Small coherent structures in rough turbulent convection

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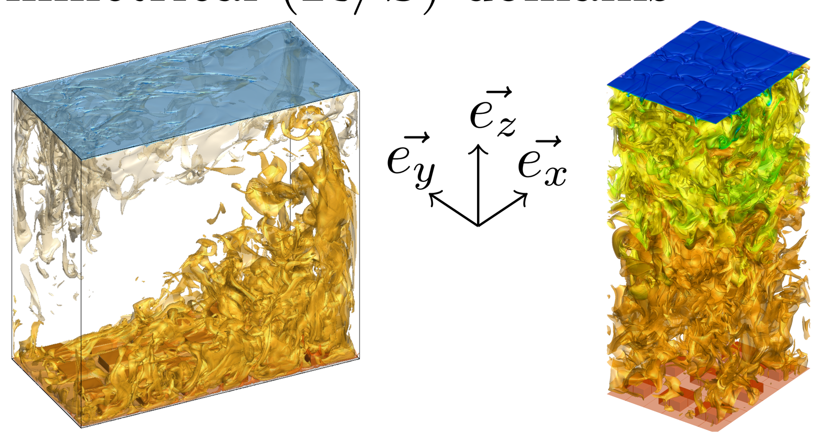
Abstract

Turbulent convection is a spontaneous physical process present in natural environments as well as in many industrial systems. However, most of these systems are not ideal in terms of underlying surfaces and involve specific topography or small-scale roughness. Interactions between plate roughness and nearby flow can induce changes in turbulence scales [Liot et al., 2017]. In addition, when the flow is confined by the side walls of a cavity, or when the fluid layer is thin, a large-scale circulation (**LSC**) becomes established [Blass et al., 2021]. The aim of this work is to reveal how the LSC changes small flow structures by considering either a cavity flow or a fluid layer of reduced size.Two types of bottom plates are considered: a smooth plate (**S/S** test case), and a rough plate with evenly distributed roughness elements (**R/S** case).

Physical configuration

symmetrical (**S/S**) or asymmetrical (**R/S**) domains

- $Ra = 10^{10}$;
- $Pr = 4.38$;
- **R/S**: $h_p/H = 0.03$



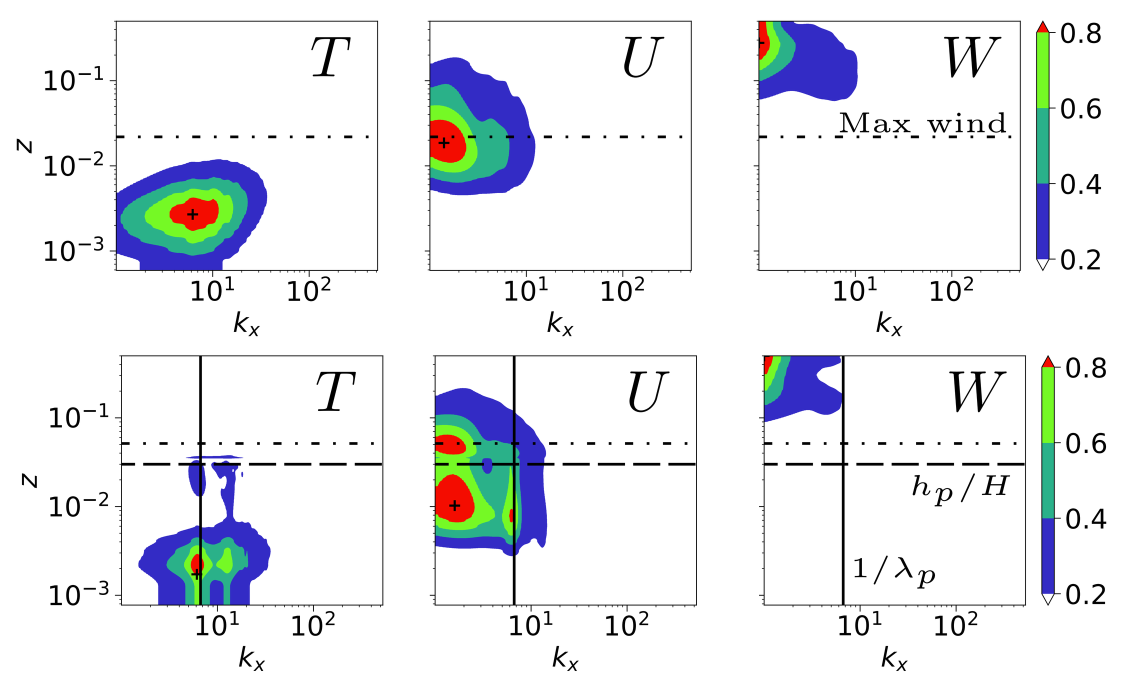
Geometry	**Cavity** 1 x 0.5 x 1	**Periodic layer** 0.45 x 0.38 x 1

Numericals Set-up

- Direct Numerical Simulations : Boussinesq equations
- Massively parallel unsteady Sunfluidh solver (Second order Finite Volume method)
  `https://sunfluidh.lisn.upsaclay.fr`
- Gridsizes
  - S/S: 448 x 384 x 1280 (layer), 1024 x 512 x 1280 (cavity)
  - R/S: 384 x 384 x 1056 (layer), 1056 x 512 x 1056 (cavity)

Confined cavity

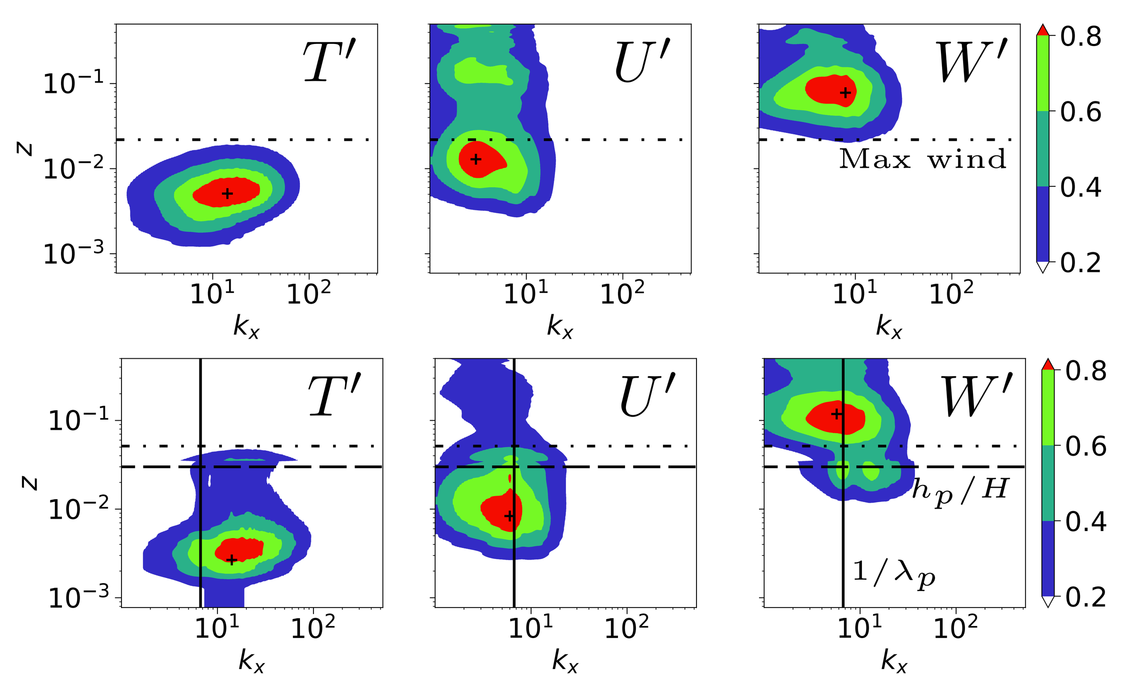
Spatial organisation of the total field ($\chi = \overline{\chi} + \chi'$)



Spectral density as a function of the altitude z

- The LSC fills the cavity (see U and W) ;
- In R/S case: LSC is above and within the valleys ;

Spatial organisation of the fluctuating field (χ')



Spectral density as a function of the altitude z

- T' and W' structures: constant in size with and w/o roughness ;
- The size of the fluctuating velocity (U') is set by the roughness wavelength.

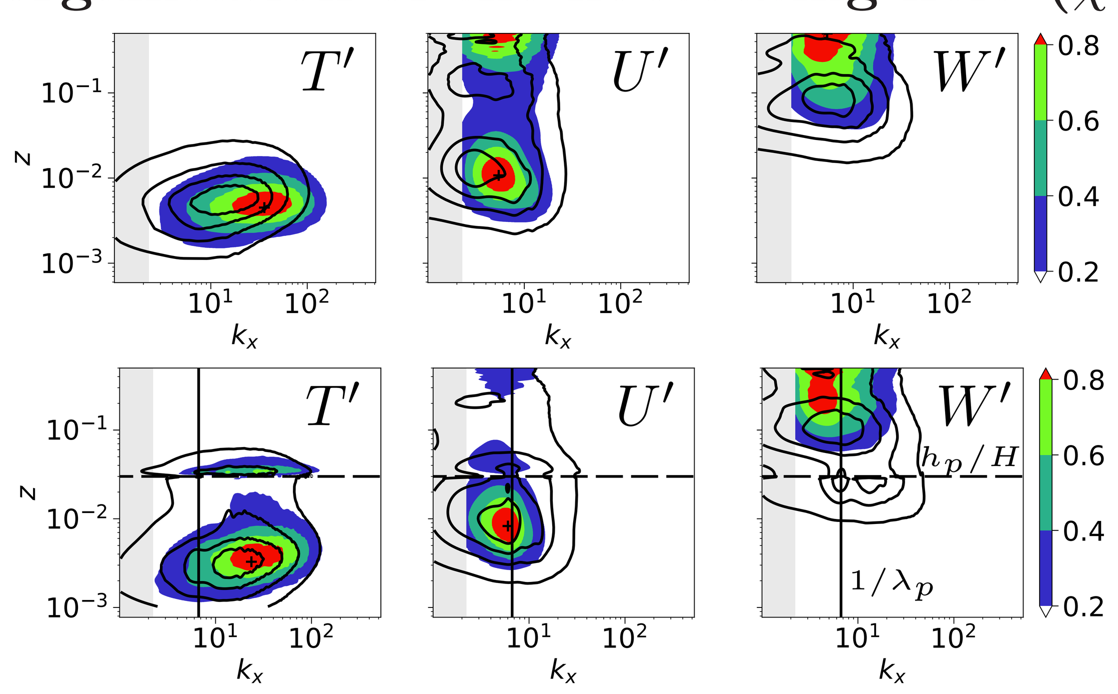
Periodic layer

Mean and turbulent energy decomposition

	$\langle TT \rangle_V$		$\langle UU \rangle_V$		$\langle WW \rangle_V$	
	$\overline{T}\,\overline{T}$	$\overline{T'T'}$	$\overline{U}\,\overline{U}$	$\overline{U'U'}$	$\overline{W}\,\overline{W}$	$\overline{W'W'}$
S/S	8e-4	3e-4	3e-3	1e-3	3e-3	1e-3
S/S-P	1e-3	5e-4	**1e-4**	1e-3	**1e-4**	3e-3
R/S	1e-3	4e-4	3e-3	1e-3	3e-3	1e-3
R/S-P	1e-3	6e-4	**1e-4**	1e-3	**2e-4**	3e-3

- Absence of LSC in the periodic layer: the mean kinetic energy (E_k) is negligible compared to its turbulent part E_t ;

Spatial organisation of the fluctuating field (χ')



Spectral density as a function of the altitude z. Colors: periodic case ; Lines: cavity ; Shaded area: unreachable k in the fluid layer.

- The absence of LSC leads to smaller T' and U' structures, while the maximum W' is re-centered at mid-height, except for the R/S case where the size of the fluctuating velocity (U') remains governed by the roughness wavelength.

References

[Blass et al., 2021] Blass, A., Verzicco, R., Lohse, D., Stevens, R. J. A. M., and Krug, D. (2021). *Journal of Fluid Mechanics*.

[Liot et al., 2017] Liot, O., Ehlinger, Q., Rusaouen, E., Coudarchet, T., Salort, J., and Chillà, F. (2017). *Physical Review Fluids*, 2.