prevalent heat-management approach based on the classical view of wall-bounded turbulence, which usually centers on directly modifying the diffusion-dominant boundary layer to enhance or inhibit turbulent heat transfer.

In the review article, Prof. Xia and his collaborators introduced, and explained in detail, the physical picture behind this newly discovered mechanism, and discussed its potential applications in passive thermal management (such as electronics cooling).

Moreover, by introducing additional examples of thermal turbulence systems that are subject to various dynamical processes (including rotation, double-diffusion, magnetic field, tilting, modification by polymer additive and so on), they further demonstrate how the framework of coherent structure manipulation can be generalized to understand heat transport behaviors in seemingly different turbulence systems in a unified way. This universal mechanism is expected to be realized in other types of turbulent flows.

This review article also covers other important progresses in this research topic and outlines some future directions. These not only provide new understanding for the communities of turbulence research and heat transfer, but also promote the design and development of engineering systems with tunable transport efficiencies.

The work is published in *National Science Review*.

More information: Ke-Qing Xia et al, Tuning Heat Transport Via Coherent Structure Manipulation: Recent Advances in Thermal Turbulence, *National Science Review* (2023). DOI: 10.1093/nsr/nwad012

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