InterPore

Three-dimensional Rayleigh-Darcy convection at high Rayleigh numbers

M. De Paoli[1,2], F. Zonta[2], S.Pirozzoli[3] & A. Soldati[2,4]
m.depaoli@utwente.nl

[1]Physics of Fluids Group, University of Twente, Enschede (The Netherlands)
[2]Institute of Fluid Mechanics and Heat Transfer, TU Wien, Vienna (Austria)
[3]Department of Aerospace and Mechanical Engineering, La Sapienza University, Rome, (Italy)
[4]Polytechnic Department, University of Udine, Udine (Italy)

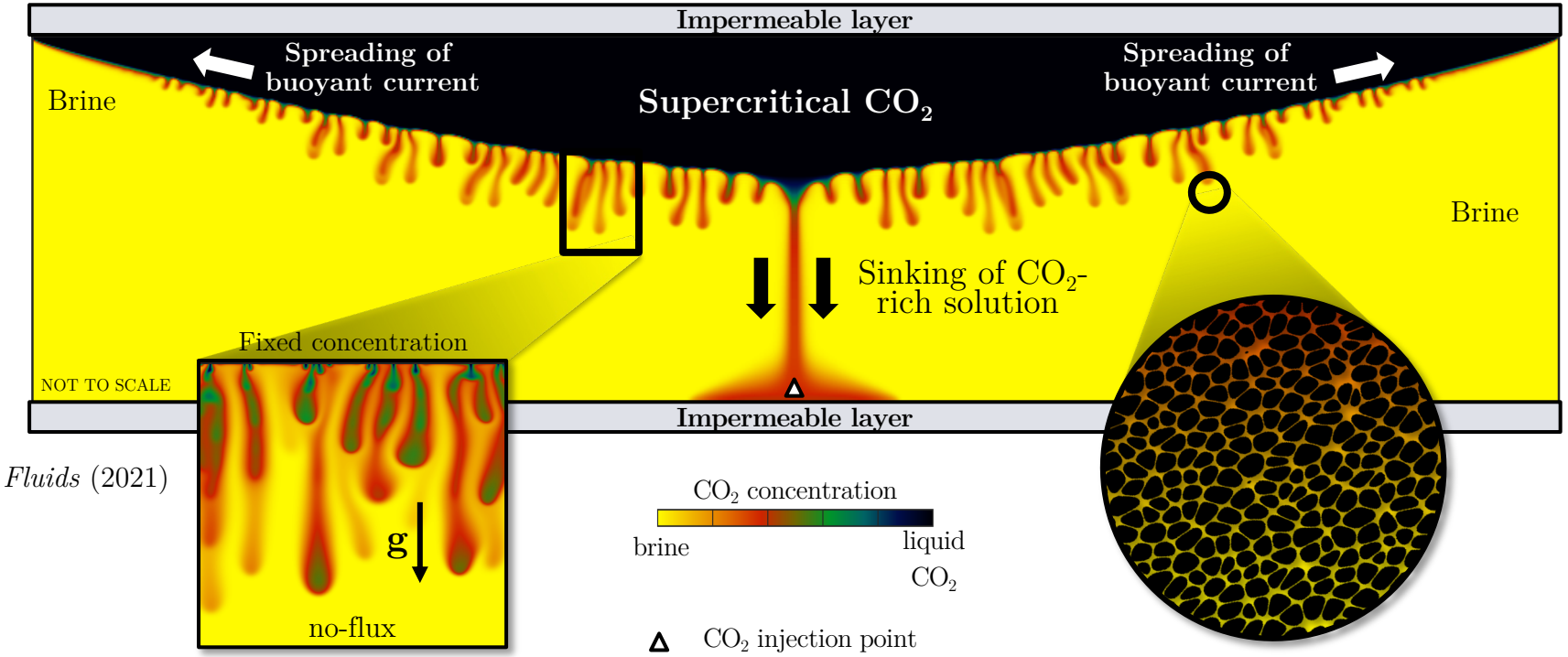
Physics of Fluids

TU WIEN

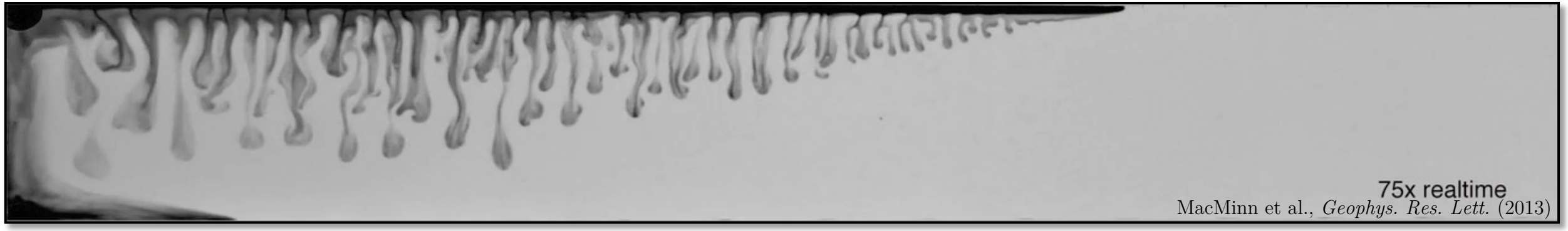
SAPIENZA
UNIVERSITÀ DI ROMA

May 30th, 2022, Abu Dhabi (United Arab Emirates) (online)

Carbon Capture and Storage

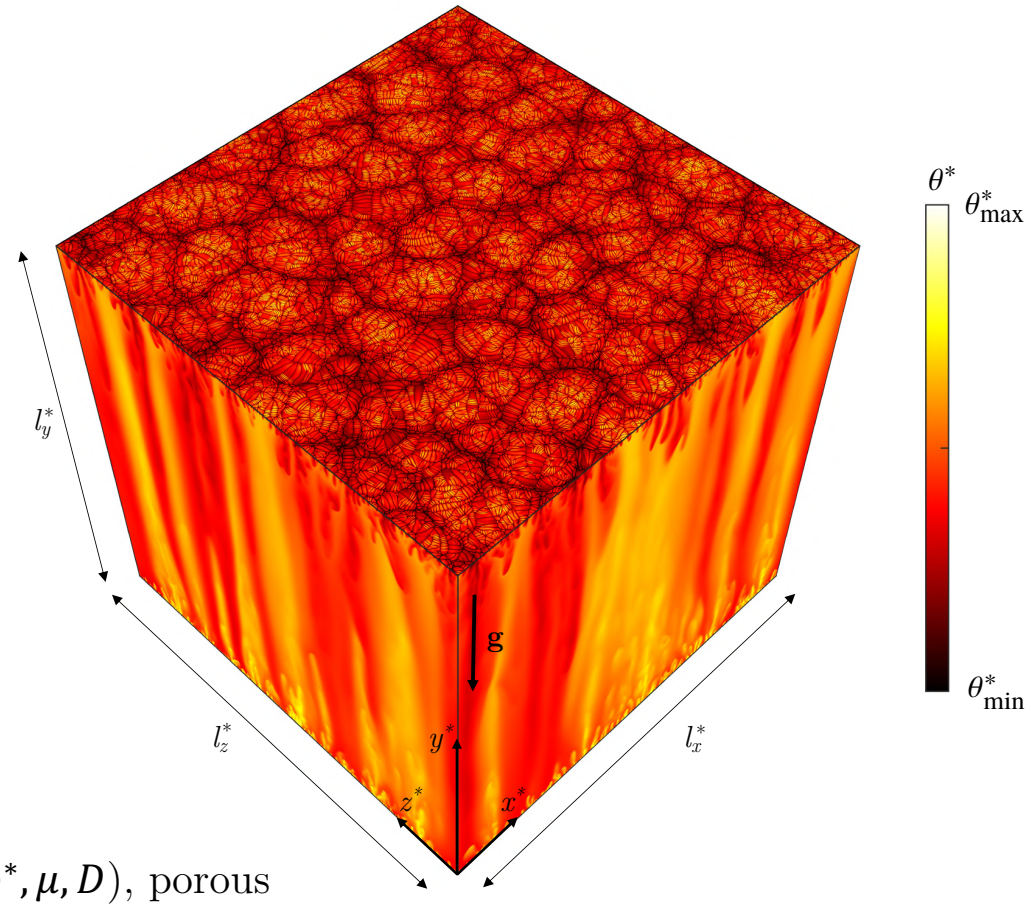


De Paoli, *Phys. Fluids* (2021)



MacMinn et al., *Geophys. Res. Lett.* (2013)

Methodology



Fluid $(\Delta\rho^*, \mu, D)$, porous medium (κ, ϕ) and domain (l^*_y) properties → $Ra = g\Delta\rho^*\kappa l^*_y/(\phi D\mu)$

De Paoli, Pirozzoli, Zonta & Soldati (under review)
Pirozzoli, De Paoli, Zonta & Soldati, *J. Fluid Mech.* (2021)

Equations

$$\frac{\partial\theta}{\partial t} + \nabla\cdot\left(\mathbf{u}\theta - \frac{1}{\mathrm{Ra}}\nabla\theta\right) = 0,$$

$$\nabla\cdot\mathbf{u} = 0 \quad , \quad \mathbf{u} = -\left(\nabla p - \theta\mathbf{j}\right),$$

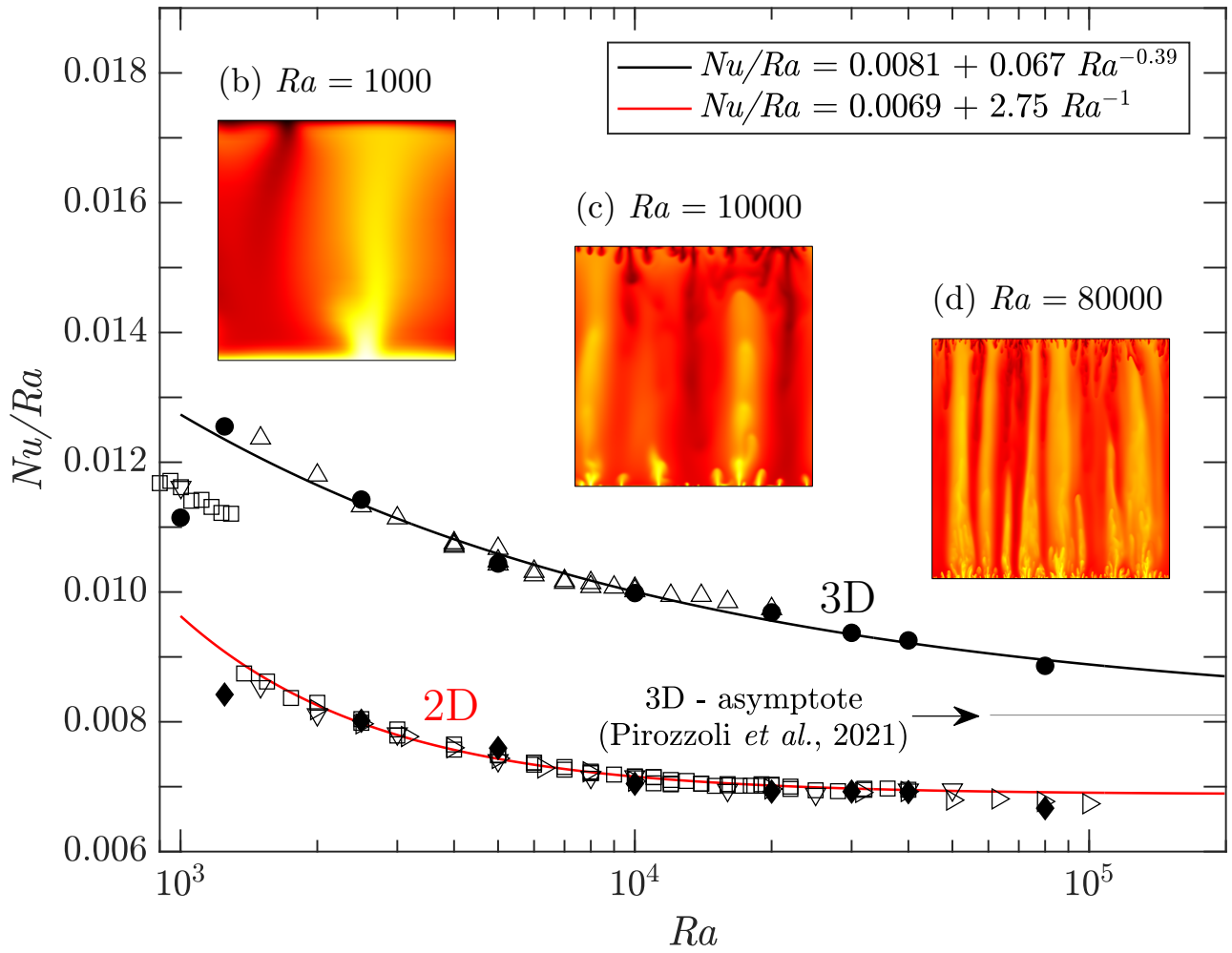
Boundary conditions

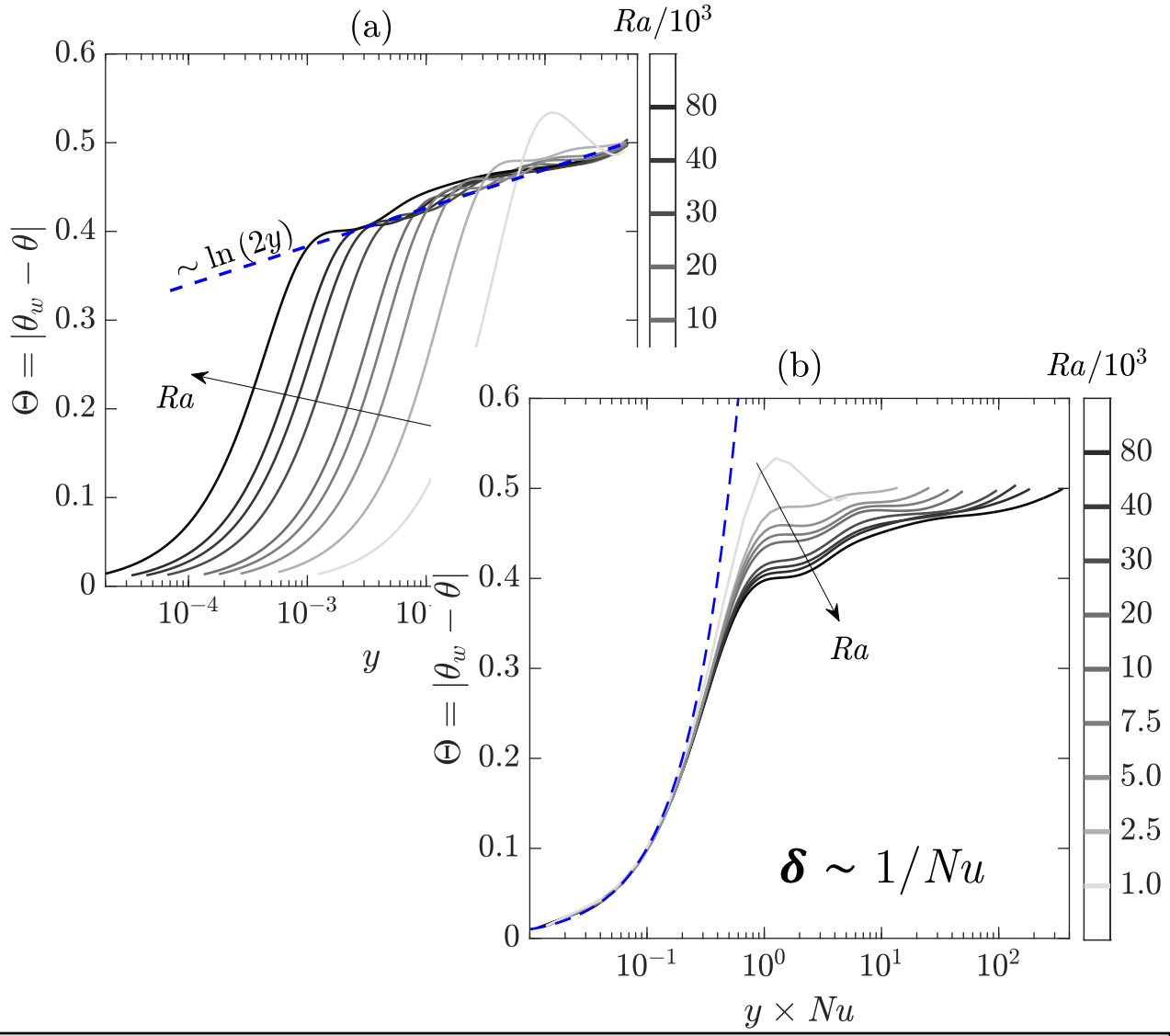
$$v(y=0) = 0 \quad , \quad \theta(y=0) = 1,$$
$$v(y=1) = 0 \quad , \quad \theta(y=1) = 0.$$

Simulations performed

Simulation	Ra	$l_x/l_y \times l_z/l_y$	$N_x \times N_z \times N_y$
Ra_1	1.0×10^3	4×4	$384\times384\times32$
Ra_2	2.5×10^3	4×4	$768\times768\times64$
Ra_5	5.0×10^3	4×4	$1536\times1536\times128$
Ra_7	7.5×10^3	4×4	$2304\times2304\times192$
Ra_{10}	1×10^4	1×1	$768\times768\times256$
Ra_{20}	2×10^4	1×1	$1536\times1536\times512$
Ra_{30}	3×10^4	1×1	$2304\times2304\times768$
Ra_{40}	4×10^4	1×1	$3072\times3072\times1024$
Ra_{80}	8×10^4	1×1	$6144\times6144\times2048$

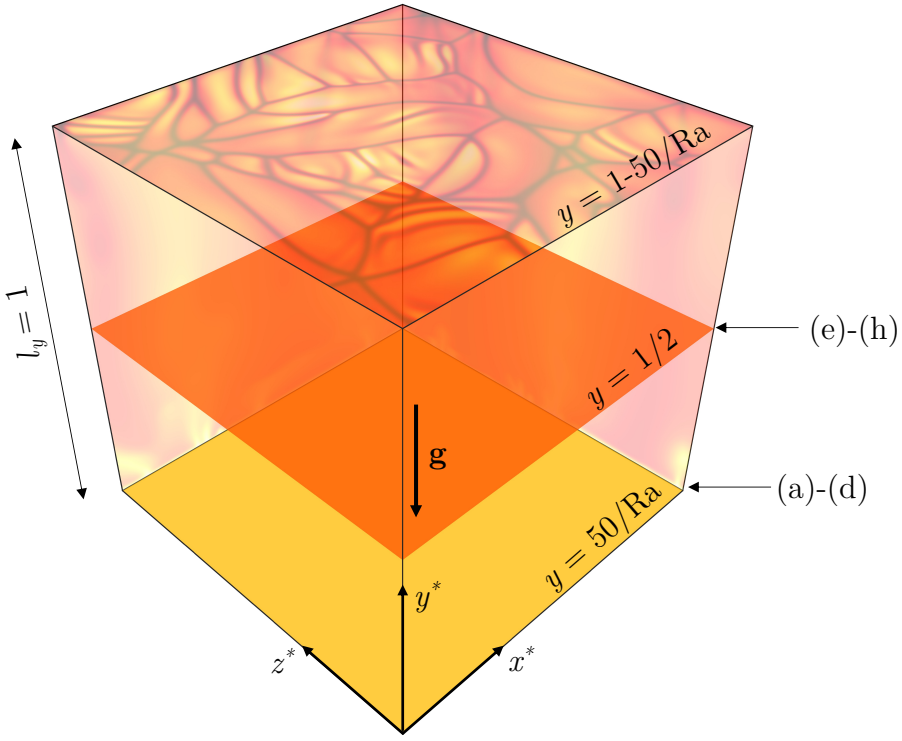
Temperature and heat transfer statistics

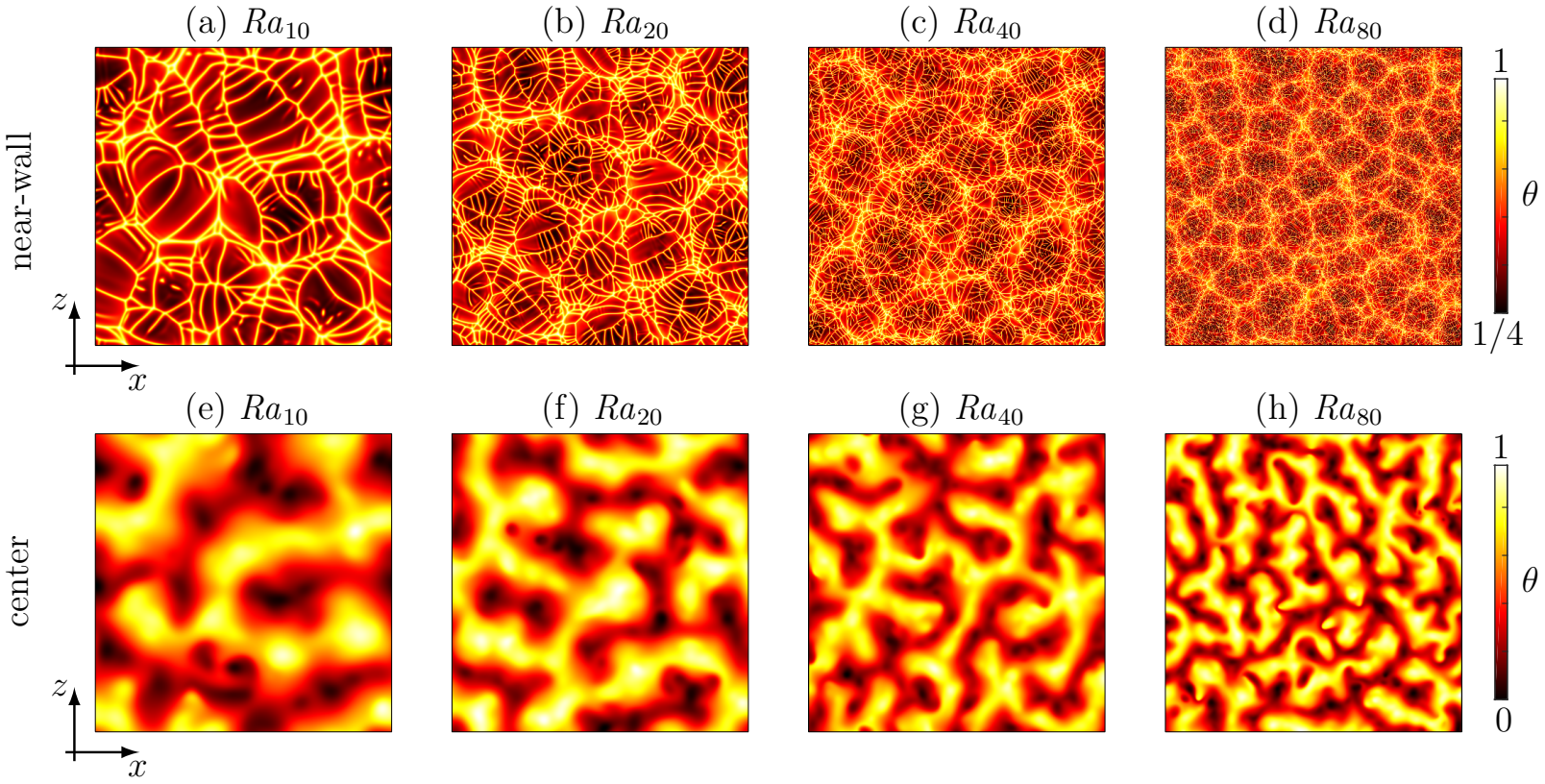




filled symbols: Pirozzoli *et al.* (2021),
open symbols: Hewitt *et al.* (2012,2014), Wen *et al.* (2015)

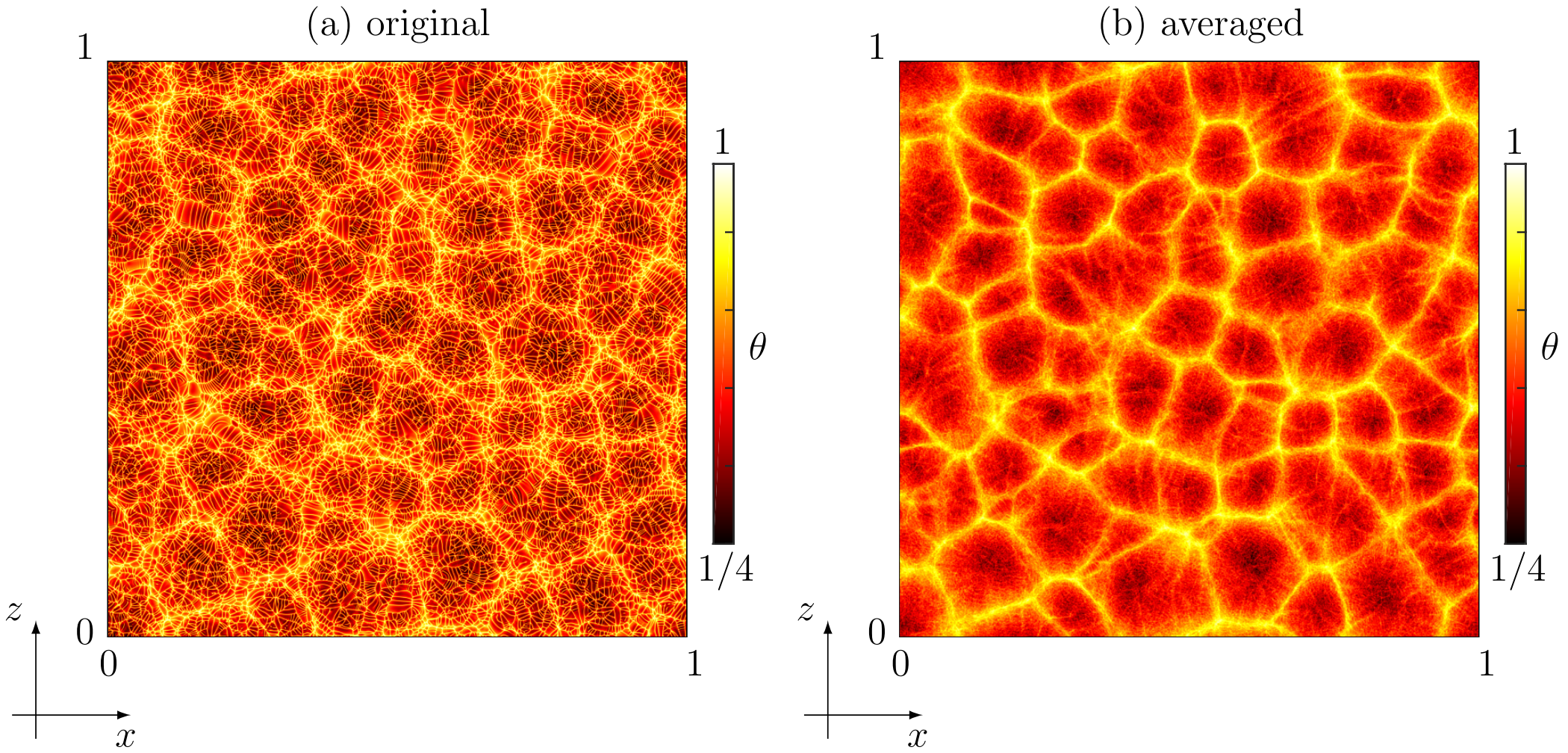
Near-wall and core flow





Near-wall flow structures and supercells

$Ra = 80{,}000$, horizontal slice near the wall



Near-wall and core flow

Mean radial wave number

$$\overline{k}_r(y) = \left\langle \frac{\int\int \sqrt{k_x^2 + k_z^2}\, E(k_x, k_z)\, \mathrm{d}x\mathrm{d}z}{\int\int E(k_x, k_z)\, \mathrm{d}x\mathrm{d}z} \right\rangle$$

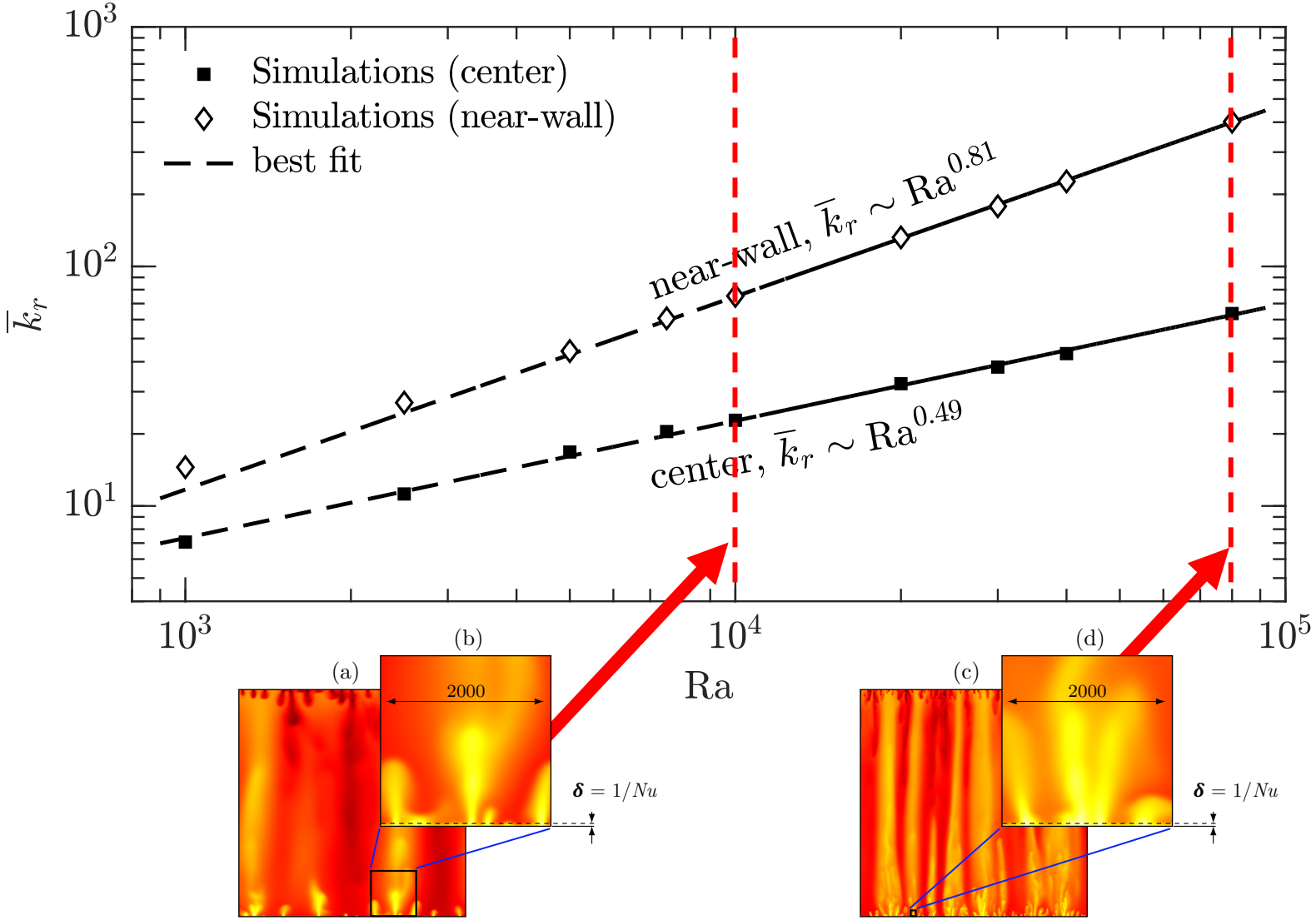
Theoretical prediction (Hewitt *et al.*, 2014):

center

$$\overline{k}_r \sim Ra^{1/2}$$

near-wall

$$\overline{k}_r \sim \boldsymbol{\delta} \sim 1/Nu$$



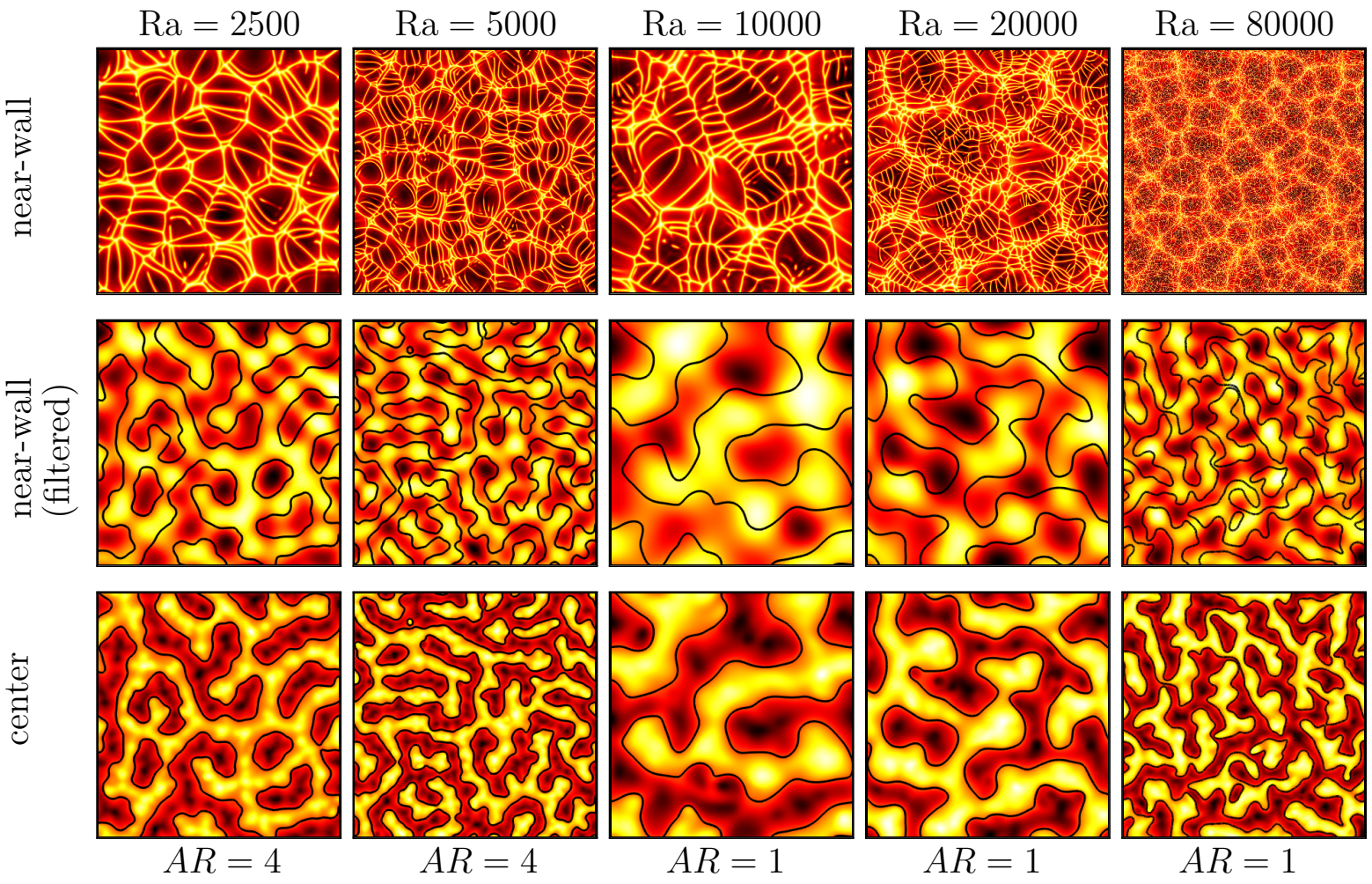
Supercells and megaplumes

Mean radial wave number

$$\overline{k}_r(y) = \left\langle \frac{\int\int \sqrt{k_x^2 + k_z^2}\, E(k_x, k_z)\, \mathrm{d}x\mathrm{d}z}{\int\int E(k_x, k_z)\, \mathrm{d}x\mathrm{d}z} \right\rangle$$

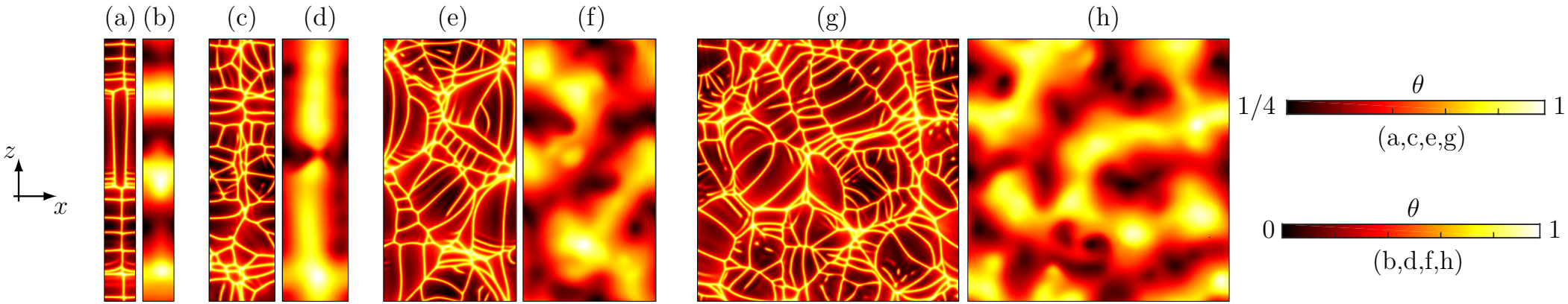
Following Krug *et al.* (2018), we filter out the small-scale structures

Supercells are the footprint of megaplumes



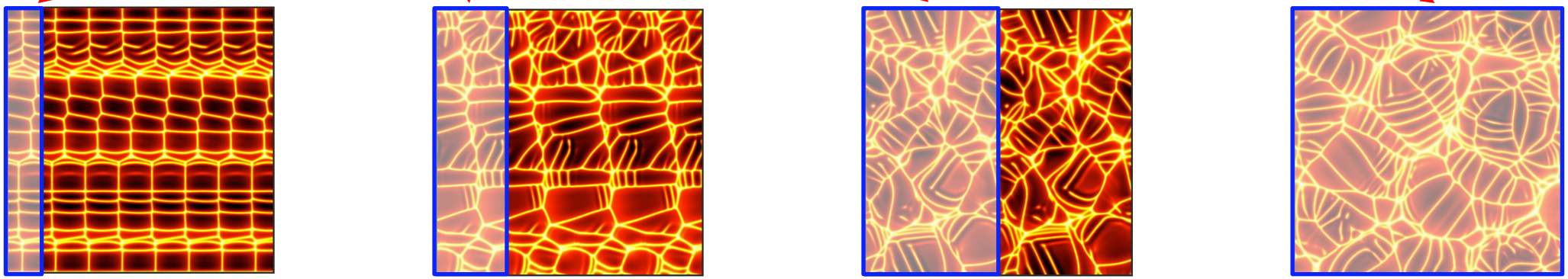
Assessment of domain size effects

$Ra = 10{,}000$



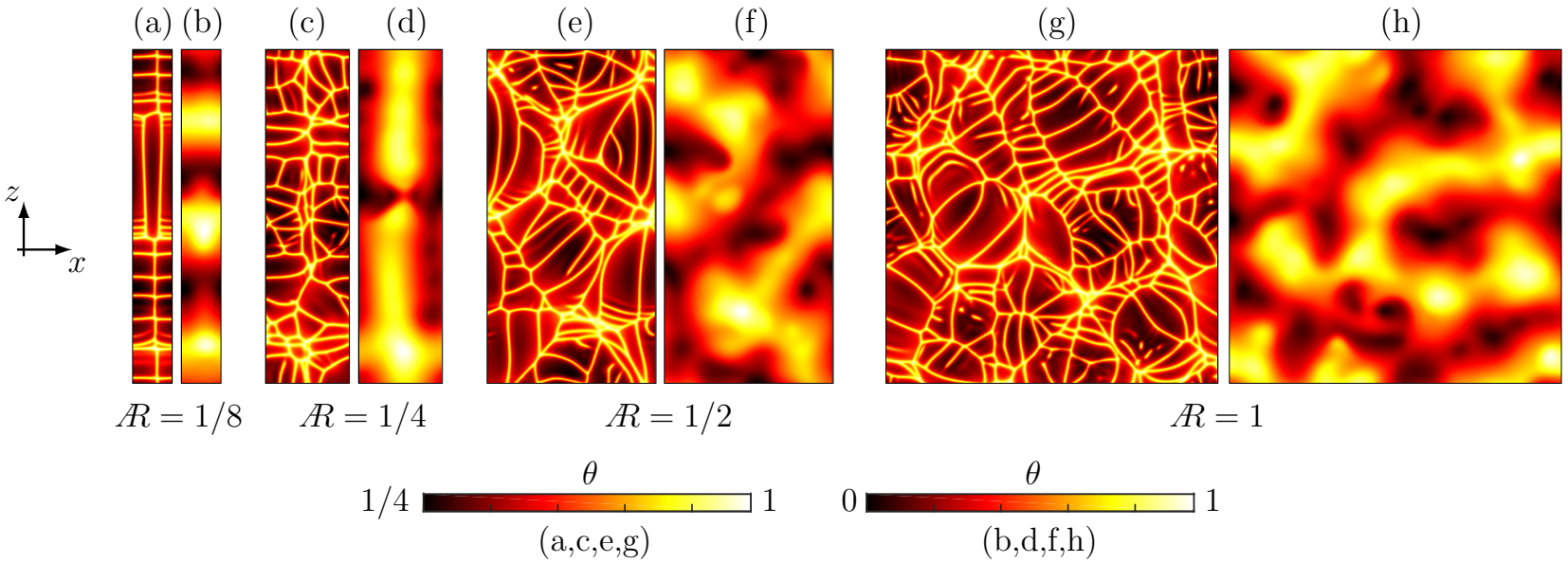
aspect ratio

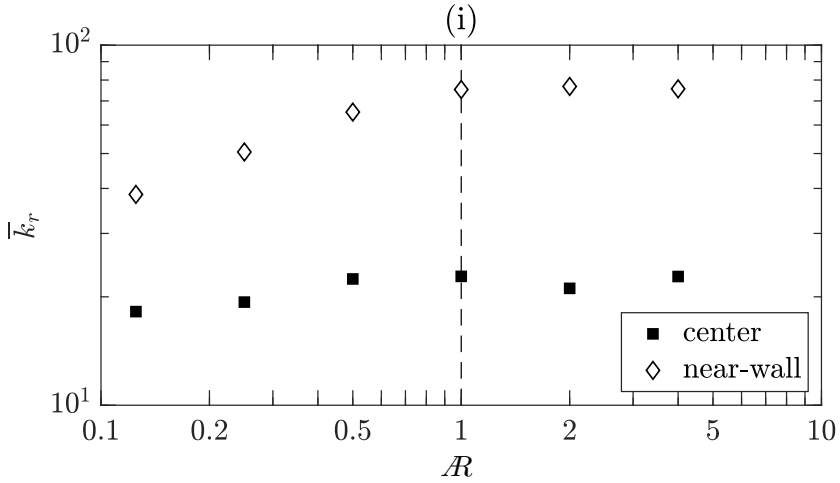
$Æ = 1/8$ $Æ = 1/4$ $Æ = 1/2$ $Æ = 1$



Assessment of domain size effects

$Ra = 10{,}000$





Also at large Ra $[O(10^3)]$, a minimum aspect ratio of 1 is required to accurately describe the large-scale flow structures

Acknowledgements

Thank you for your attention!
Questions?

This research was funded in part by the
Austrian Science Fund (FWF) [Grant J-4612]

FWF
Der Wissenschaftsfonds.