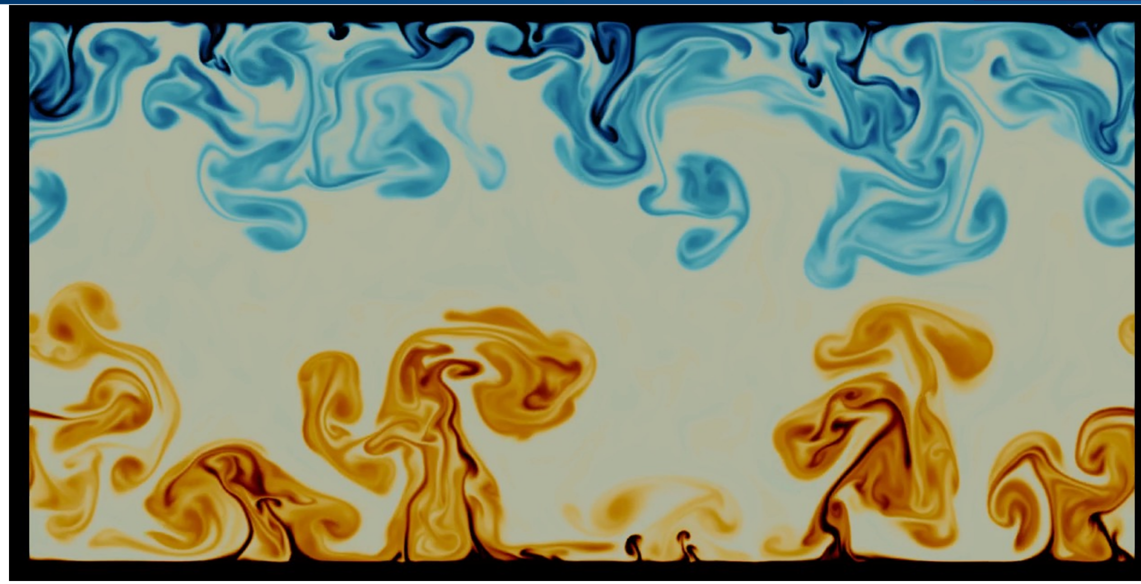

Reconstruction and Modulation of Convection through heat injection

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Collaborators

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- Prof. Federico Toschi - Eindhoven University of Technology, Netherlands
- Dr. Patricio Clark Di Leoni – Universidad De SanAndres, Argentina

Outline of today's talk

- Introduction and Motivation
- Numerical set-up and methods
- Main Results
- Discussion

Introduction

- Modification of a flow using Lagrangian thermal fluctuations - along the trajectory of virtual, thermally active tracer particles
- Perform 2D simulations of a thermal fluid system with particles suspended
- Particles are point-like, massless tracers with given temperature which locally heat or cool the fluid
- Temperature of the particle is set by a given temperature protocol

Motivation

- Devise proof of concept demonstration to show we can invent hard-wired Lagrangian protocols to modulate thermal flows
- Trigger more phenomenological studies, different protocols, extension with reinforcement learning
- Novelty – Temperature of particle depends on underlying dynamics of fluid

Fluid equations

- **Oberbeck-Boussinesq system**

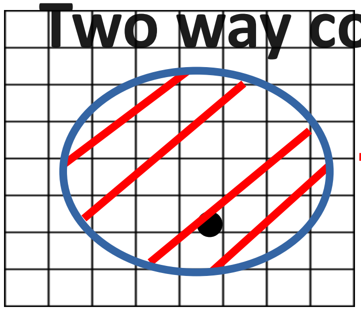
$$\boldsymbol{\nabla} \cdot \boldsymbol{u} = 0$$

$$\partial_t \boldsymbol{u} + (\boldsymbol{u} \cdot \boldsymbol{\nabla})\boldsymbol{u} = -\boldsymbol{\nabla} p + \nu \nabla^2 \boldsymbol{u} - \beta T \mathbf{g};$$

$$\frac{\partial T}{\partial t} + \boldsymbol{u} \cdot \boldsymbol{\nabla} T = \kappa \nabla^2 T + \Phi$$

- **Thermal forcing is Lagrangian and depends on the particles (next slide)**

- **Two way coupled system**



Particles heats (cools) fluid in it's vicinity

Heated (cooled) fluid accelerates

Accelerating fluid accelerates particle

Particle Policy and Thermal coupling

- Upward moving particles are hot and vice versa

$$T_i = \begin{cases} T_+, & \text{if } v_i > 0, \\ -T_+, & \text{if } v_i < 0. \end{cases}$$

- Each particle heats/cools a small local region

$$\alpha_i(\boldsymbol{r}, t) = \begin{cases} \alpha_0 \exp\left(-\frac{|\boldsymbol{r}-\boldsymbol{r}_i(t)|^2}{2\epsilon^2}\right), & \text{if } |\boldsymbol{r} - \boldsymbol{r}_i(t)| \leq \eta, \\ 0, & \text{if } |\boldsymbol{r} - \boldsymbol{r}_i(t)| > \eta. \end{cases}$$

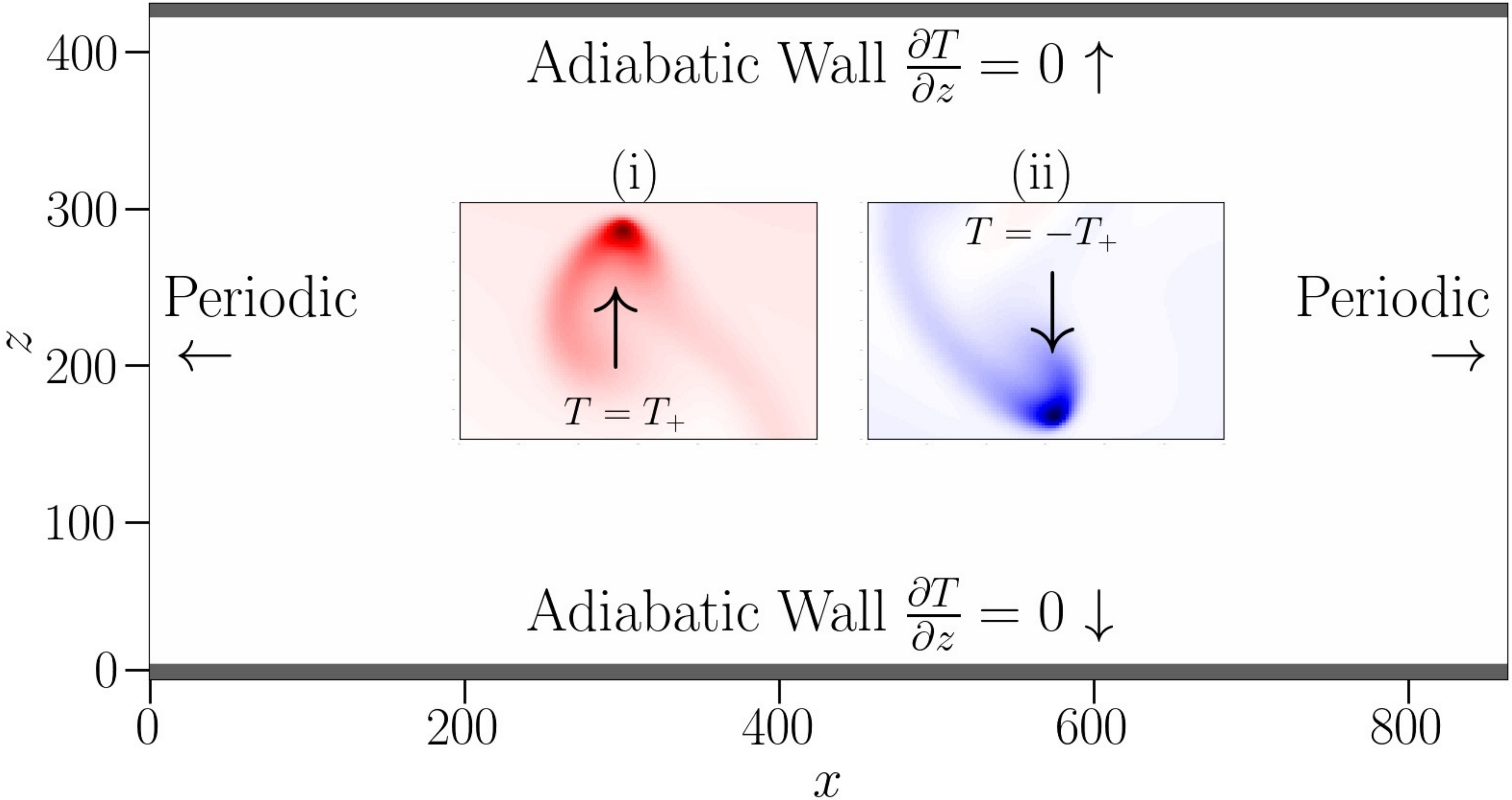
- The strength of thermal coupling follows a Gaussian

$$\alpha(\boldsymbol{r}, t) = \sum_{i=1}^{i=N_p} \alpha_i(\boldsymbol{r}, t); \qquad T_p(\boldsymbol{r}, t) = \frac{\sum_{i=1}^{i=N_p} \alpha_i(\boldsymbol{r}, t) T_i(t)}{\sum_{i=1}^{i=N_p} \alpha_i(\boldsymbol{r}, t)}$$

- The thermal forcing is thus set

$$\Phi = -\alpha(T - T_p).$$

Overview



- **Fluid equations solved with a 2 population, D2Q9 Lattice-Boltzmann scheme**

Behaviour of a single particle

- **Net heat-transport from bottom of domain to top**
- **Simple, oscillatory motion**

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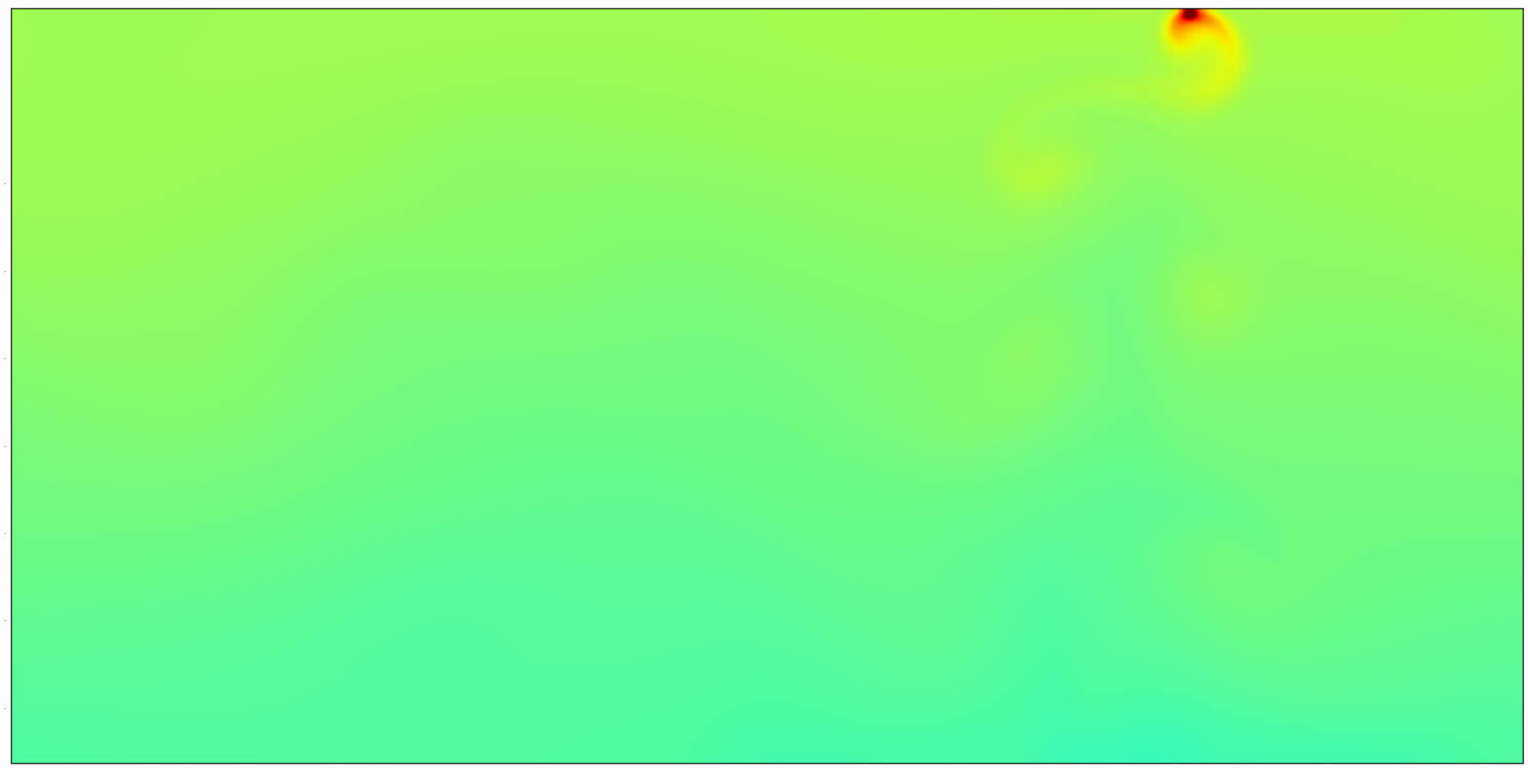

Aggregate Particle Behaviour

- **Protocol leads to two types of flows**

- **Stable** - low kinetic energy, quiescent with no clear large-scale flow structure, a strongly stable temperature gradient

- **Convective** - higher kinetic energy, convective large-scale flow and a weaker, stable temperature gradient

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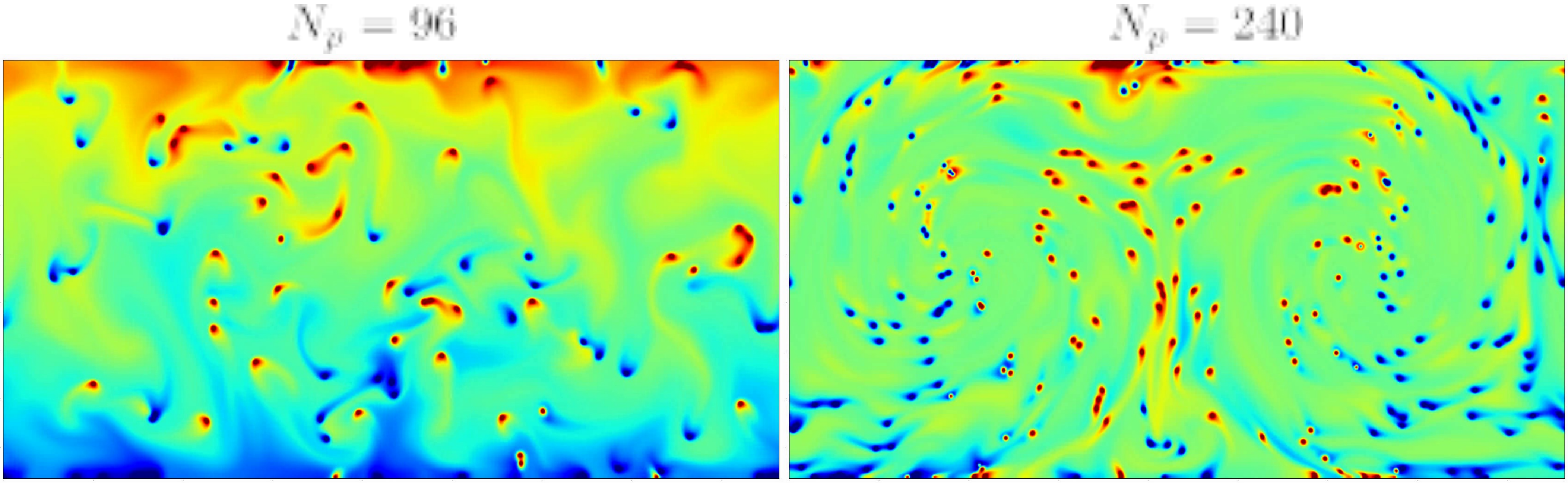
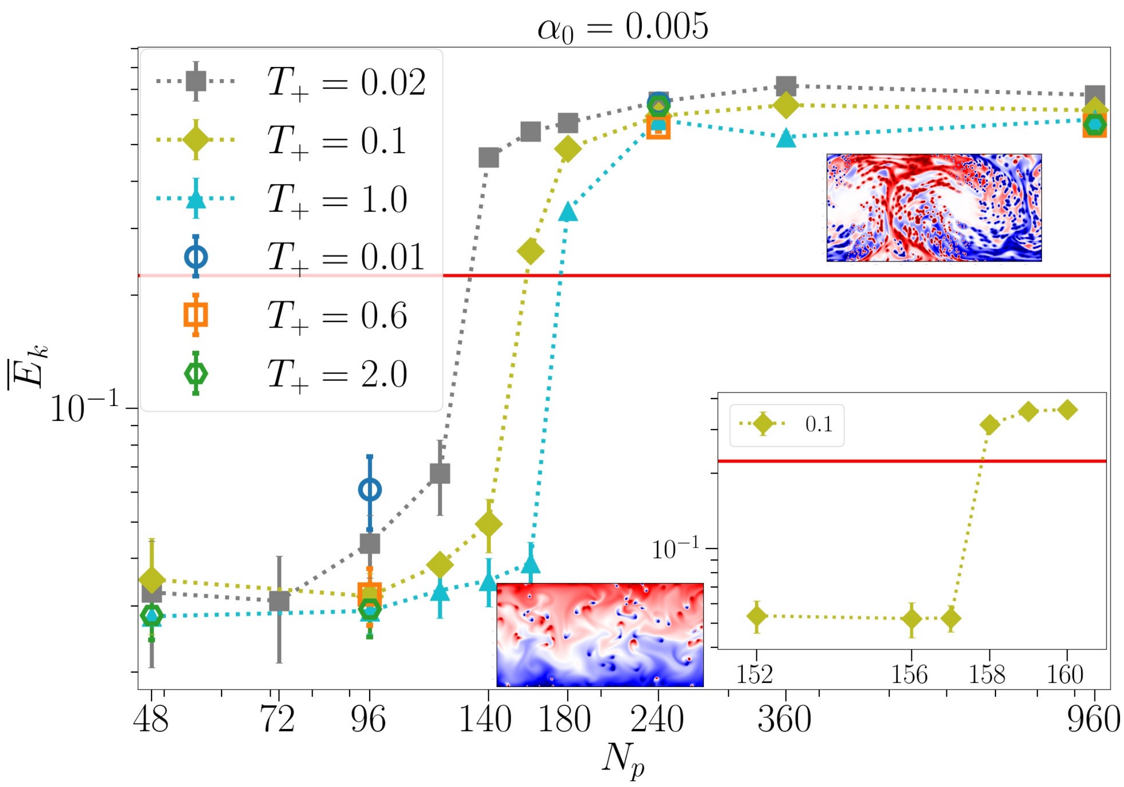


Large increase in TKE

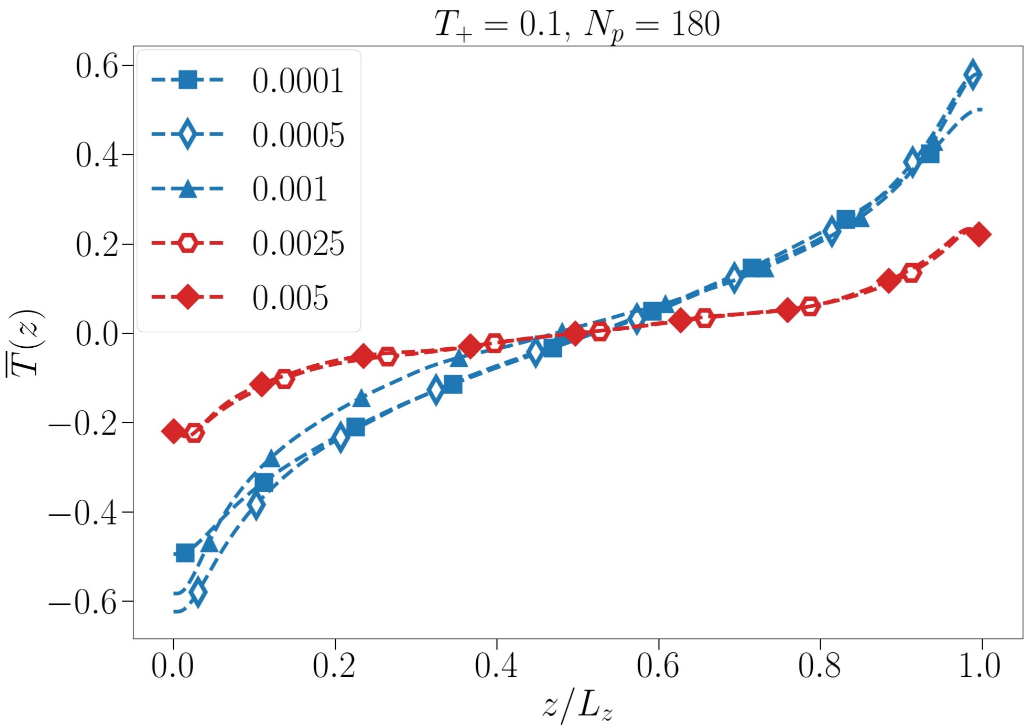
$$\overline{E_k} = \frac{1}{2}\frac{\langle|u|^2\rangle}{u_0^2 N_p}$$ - **Normalised Kinetic Energy per particle**

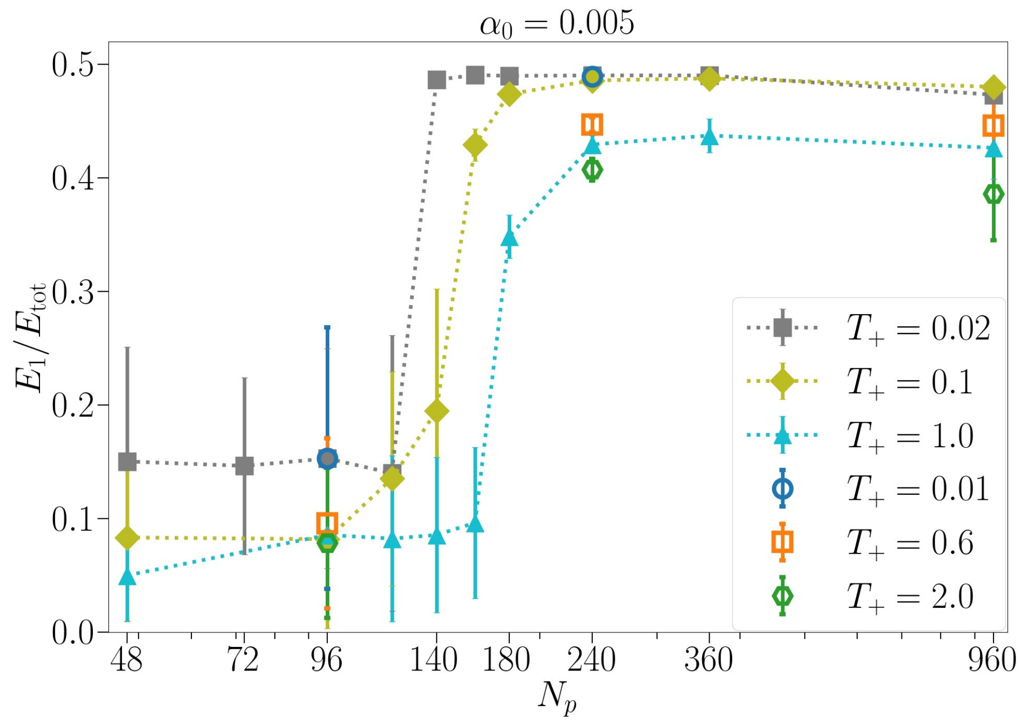
$$u_0 = \sqrt{cg\beta\frac{\alpha_0}{\alpha_0 + \frac{\varepsilon}{2\kappa^2}}T_+}$$

- **Transition from stable to convective occurs for a small change in number of particles**



Temperature Profile, Strength of Large scale circulation





- **Stable flows (blue) show a strongly stable temperature gradient which suppresses convection while the convective flows (red) show a weaker stable gradient**

- **The fraction of energy contained in the first mode of the Energy spectrum is a measure of the strength of the large scale convection**

Summary of the study

- Individual particles lead to transport of heat from the bottom to the top of the domain, making the system more stable
- When number of particles is small, heating effect is local and the stabilising effect of the particles dominates
- On achieving a critical number of particles, a large-scale circulation develops with stable temperature gradient
- Temperature gradient of convective flow is weaker due to greater mixing, faster turnaround time of particle
- Transition can be triggered by increasing α or c
- Highly non-linear, non-trivial system with scope for much exploration, extensions

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Thank you

- Manuscript submitted to JFM, currently waiting for second round of review (arXiv:2205.03856)

- For study on reconstruction of Rayleigh-Bénard convection using partial thermal measurements with a similar thermal forcing/relaxation term, see - *Physics of Fluids* 34 (1) (2022) 015128