Influence of wall roughness and thermal conductivity on turbulent natural convection

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Natural convection

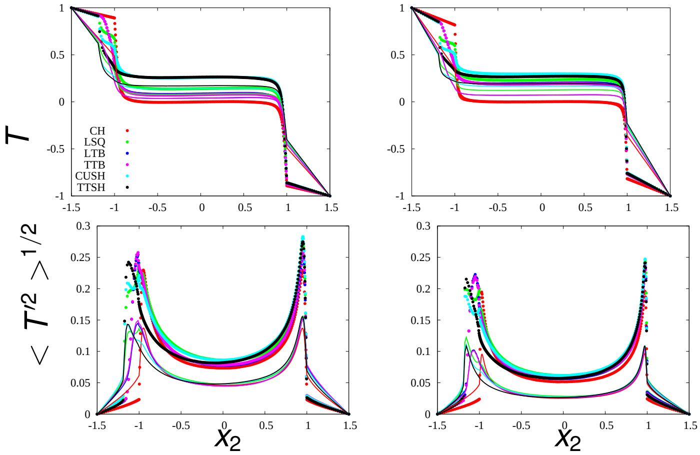
- Physics of turbulent natural convection studied
- Through theoretical, numerical and laboratory experiments
  - $Nu \approx Ra^n$ several n proposed
  - $E_u \approx k^{-5/3}$ $E_T \approx k^{-4/3}$ inertial range
  - $E_u \approx k^{-11/5}$ $E_T \approx k^{-7/5}$ for $1/k < L_B$
- DNS could validate theory and relate spectra to flow structures

- DNS in cylindrical boxes relay on spectra from time signals

Natural convection with rough surfaces

- Present DNS in a periodic box with conducting rough solid layers
- Fluid for $-1 < x_2 < 1$ $L_1 = L_3 = 4$ $\quad Pr_F = 1$
- Top smooth T_S at $x_2 = 1$
- Bottom $-1.5 < x_2 < -1.2$ solid
- Roughness $-1.2 < x_2 < -1$ $\quad T_R$ at $x_2 = -1$
- Present $H = 2h, \Delta T = 2\Delta\theta$ $Re = U_0 H/2\nu$
- $U_0 = \sqrt{\alpha \Delta T g H/4}$
- Several shapes *LSQ*, *LTB*, *TTB*, *CUSH*, *TTSH* compared with *CH*
- $Pr_S = 0.134$ (copper) conductivity
- $Pr_S = 0.0134$ ideal high conductivity material
- $(T_R - T_S)$ different for each flow
- Rayleigh $Ra = (4Re)^2(T_R - T_S)/2$
- Nusselt $(\frac{1}{Re}\frac{\partial T}{\partial y} - < v'T' >)|_R Re/(T_R - T_S)/2$

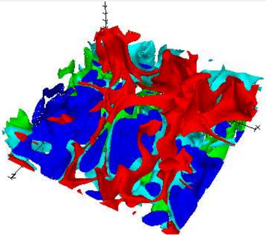
Thermal profiles



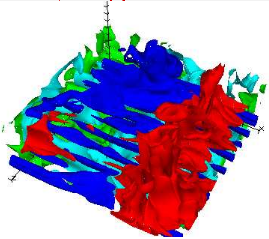
$Re = 1000$ $Re = 3000$

line $Pr_S = 0.134$ symbols $Pr_S = 0.0134$

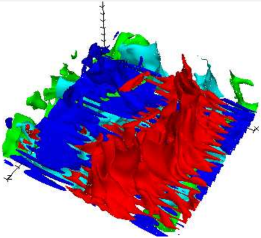
V and T $Re = 1000, Pr_S = 0.134$



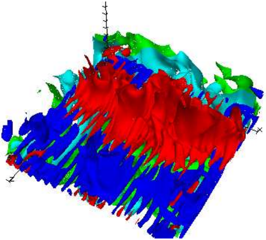
CH



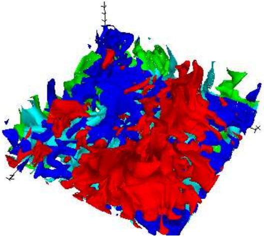
LSQ



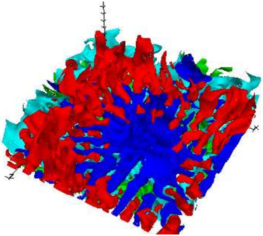
LTB



TTB

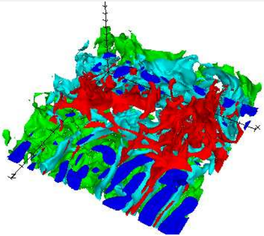


CUSH

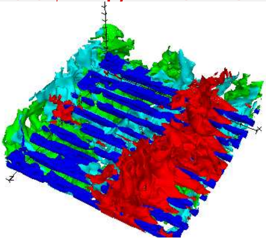


TTSH

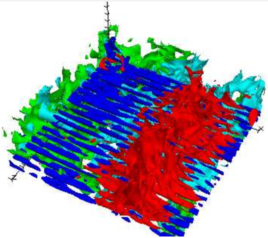
V and T $Re = 3000$, $Pr_S = 0.134$



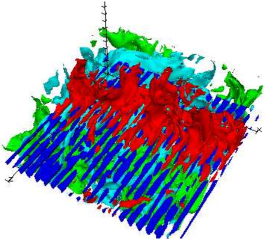
CH



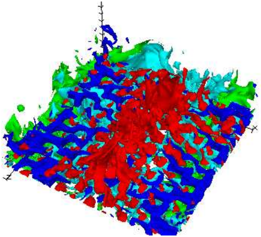
LSQ



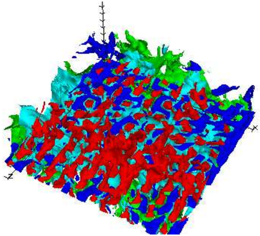
LTB



TTB

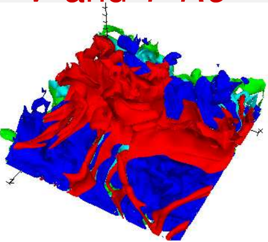


CUSH

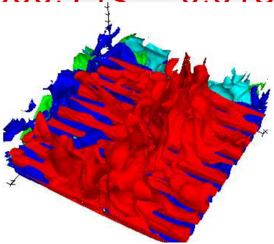


TTSH

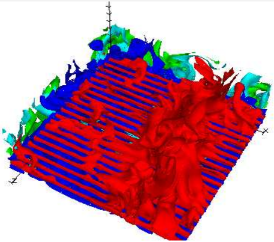
V and T $Re = 1000$, $Pr_S = 0.0134$



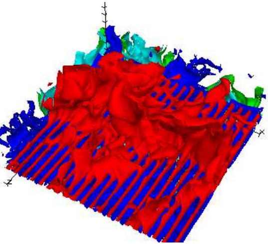
CH



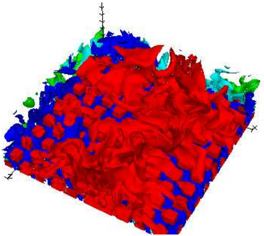
LSQ



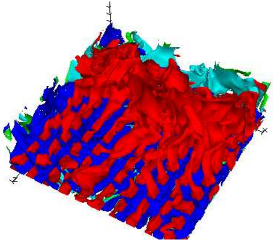
LTB



TTB

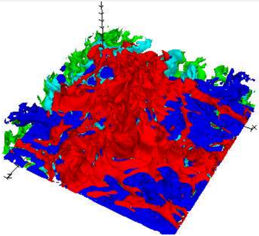


CUSH

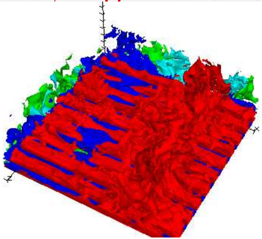


TTSH

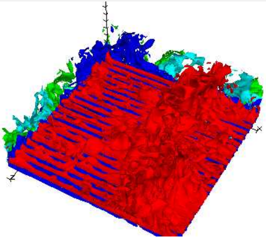
V and T $Re = 3000$, $Pr_S = 0.0134$



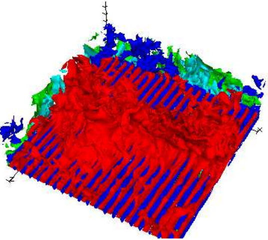
CH



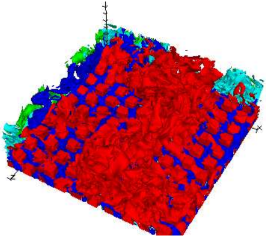
LSQ



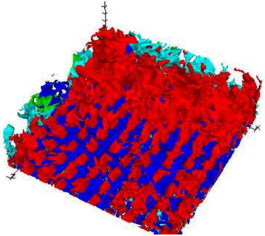
LTB



TTB

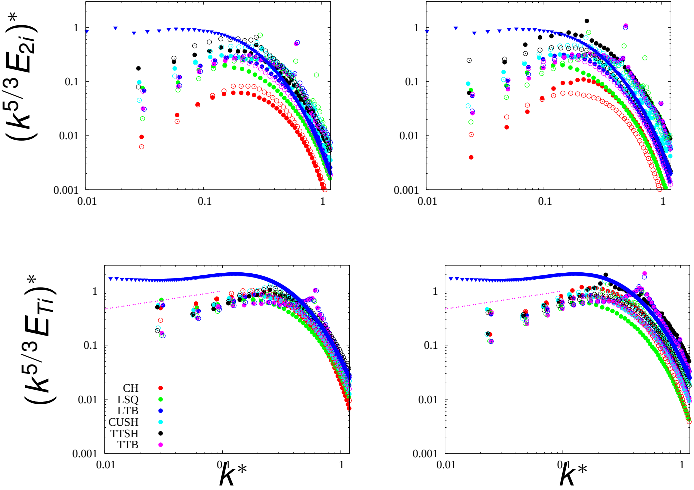


CUSH



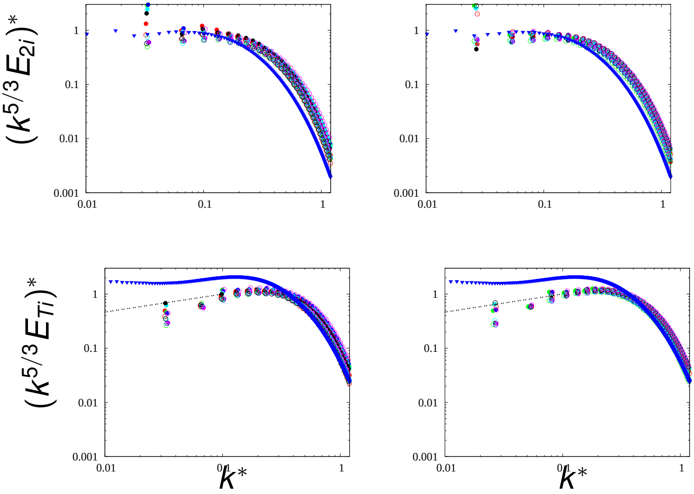
TTSH

1D spectra for v and T at $y = 0.05$ $Re = 1000$



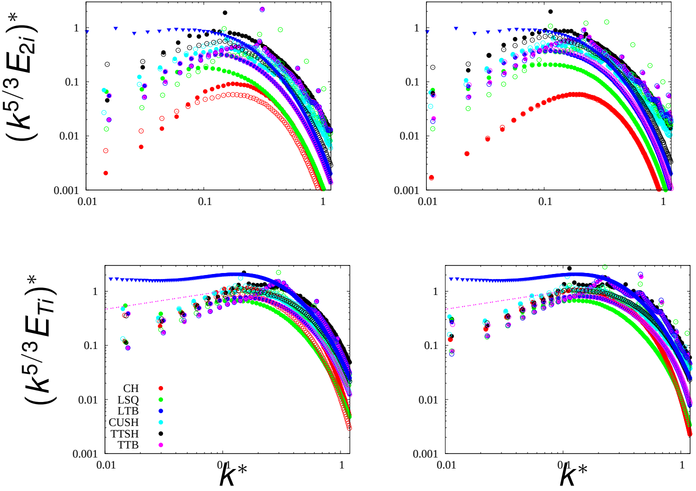
$Pr_S = 0.134$ $Pr_S = 0.0134$

1D spectra for v and T at centerline $Re = 1000$



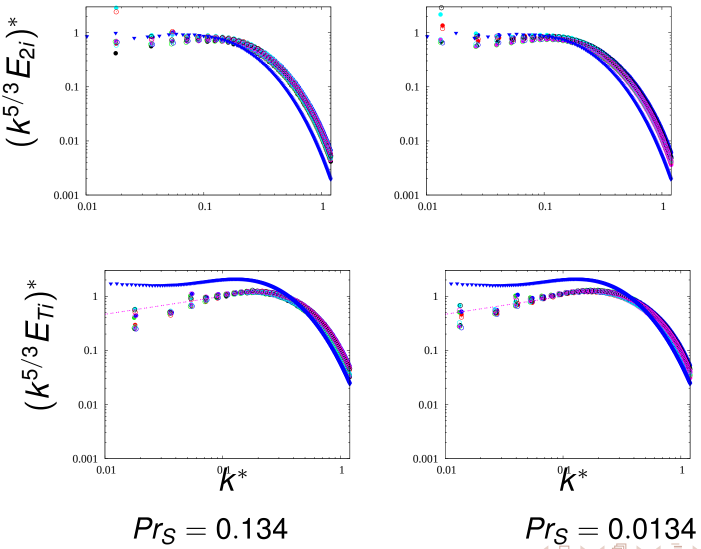
$Pr_S = 0.134$ $\qquad$ $Pr_S = 0.0134$

1D spectra for v and T at $y = 0.05$ $Re = 3000$

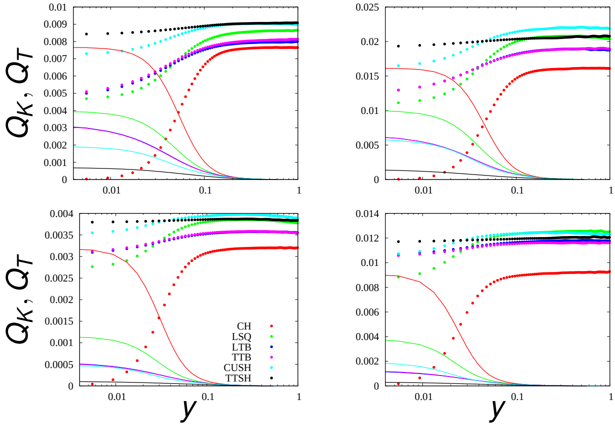


$Pr_S = 0.134$ $Pr_S = 0.0134$

1D spectra for v and T at centerline $Re = 3000$



Heat flux contribution



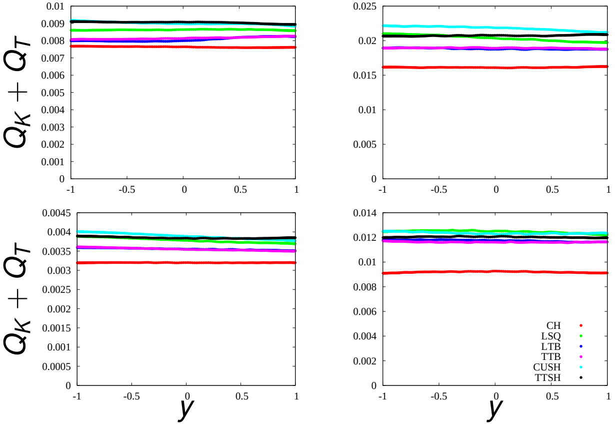
$Re = 1000$

$Re = 3000$

$Pr_S = 0.134$

$Pr_S = 0.0134$

Heat flux total



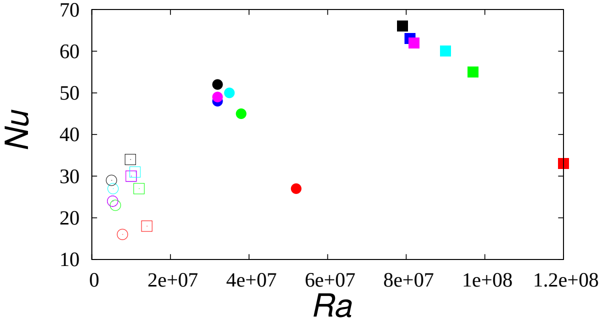
$Re = 1000$

$Re = 1000$

$Pr_S = 0.134$ $Pr_S = 0.0134$

$Nu(Ra)$ effect shape

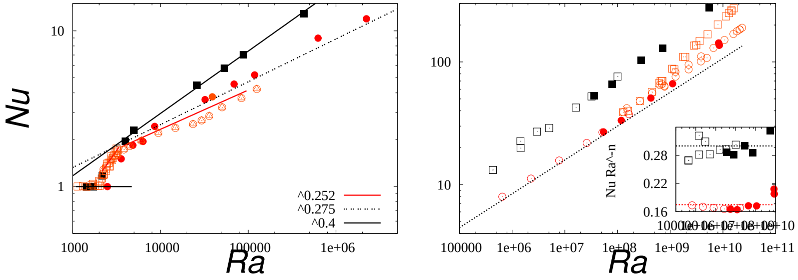
- $Re = U_0 H/2\nu \quad U_0 = \Delta T g H/4$
- $(T_R - T_S)$ different for each flow
- Rayleigh $Ra = (4Re)^2(T_R - T_S)/2$
- Nusselt $(\frac{1}{Re}\frac{\partial T}{\partial y} - < v'T' >)|_R Re/(T_R - T_S)/2$



circle $Re = 1000$ square $Re = 3000$

open $Pr_S = 0.134$ closed $Pr_S = 0.0134$

Nu versus *Ra*

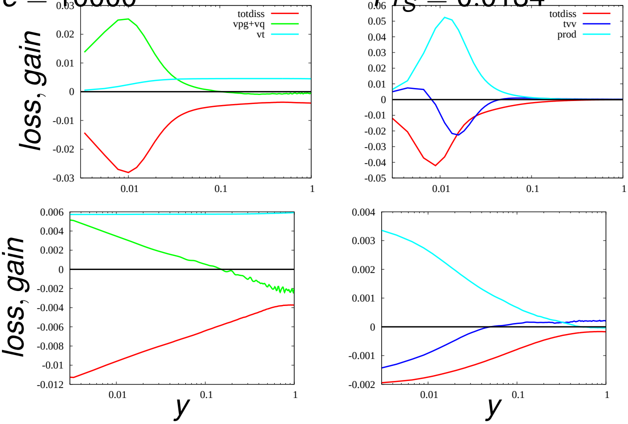


red *CH* green *TTSH*

- Left Silverton (from Chandrasekar) right Tisserand (2011)
- Red $Ra^{0.286}$ green $Ra^{0.3}$ Kerr (1996) $Ra^{0.276}$

Budgets for closures

- TKE $prod = < v'\theta' >$, $totdi = \nu < v_i \nabla^2 v_i >$
- $< \theta' >^2$ $prod = < v'\theta' > \frac{\partial T}{\partial y}$ $totdi = \nu < \theta' \nabla^2 \theta' >$
- $Re = 10000$ $Pr_S = 0.0134$



CH

TTSH

TKE $< \theta' >^2$