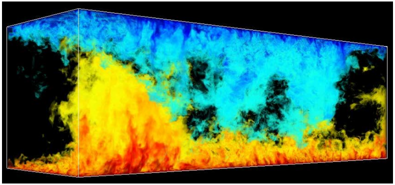
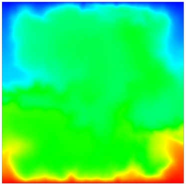
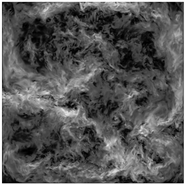
Centre Tecnològic de Transferència de Calor
UNIVERSITAT POLITÈCNICA DE CATALUNYA

On the effect of Prandtl number to SGS heat flux models

F.Xavier Trias[1], Daniel Santos[1], Jannes Hopman[1]
Andrey Gorobets[2], Assensi Oliva[1]

[1]Heat and Mass Transfer Technological Center, Technical University of Catalonia
[2]Who cares?

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On the effect of Prandtl number to SGS heat flux models

Is it possible to hit the ultimate regime of turbulence with LES?

F.Xavier Trias[1], Daniel Santos[1], Jannes Hopman[1]
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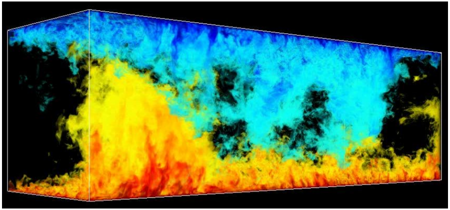
Contents

Motivation

Research question #1:

- Can we find a nonlinear SGS heat flux model with **good physical** and **numerical properties**, such that we can obtain satisfactory predictions for a turbulent Rayleigh-Bénard convection?



DNS of an air-filled Rayleigh-Bénard convection at $Ra = 10^{10}$

[1] F.Dabbagh, F.X.Trias, A.Gorobets, A.Oliva. *On the evolution of flow topology in turbulent Rayleigh-Bénard convection*, **Physics of Fluids**, 28:115105, 2016.

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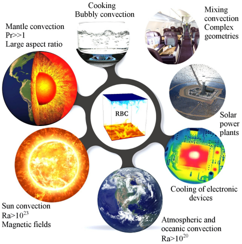

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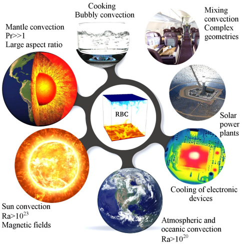
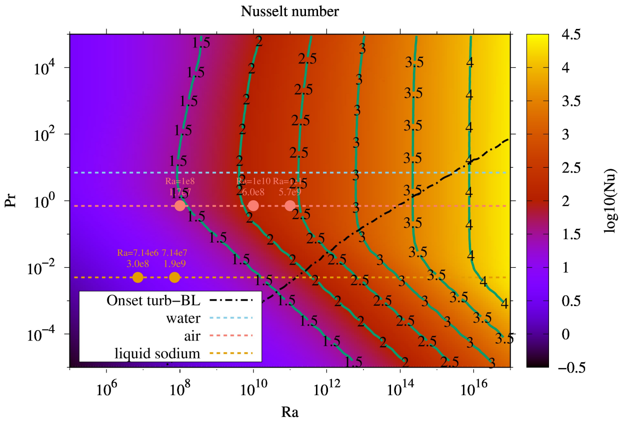
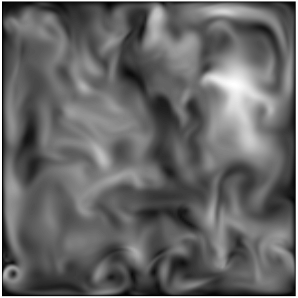




Motivation

Air-filled RB: $Pr = 0.7$

$Ra = 10^8$



[2] F.Dabbagh, F.X.Trias, A.Gorobets, A.Oliva. *Flow topology dynamics in a 3D phase space for turbulent Rayleigh-Bénard convection*, **Phys.Rev.Fluids**, 5:024603, 2020.

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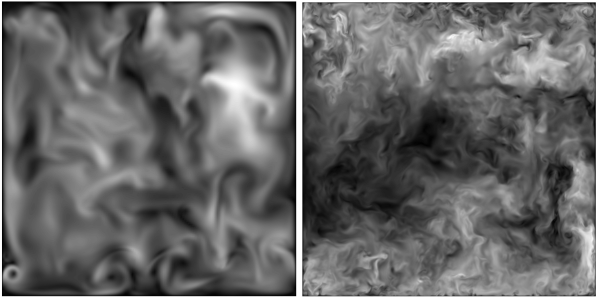

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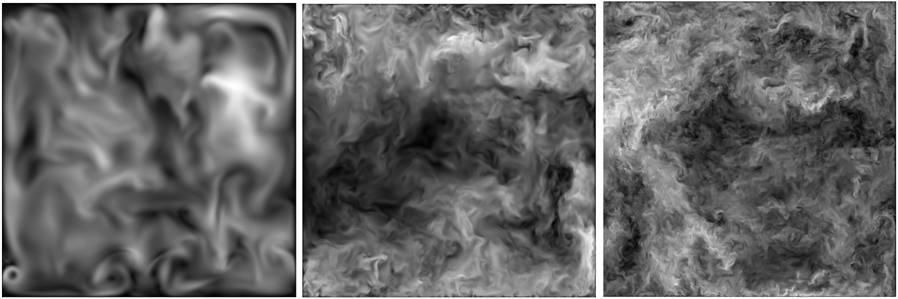

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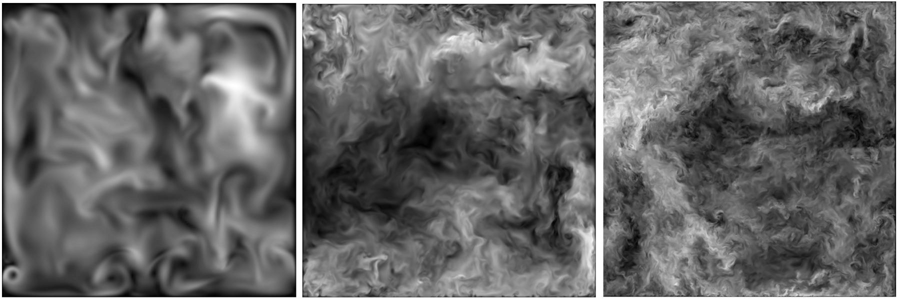

$208 \times 208 \times 400$ **17.5M** | $768 \times 768 \times 1024$ **607M** | $1662 \times 1662 \times 2048$ **5600M**

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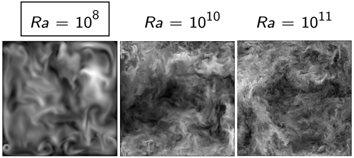
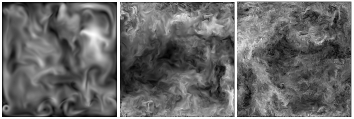


Motivation

DNS: $208 \times 208 \times 400$

LES: $80 \times 80 \times 120$

$Ra = 10^8$ $\quad Ra = 10^{10}$ $\quad Ra = 10^{11}$



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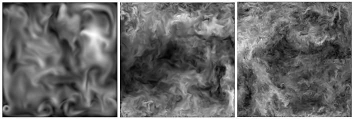

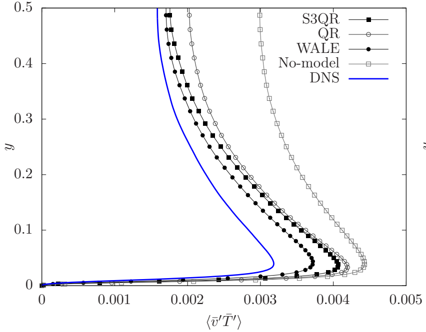

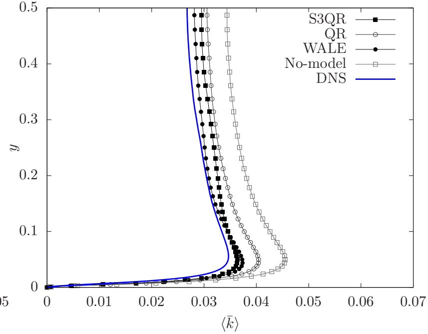

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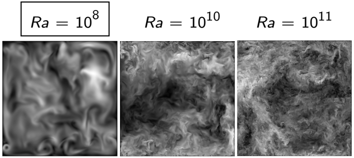

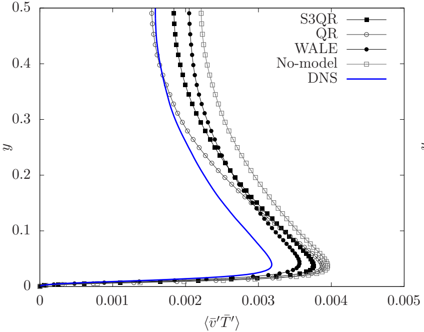

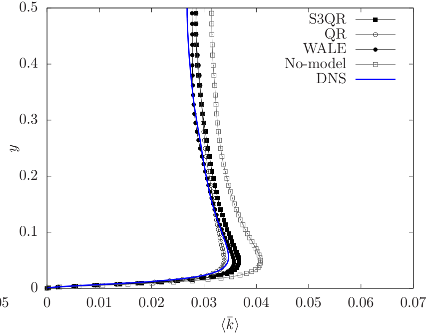

How to model the subgrid heat flux in LES?

$$\partial_t \overline{u} + (\overline{u} \cdot \nabla)\overline{u} = \nu \nabla^2 \overline{u} - \nabla \overline{p} \qquad - \nabla \cdot \tau(\overline{u}) \quad ; \qquad \nabla \cdot \overline{u} = 0$$

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$$G \equiv \nabla \overline{u} \qquad\qquad q = -\frac{\delta^2}{12} G \nabla \overline{T} + \mathcal{O}(\delta^4)$$

A priori alignment trends[3]

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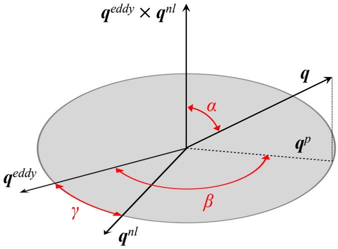

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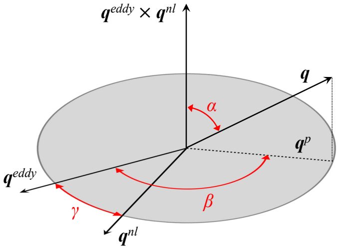

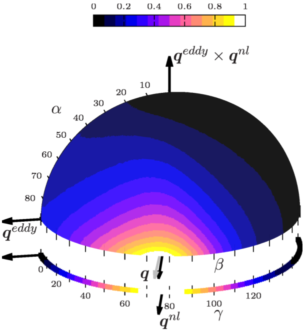

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[4]S.Peng and L.Davidson. **Int.J.Heat Mass Transfer**, 45:1393-1405, 2002.

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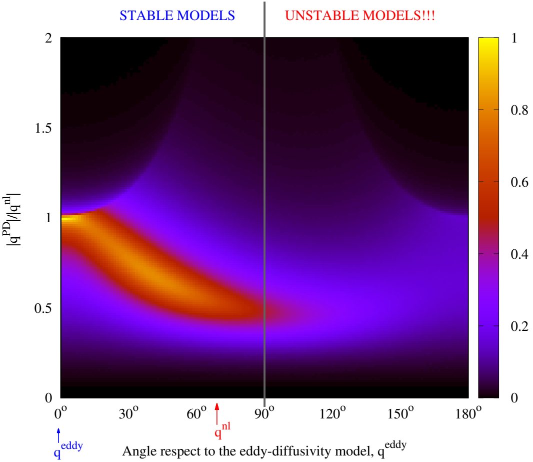

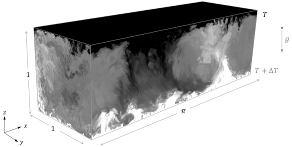

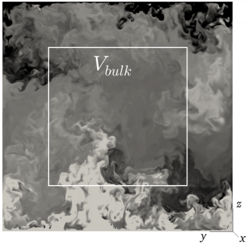

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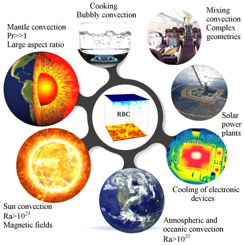
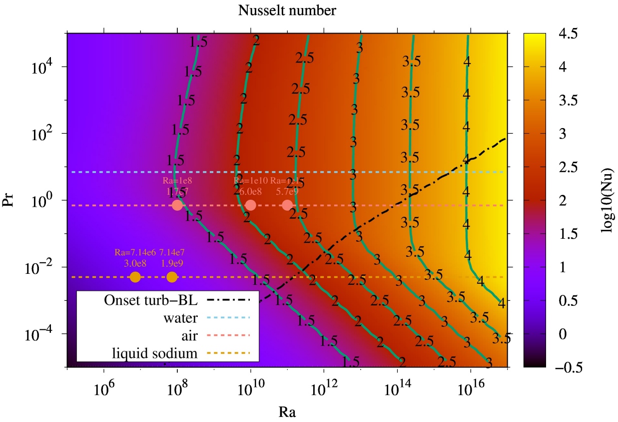
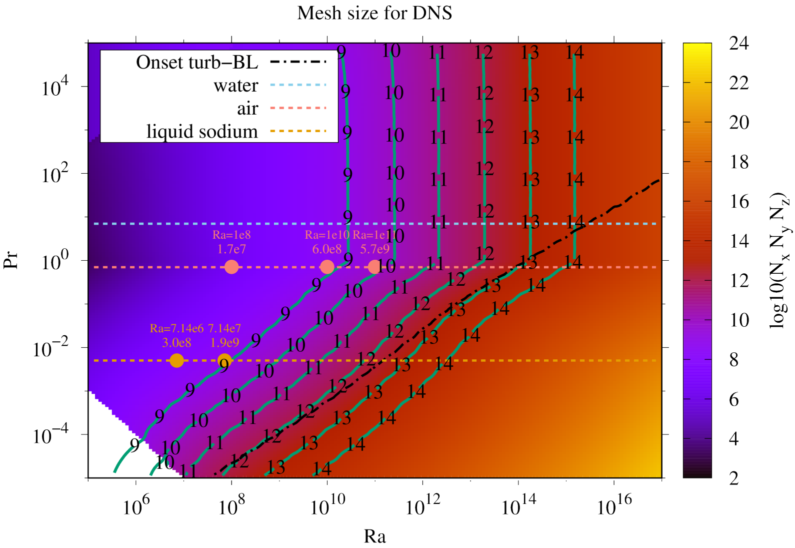




Can we reach the ultimate regime of turbulence?

DNS is far too expensive



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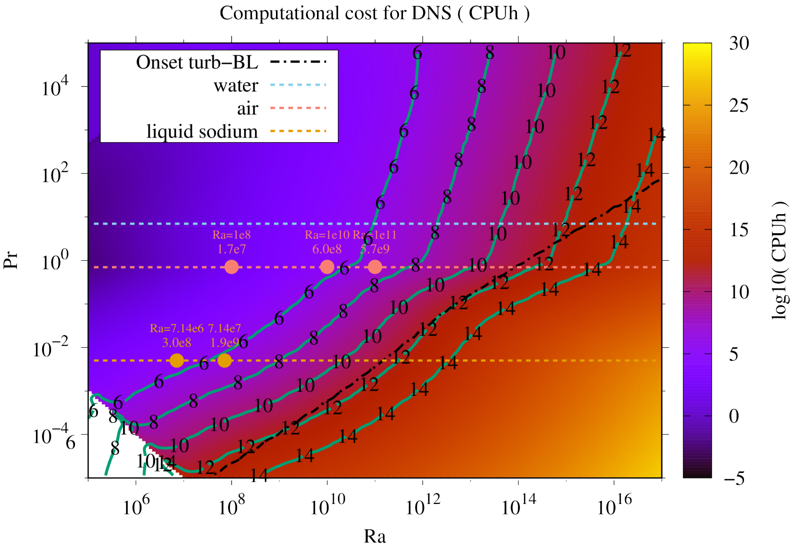

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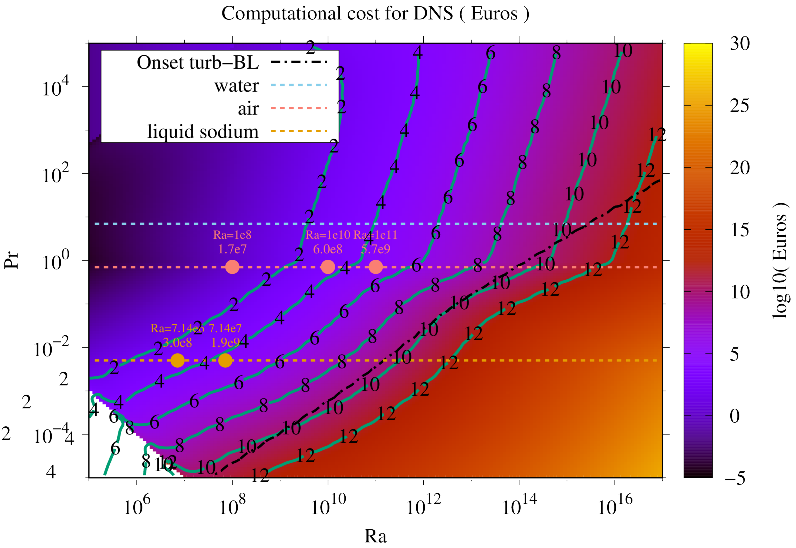

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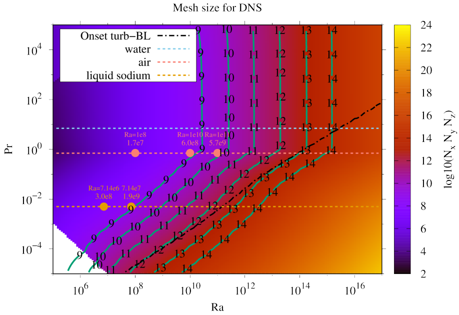
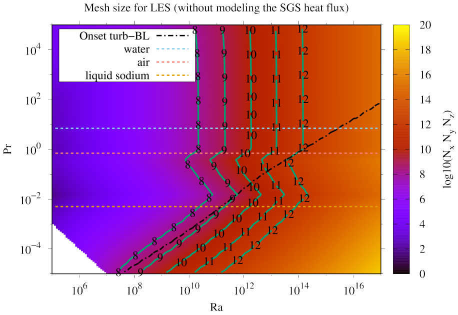
It may be possible with LES at low-Pr...





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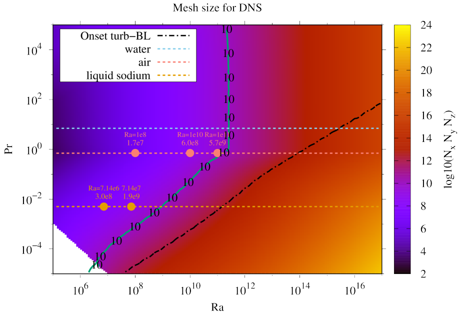

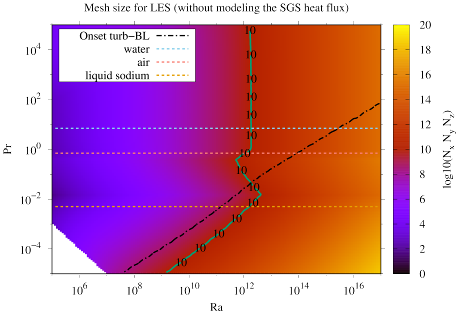

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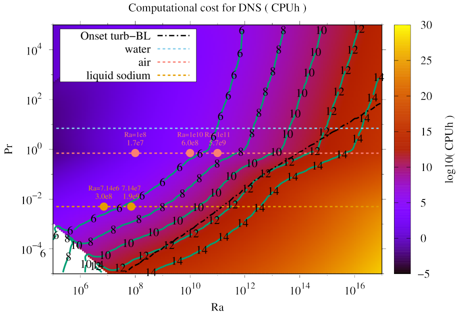

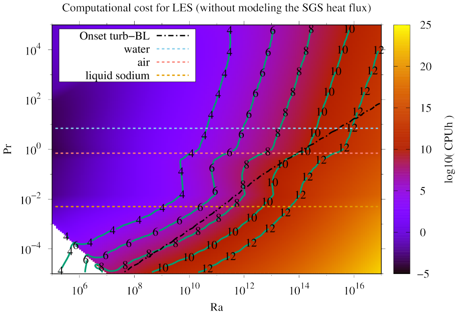

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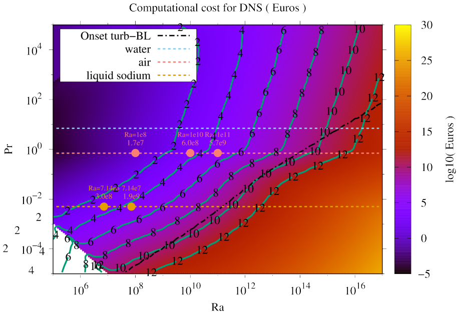

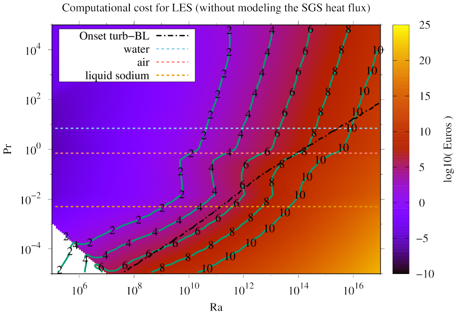

Can we obtain good a *a posteriori* results?

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⚠ But first we need to answer the following **research question**:

- Are **eddy-viscosity models** for momentum able to provide satisfactory results for turbulent Rayleigh-Bénard convection?

Can we obtain good a *a posteriori* results?

$$\partial_t \overline{u} + (\overline{u} \cdot \nabla)\overline{u} = \nu \nabla^2 \overline{u} - \nabla \overline{p} + \overline{f} - \nabla \cdot \tau(\overline{u}) \quad ; \qquad \nabla \cdot \overline{u} = 0$$

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⚠ But first we need to answer the following **research question**:

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Idea: let's do an LES for momentum and a DNS for temperature!

DNS at very low Pr number

Why? scale separation grows as $\eta_K/\eta_T = Pr^{3/4}$.

η_T: Obukhov-Corrsin scale; η_K: Kolmogorov scale

DNS at very low *Pr* number

Why? scale separation grows as $\eta_K/\eta_T = Pr^{3/4}$. Here: $\eta_T \approx 53.2\eta_K$

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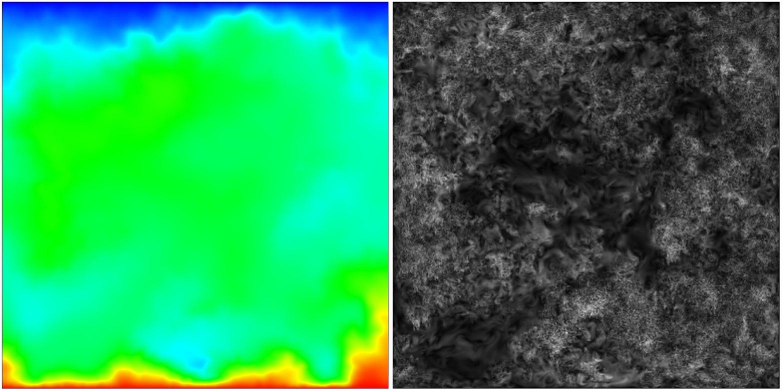

DNS of a RB at $Ra = 7.14 \times 10^6$ and $Pr = 0.005$ (liquid sodium)

$488 \times 488 \times 1280 \approx$ **305M**

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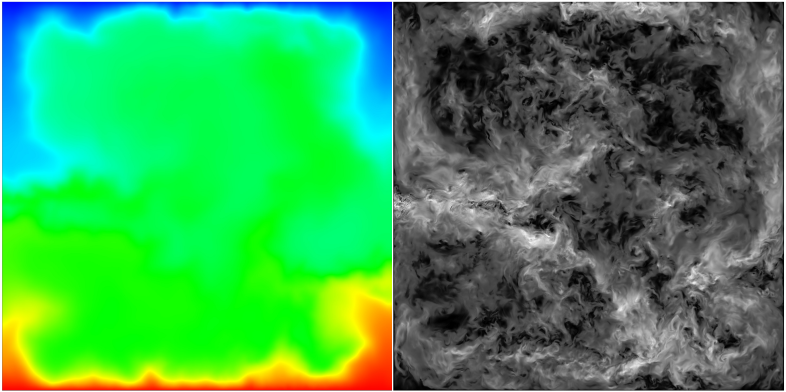

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$966 \times 966 \times 2048 \approx$ **1911M**

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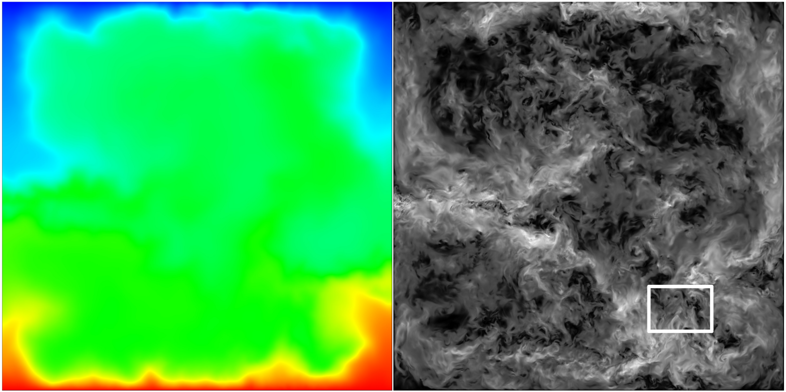

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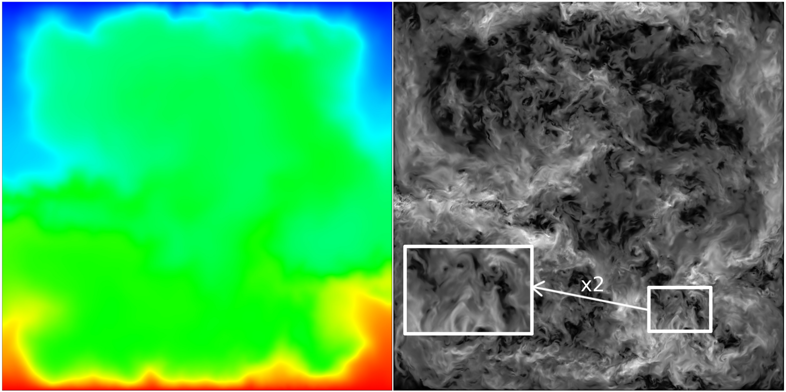

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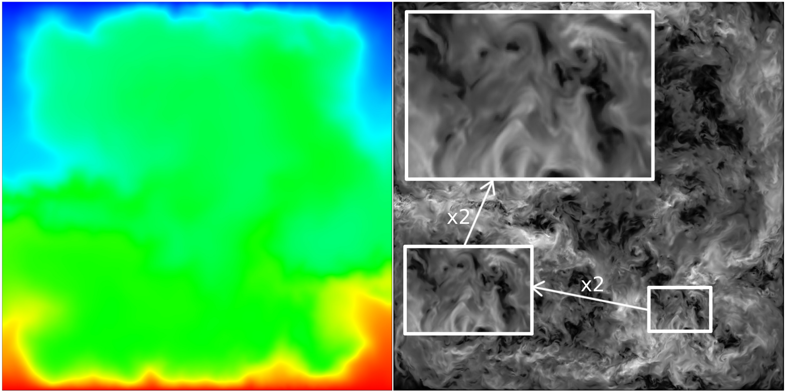

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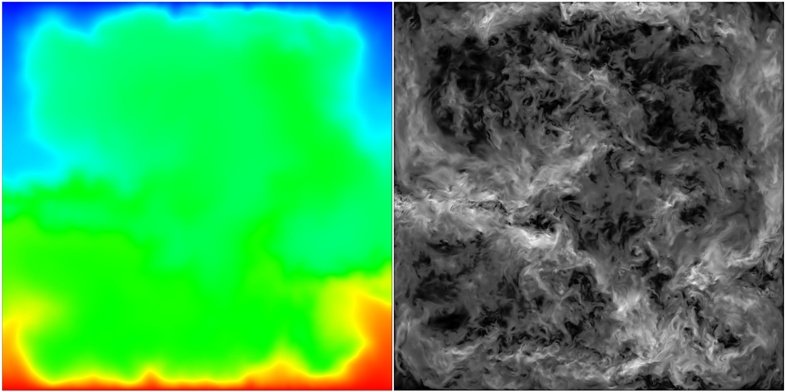

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LES[6] results at very low Pr number

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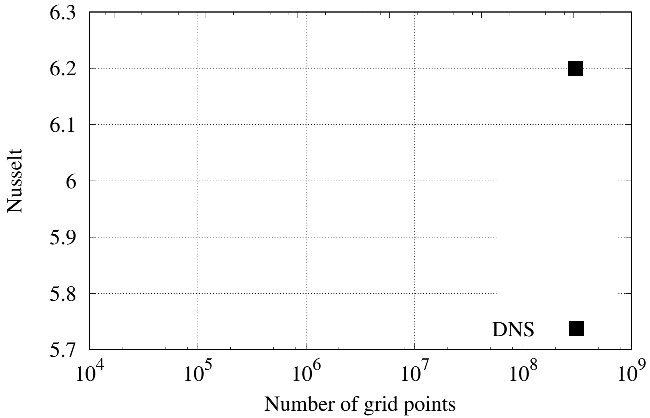

[6] F.X.Trias, D.Folch, A.Gorobets, A.Oliva. *Building proper invariants for eddy-viscosity subgrid-scale models*, **Physics of Fluids**, 27: 065103, 2015.

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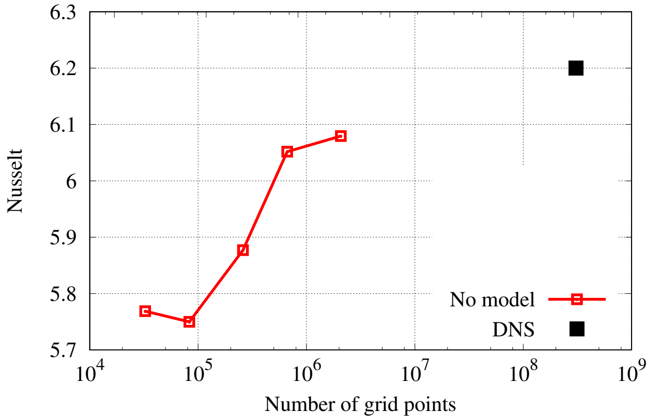

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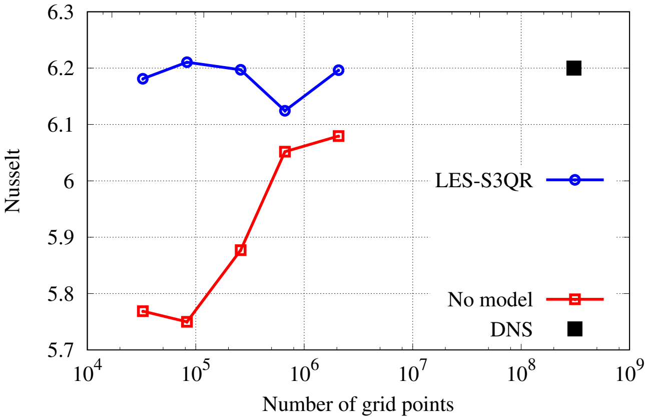

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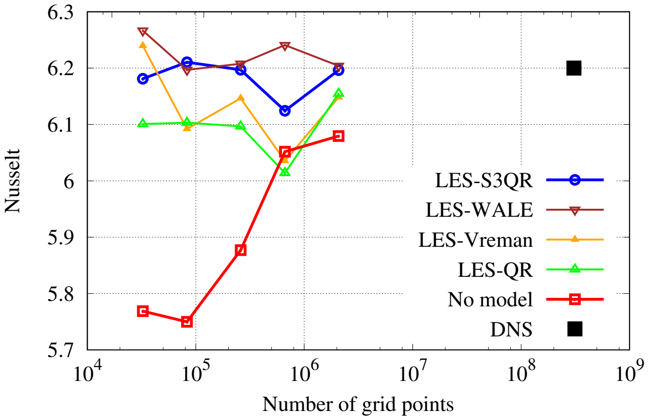

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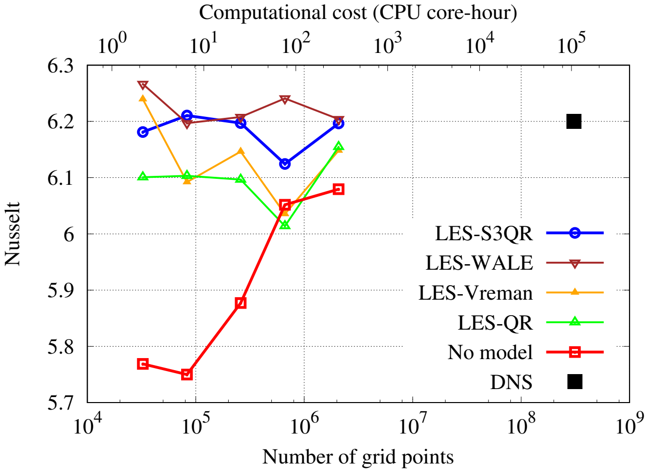

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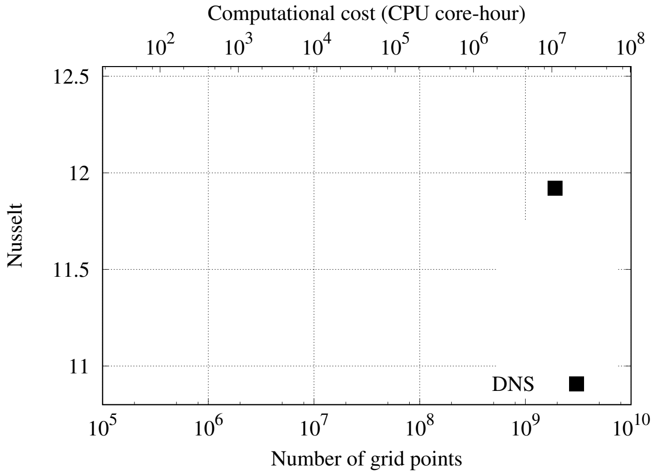

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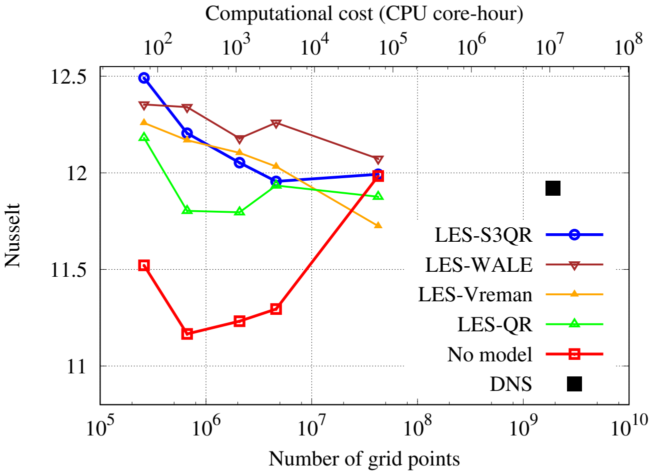

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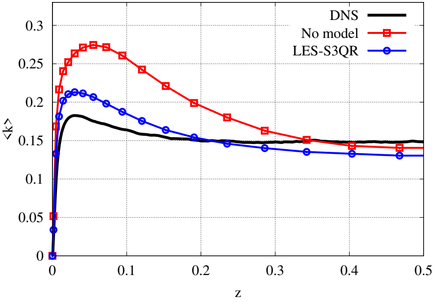
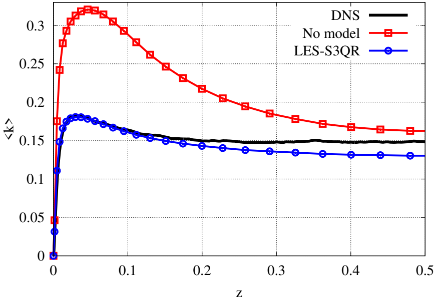


$64 \times 32 \times 32$



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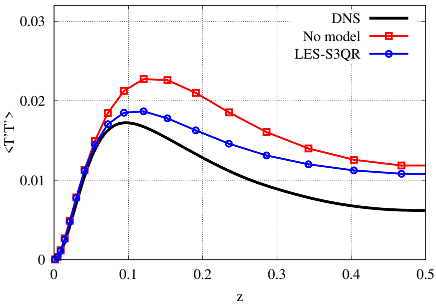

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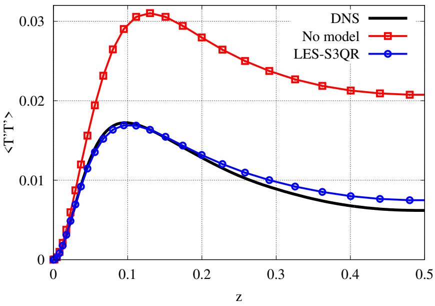

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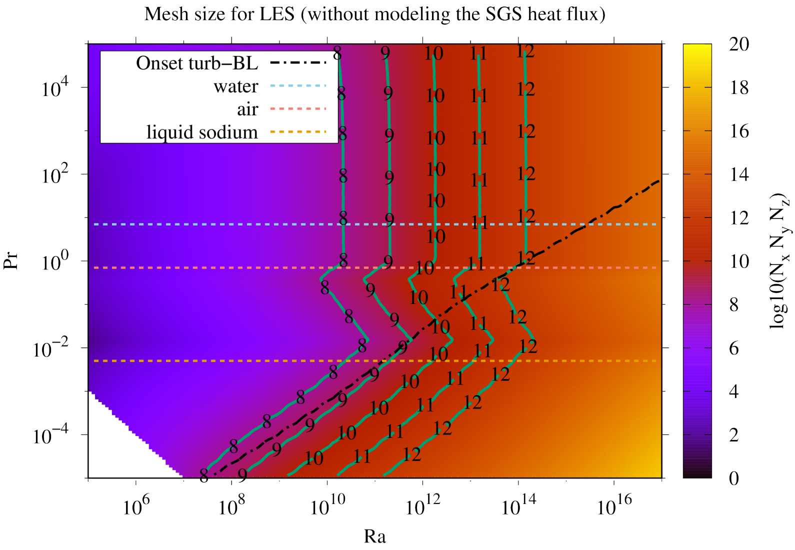
Fresh LES results (still running)



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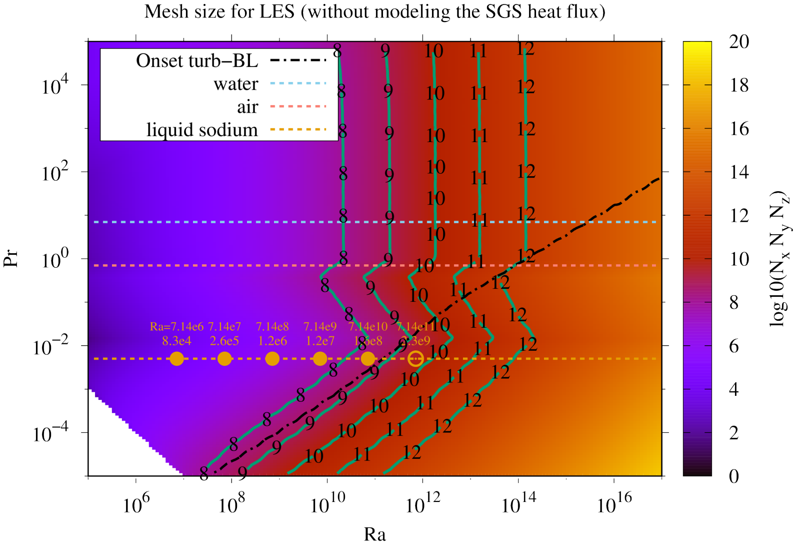

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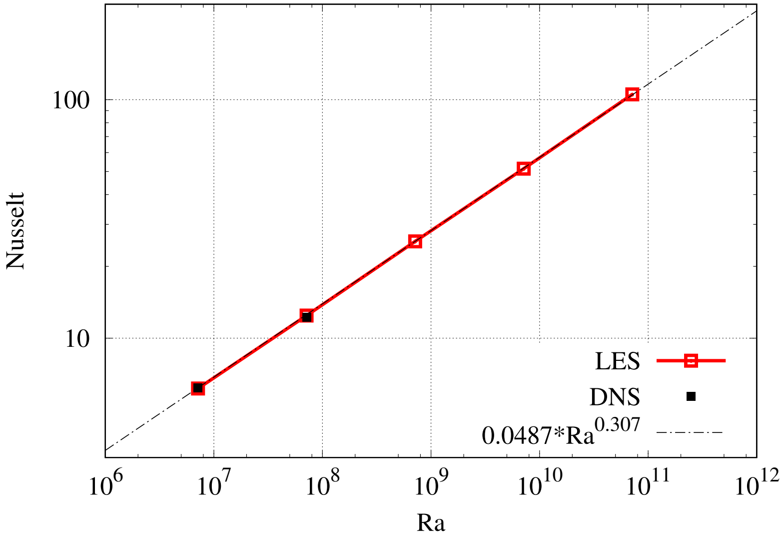
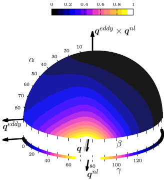


Concluding remarks

- Modeling the SGS heat flux, q, is the main difficulty for LES of buoyancy-driven flows



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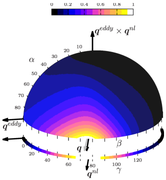

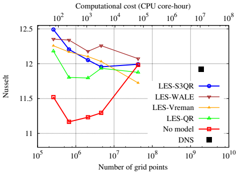

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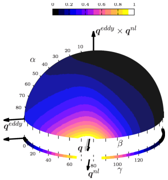

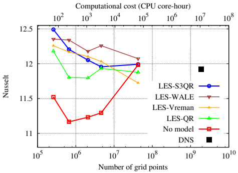

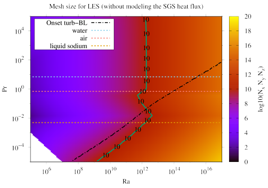

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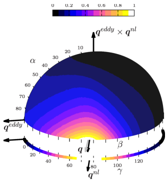

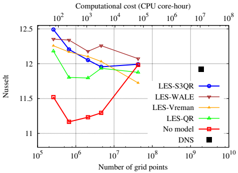

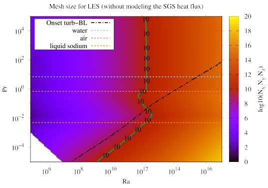

Future research:

- LES simulations at low-Pr and very large Ra
- *A posteriori* tests at $Pr = 0.7$ for the new non-linear SGS heat flux models proposed[a]

[a] F.X.Trias, F.Dabbagh, A.Gorobets, C.Oliet. *On a proper tensor-diffusivity model for LES of buoyancy-driven turbulence*, **Flow Turbul Combust**, 105:393-414, 2020.

Thank you for your ~~virtual~~ attendance