Local analysis of the effect of radiation on the large-scale circulation in a cubic Rayleigh-Bénard cell

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In the presence of water vapour or carbon dioxide, natural convection phenomena in air are generally coupled with radiation effects, which are often *a priori* omitted from the analysis despite their possible significance. To study these effects, we consider the radiatively coupled numerical simulation of a Rayleigh-Bénard cell in the range of Rayleigh numbers $[10^6, 10^8]$. The flow is organized into a large-scale circulation (LSC), the orientation of which can change intermittently, with a characteristic frequency that tends to increase with radiation. To understand the origin of this variation, local analysis of the simulation is carried out using conditional averaging and statistical clustering based on Latent Dirichlet Allocation (LDA). LDA provides a compact representation of instantaneous flow snapshots in terms of local structures called motifs, the weights of which vary with time. It can be shown that the dominant heat flux motif weights provide a quantitative measure of the plume ejection rate within the LSC and outside (corner structures). This makes it possible to derive a LDA-based model for the reorientation frequency, which depends on the plume ejection rates as well as on a global convective time scale. Results show that the presence of radiation accentuates the asymmetry between the LSC and the corner structures (figure 1), which tends to impede reorientations, but also significantly increases the global kinetic energy and heat flux in the cell, which results in shorter global time scales. The predictions of the model are found to be in good agreement with the reorientation frequency measured in the simulations.

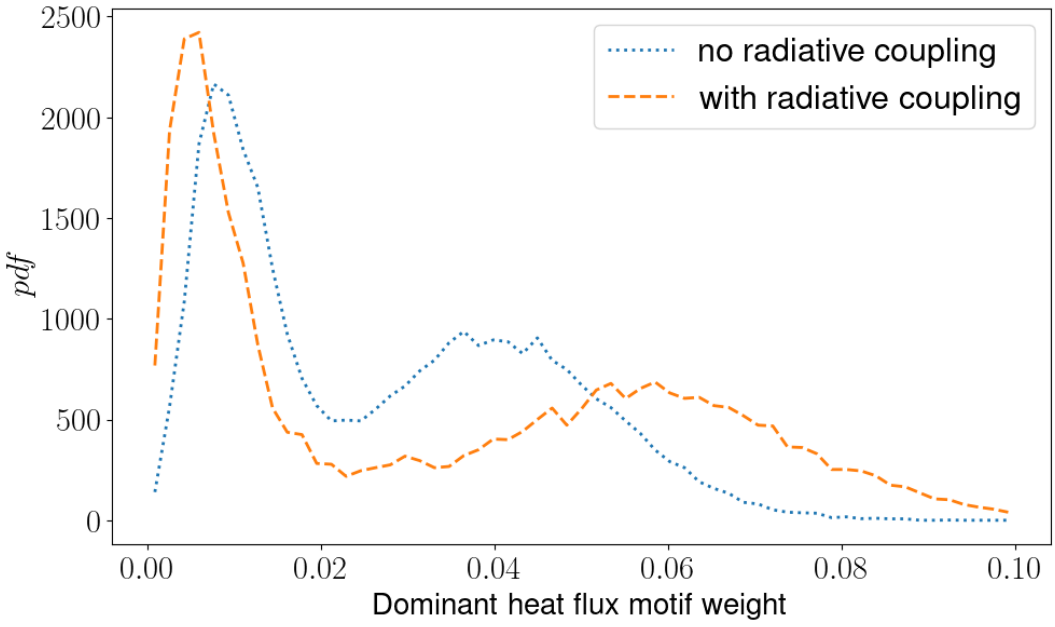

Figure 1: Probability distribution function of the dominant heat flux motif weights at $Ra = 10^7$ in the uncoupled and coupled cases (the signals have been low-pass-filtered with a moving average of 200 convective time units). The distributions are bimodal with a high-value mode corresponding to the LSC and a low-value mode corresponding to corner structures. The presence of radiation accentuates the dissymmetry between the LSC and the corner structure.

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