An efficient 2nd order finite difference method to understand the physics of the near wall turbulence

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Numerical methods for database

- Finite differences easier to understand than spectral methods
- Requirements:
  - Orthogonal grids energy conservation for zero viscosity
  - Homogenous in x1 and x3 uniform
  - Non-homogeneous coordinate transformation
  - Codes for serial computers available on Orlandi's book

Validation

- On serial computers with coarse grid
  - Energy conservation
  - Comparison with pseudospectral
  - To convince the skeptical
- Choice of interesting physics
  - Homogeneous in all the directions
  - Periodicity assumption
  - Optimal conditions for pseudospectral

Taylor Green with time reversal

- Inviscid test of non linear terms
  - Forward up to t=10

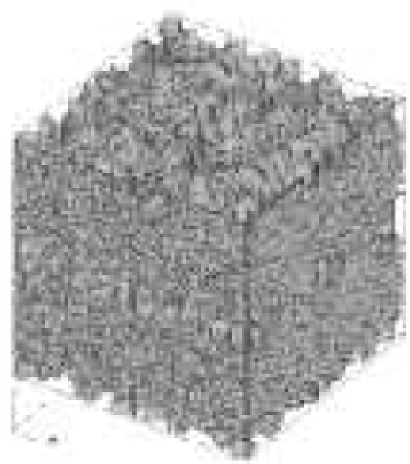
$$V(x_i) = -V(x_i)$$

  - Backward up to t=20
  - Return to initial conditions

Results

Isosurface of $\lambda_2 = -0.025$

$t = 0$

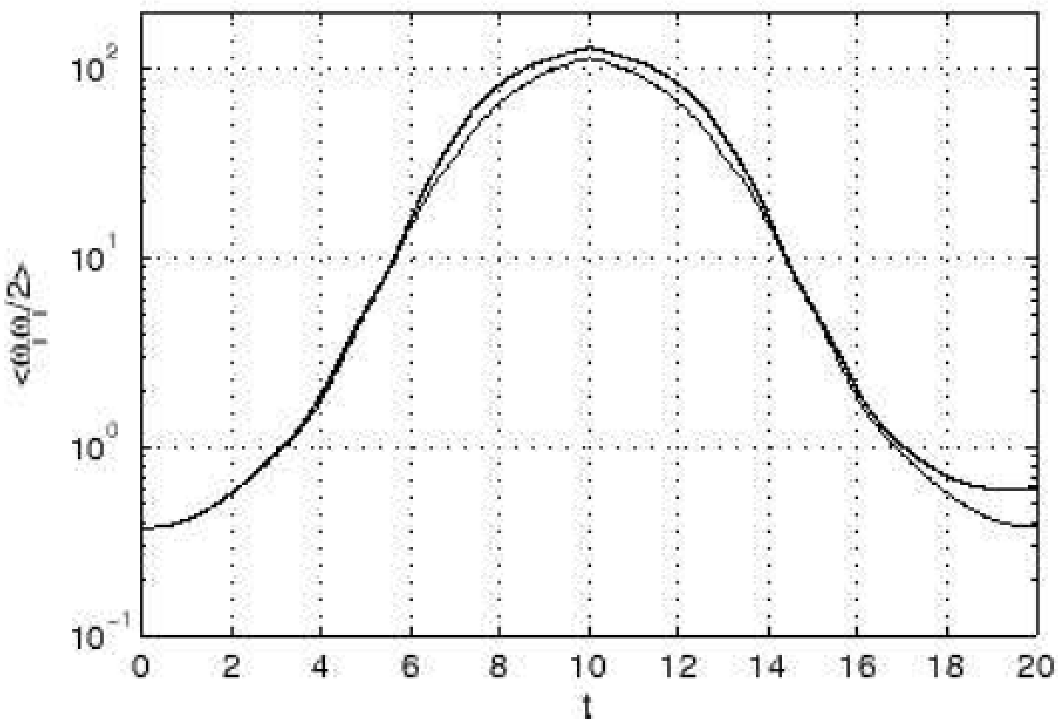


$t = 10$

$t = 20$

Comparison with pseudospectral

Time history of enstrophy

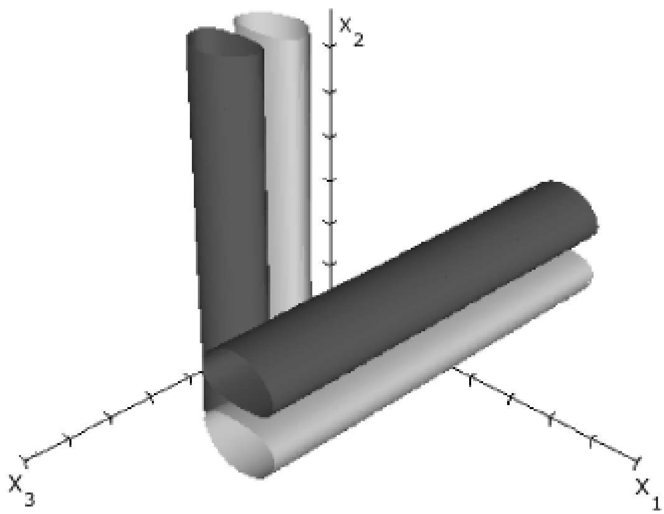


Physics requires resolution

- Limitation with serial computers
- Necessity of parallel computers
  - **For moderate resolution** in house clusters (with 16nodes allow 512^3)
  - **For high resolution** Super Computers (with 2048 nodes Jimenez N_x=6144 N_y=633 N_z=4608). Simulations run for 6 10^6 processors hours
  - Re close to experiments

Tercentenary Euler Birth

- DNS to understand whether a FTS exists
- Importance Initial Conditions



Two interacting Lamb dipoles

Lamb dipole shape preserving

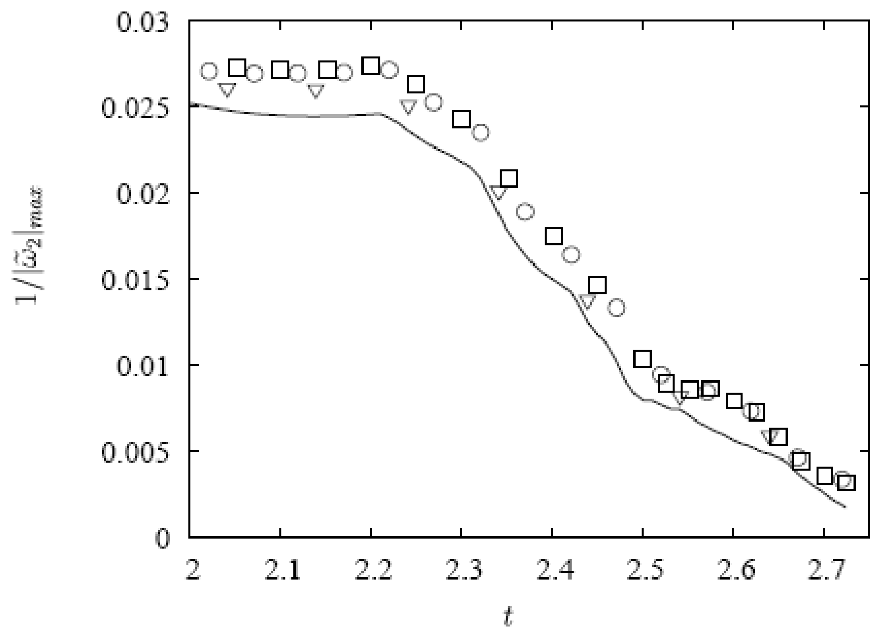
Two planes of symmetry

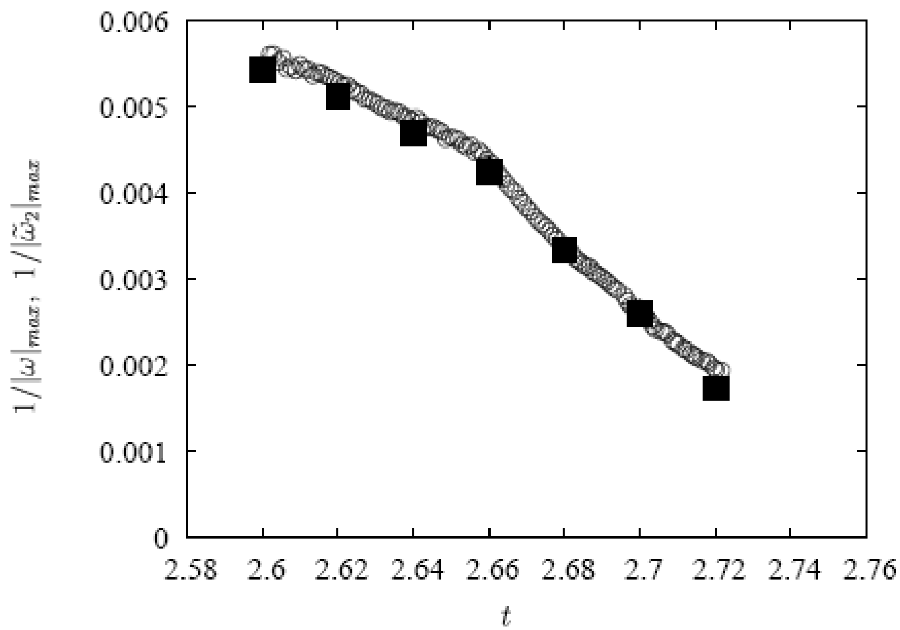
$32\ \mathbf{nodes}\ N_x = 1024, N_y = 512, N_z = 512$

Vorticity amplifications

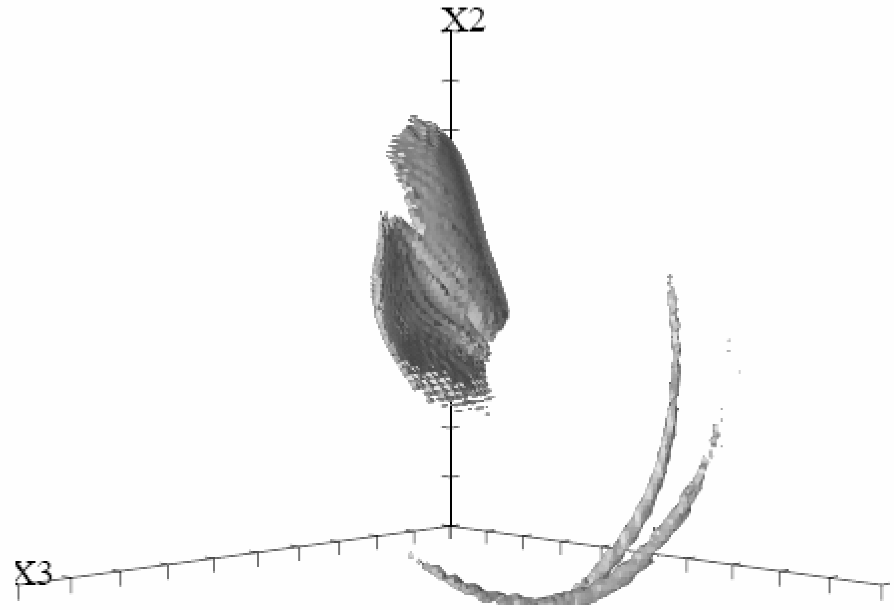
$$\textbf{FTS when } |\omega|_{max} \approx /(t_s - t)^{-1}$$

DNS provides any desired quantity
Vorticity components principal axes
Along intermediate strain $\tilde{\omega}_2$ relevant





Vorticity visualization



$\frac{\partial \widetilde{\omega}_\lambda}{\partial t} = \widetilde{S}_\lambda \widetilde{\omega}_\lambda$

if $\widetilde{S}_\lambda \approx \widetilde{\omega}_\lambda$

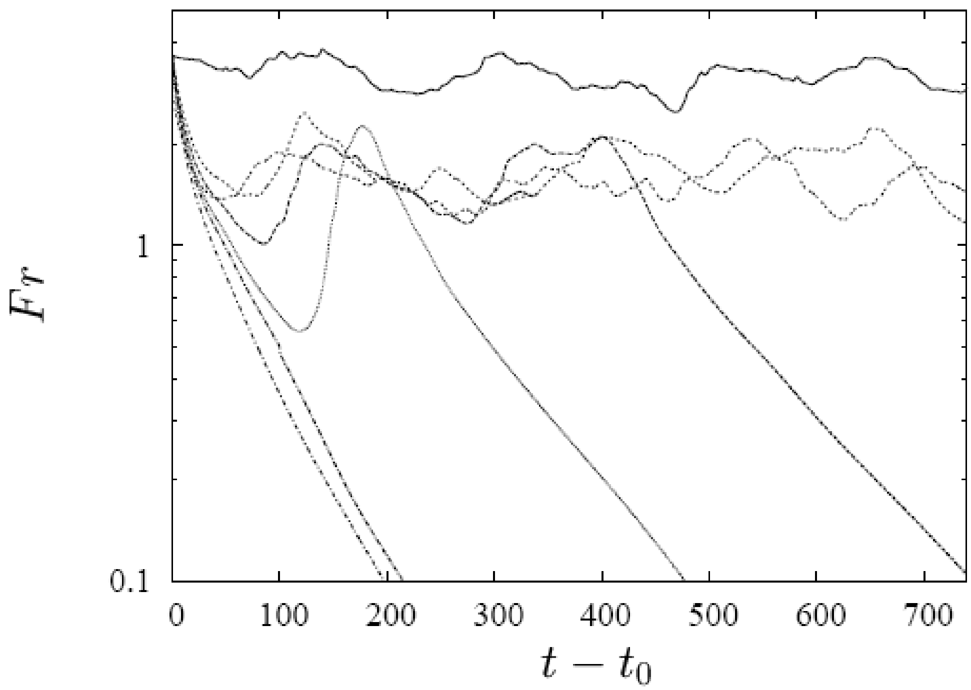
Model equation $\frac{\partial \phi}{\partial t} = \phi^2$

Having FTS

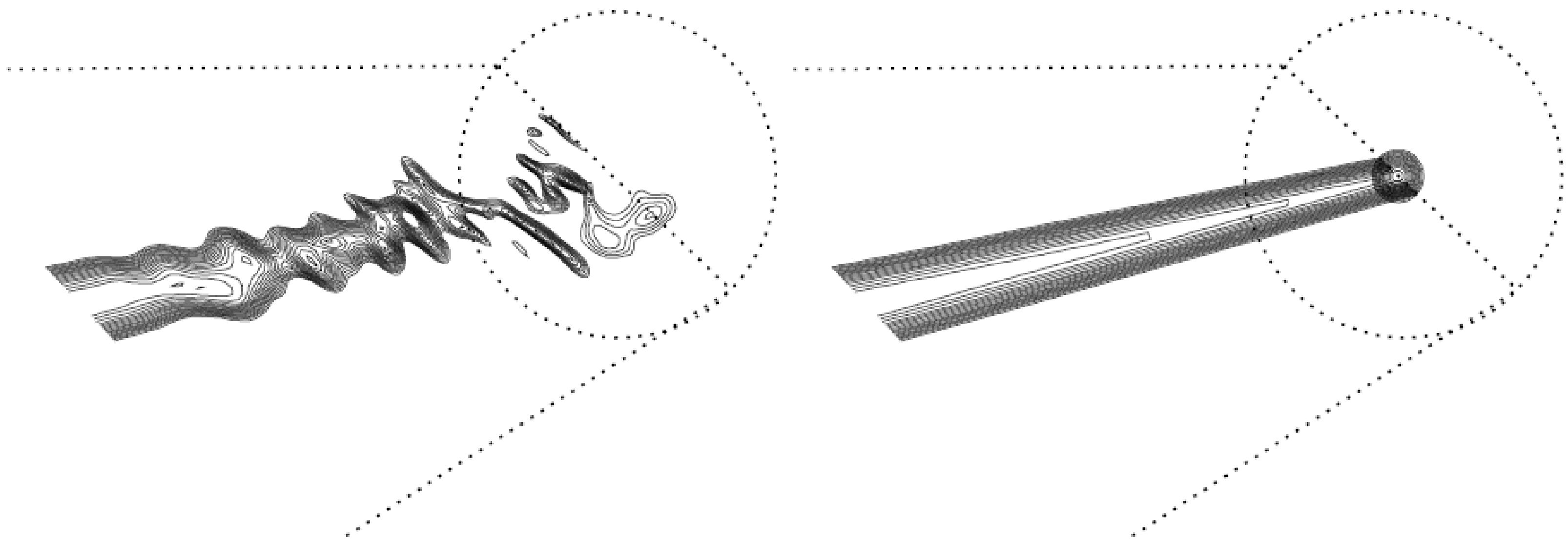
Impossibility to prove FTS by DNS of Euler

Experiment of O. Reynolds

- Importance of inlet conditions
- Usually Poiseuille + disturbance
- Here fully turbulent
- It remains turbulent for $\mathrm{Re} \approx 3000$
- Necessity of Clusters for several long simulations

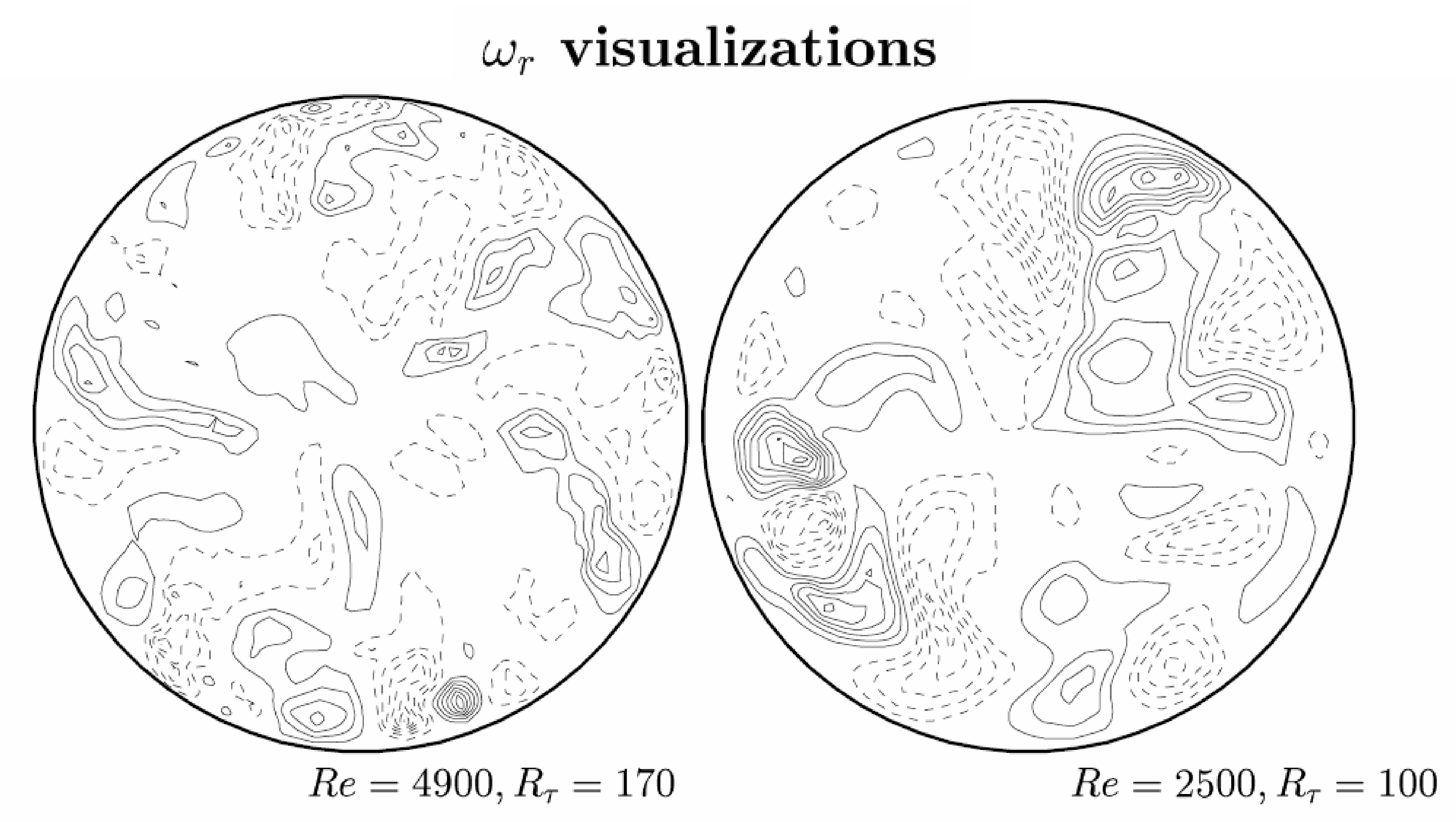


Dye visualizations



Injecting dye as Reynolds did
Flow time developing
Dye space evolving

Explanation of Transition

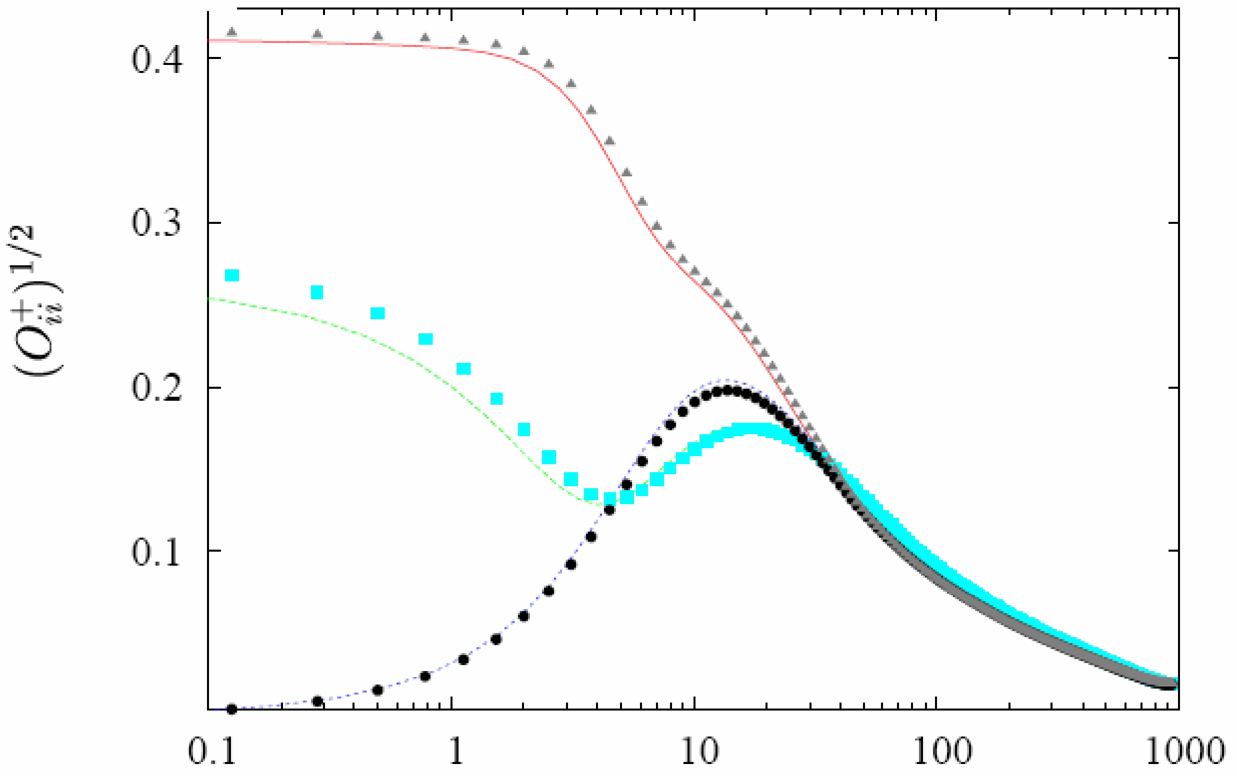


To remain turbulent, radius 20 wall units

Validation turbulent channel

DNS of wall bounded flows

- **Finite difference at high** Re
- **To create a further database**
- **Results for** $u_\tau = 900$
- **Comparison with Jimenez**
- **Necessity of clusters**



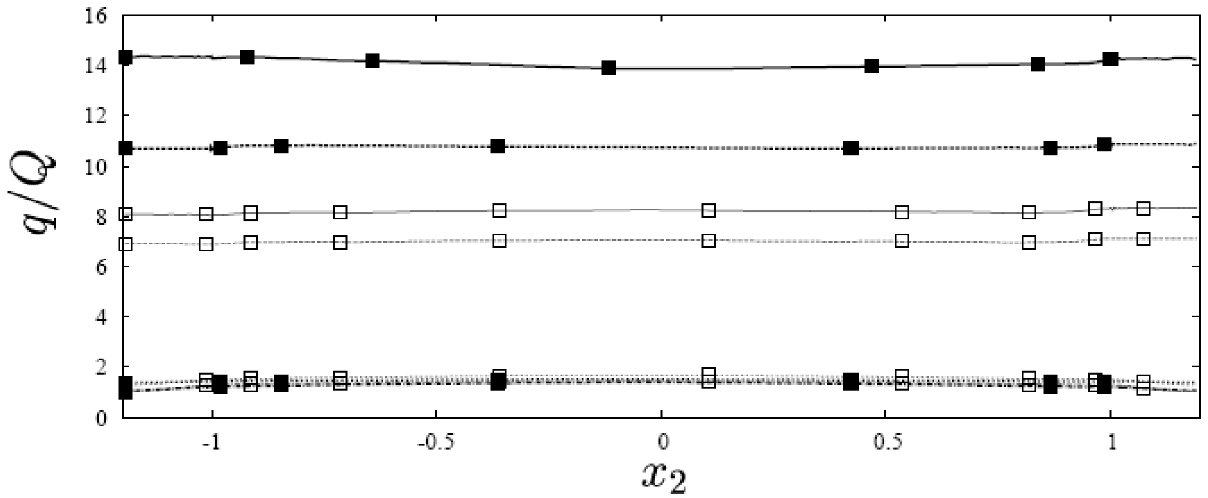
Conjugate heat transfer

- DNS to understand the influence of the solid wall
- Channel height 2h, solid height 0.2h

$$Pr_F = 1,\ Pr_S = 0.0134, .0134, 10.5, 30.8$$

$$R_\tau = 180\ \ 128 \times 193 \times 128$$

$$R_\tau = 330\ \ 256 \times 353 \times 256$$



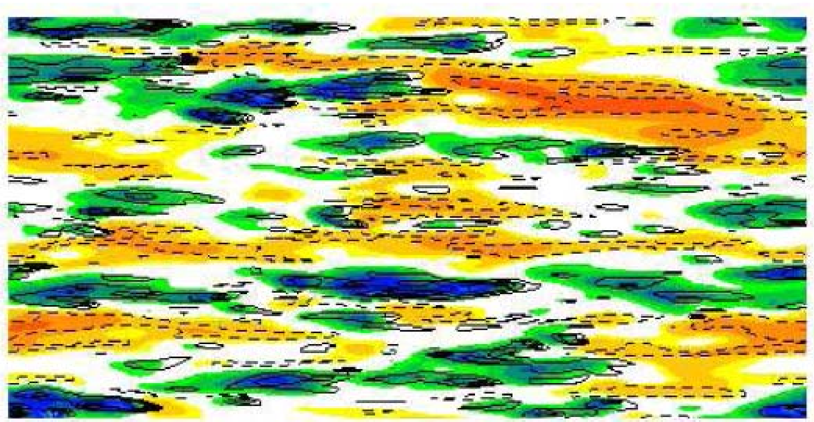
Long simulations to have convergence of the temperature.

<u>Clusters of CPUs are therefore necessary</u>

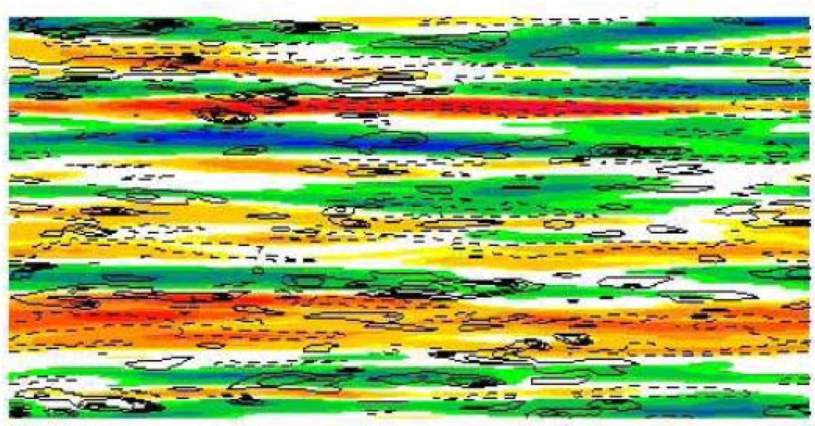
Temperature in the solid wall

To understand influence of fluid

Fluctuations normalised by rms



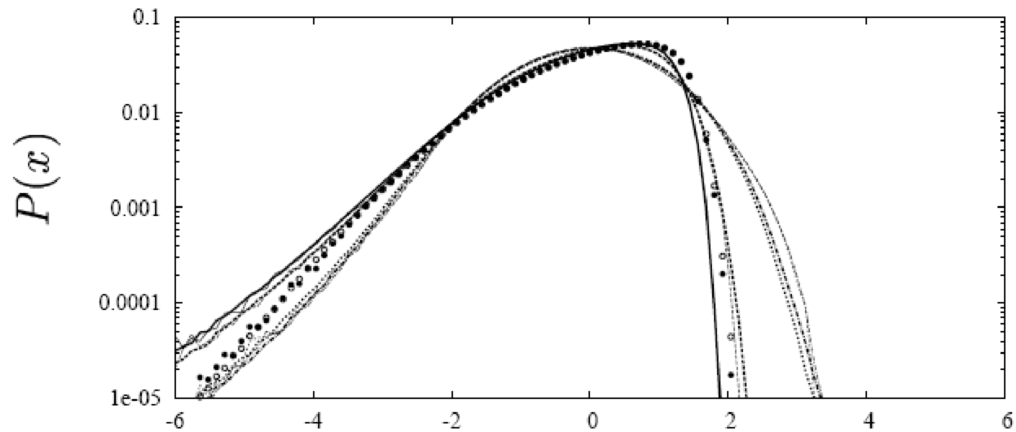
HIGHCOND.



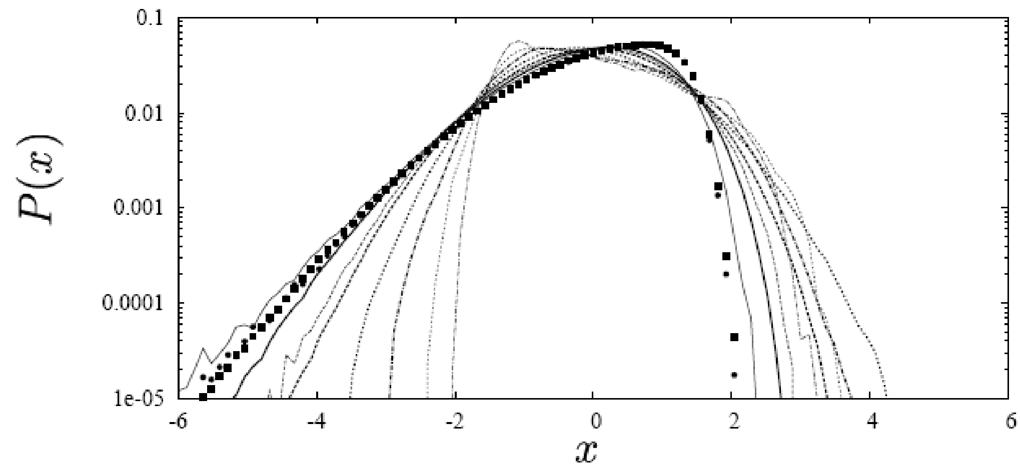
LOW COND.

PDF of θ' and u_1'

To understand Re and Pr_S dependence



$FLUID$



$SOLID$

MOVING WALLS

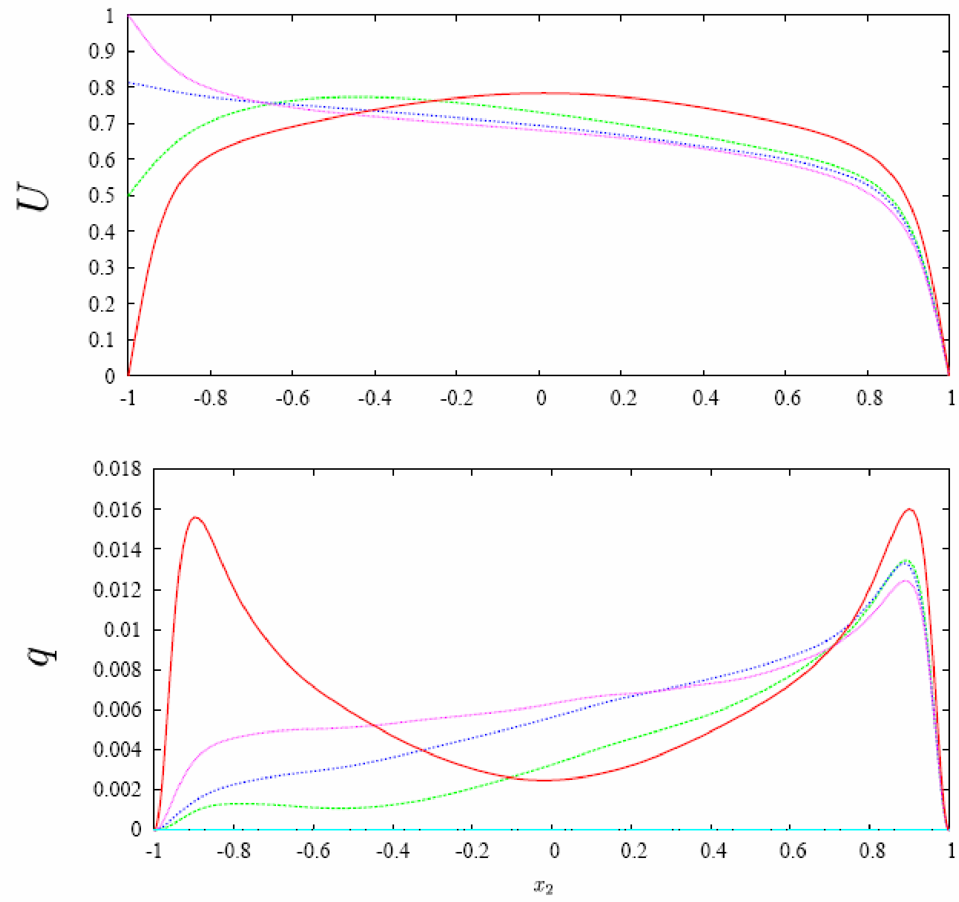
- To understand the effect of the shear near the wall

Simulations for $Re_b = 2400$ **and** 4800
Couette $U_w = 1$
Intermediate $U_w = 0.81$
Poiseuille $U_w = 0.5$

- Create a Database for turbulence modeling
  - Simple geometries for RANS 1D
  - Appropriate for structure based models
  - Absence of wall structures
  - Helps LES users providing better sgs
  - In this case necessity of higher Re
  - Future in the WALLTURB project
  - Necessity students and computational time

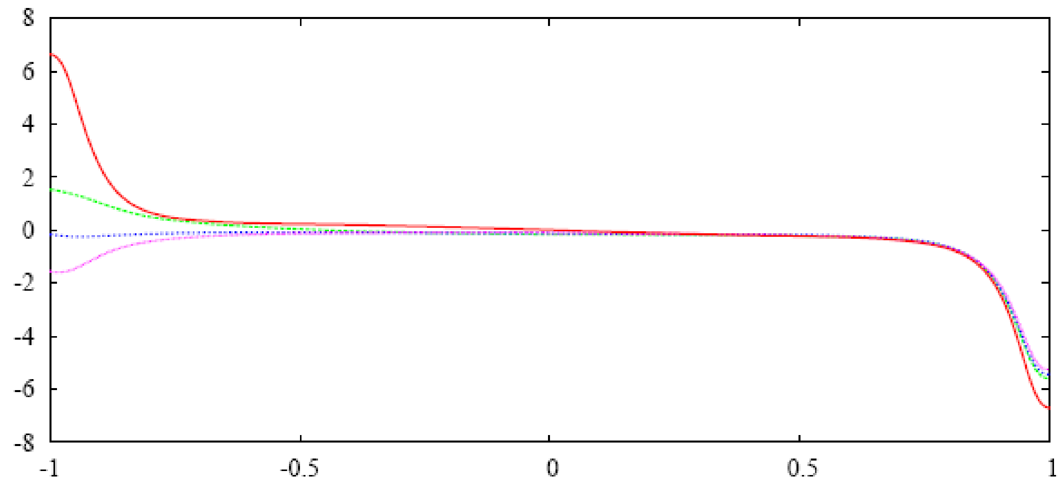
Mean Velocity and TKE

Comparison between two walls

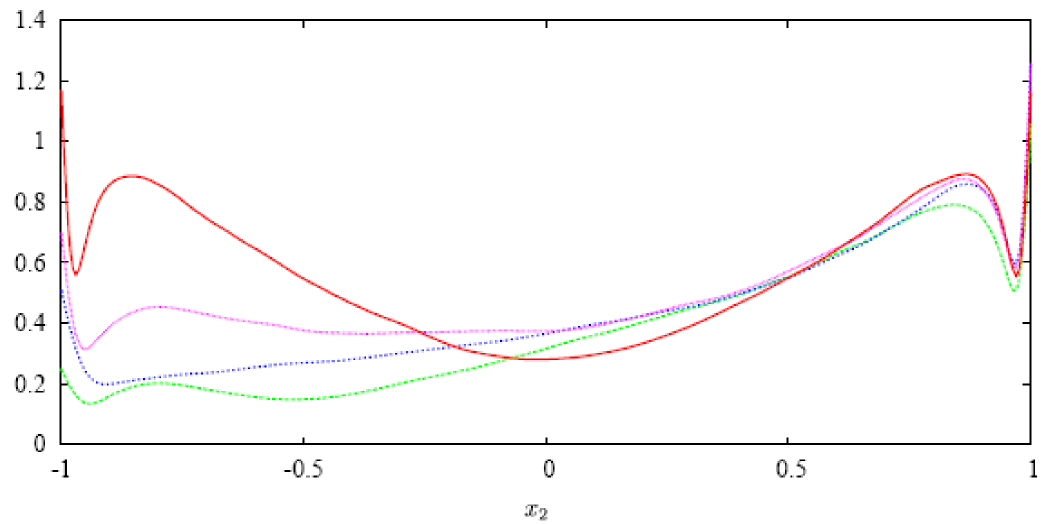


Vorticity statistics

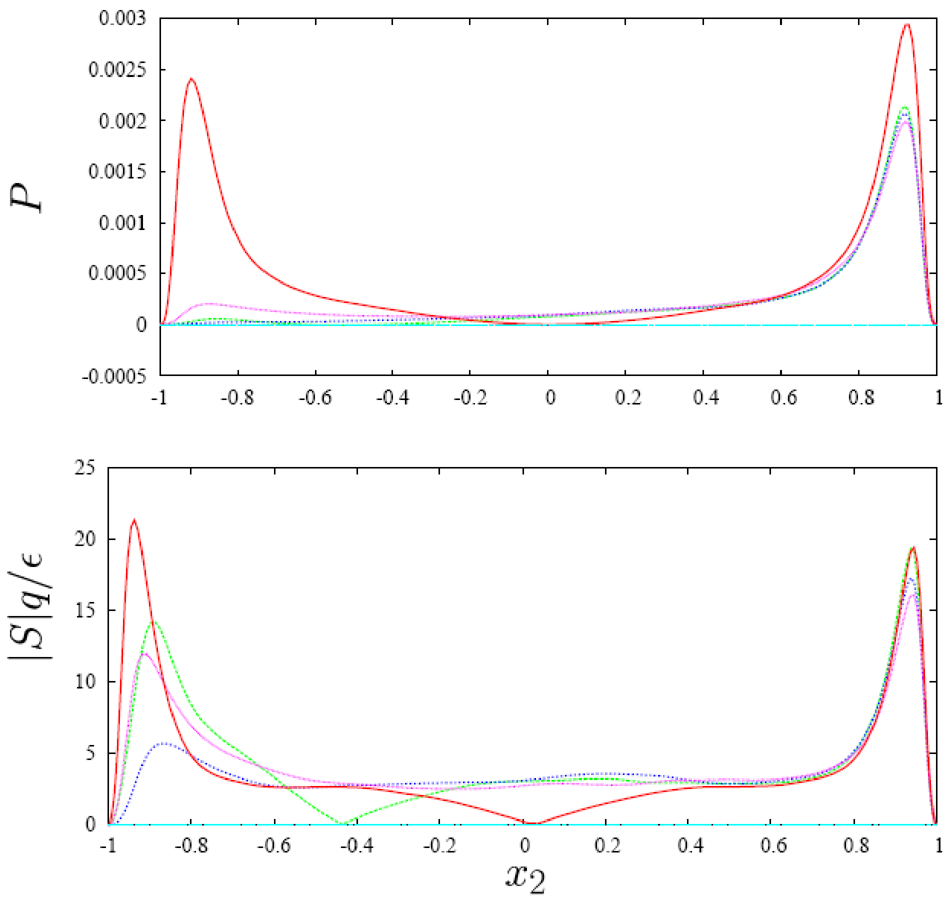
$\langle \omega_1 \rangle$



$\langle \omega'^2_1 \rangle^{1/2}$

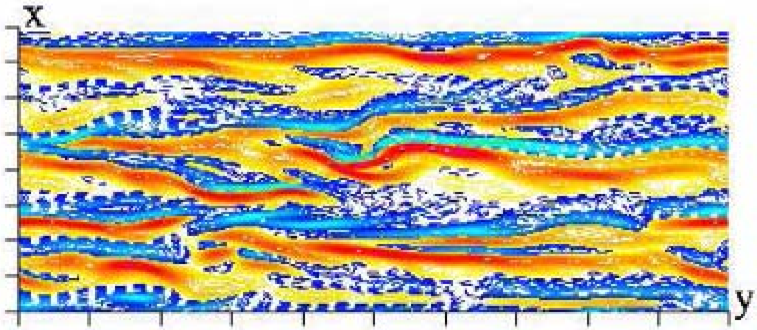


TKE Balance

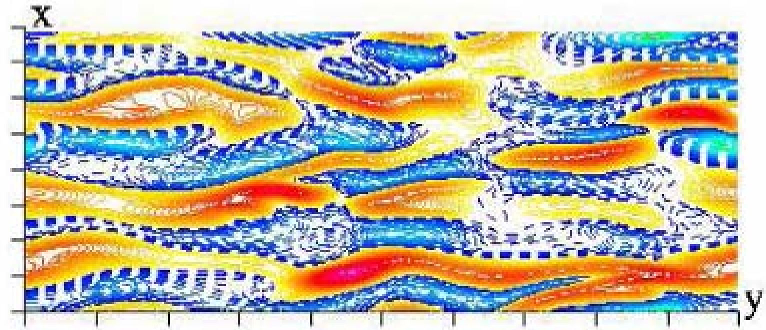


High Reynolds database performed

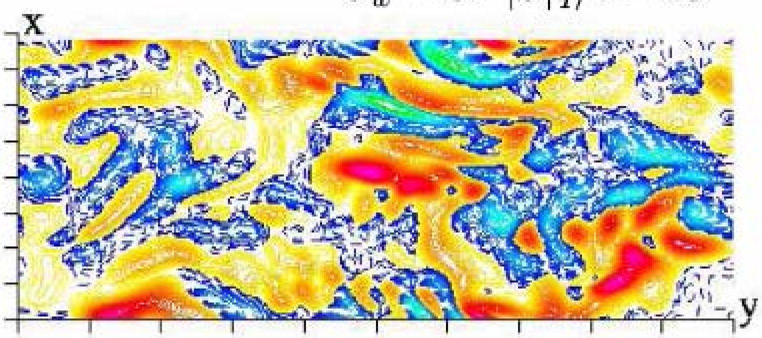
Wall structures



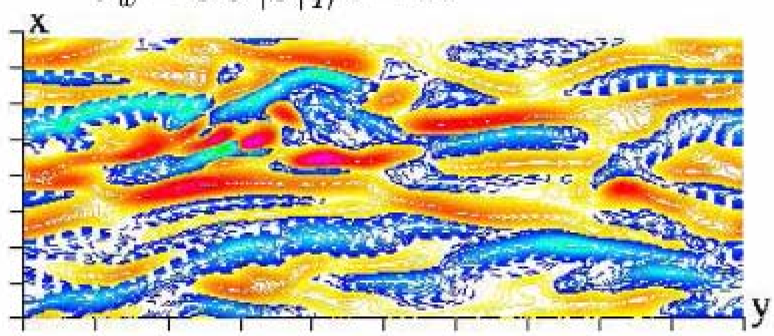
$U_w = 0. \quad |S|q/\epsilon = 15$



$U_w = 0.5 \; |S|q/\epsilon = 14$



$U_w = 0.8 \; |S|q/\epsilon = 5$



$U_w = 1. \quad |S|q/\epsilon = 12$

Database available to be analyzed

DNS of rough flows

- To understand the effect of roughness shape on the flow
  - Dependence on the orientation of the elements and roughness density (w/k)
- Orthogonal
  - At high w/k, small effect of the shape of the elements
  - Low w/k more practical
  - Drag increase
- Parallel Disturbances “riblets”
  - Interest for small w/k
  - Drag reduction w/k=0
- Three dimensional disturbances
  - Towards Nikuradse’s sand grain (1933)
  - Very high Drag

Global effects

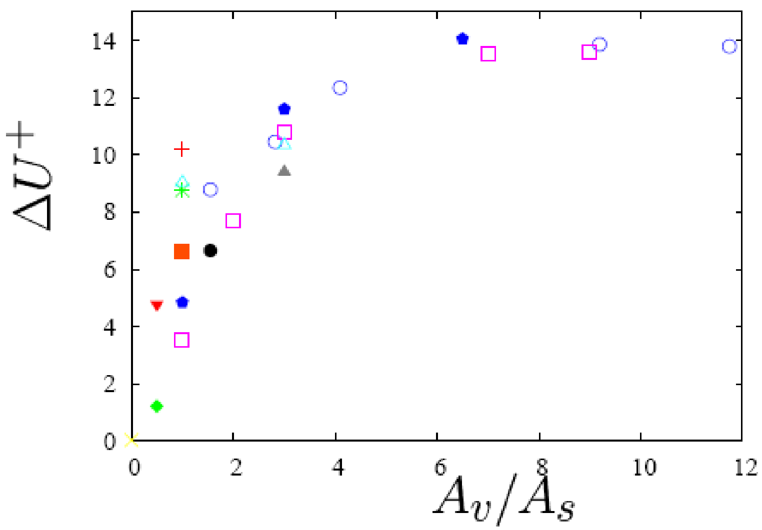
Roughness function ΔU^+

different definition depending on d_0 **"error in origin"**

Here $d_0 = 0$; y **from crest plane**

$$U^+ = (\langle U_1 \rangle - U_{10})/(u_\tau)_L$$

At $y = 0$ $U_{10} \neq 0$

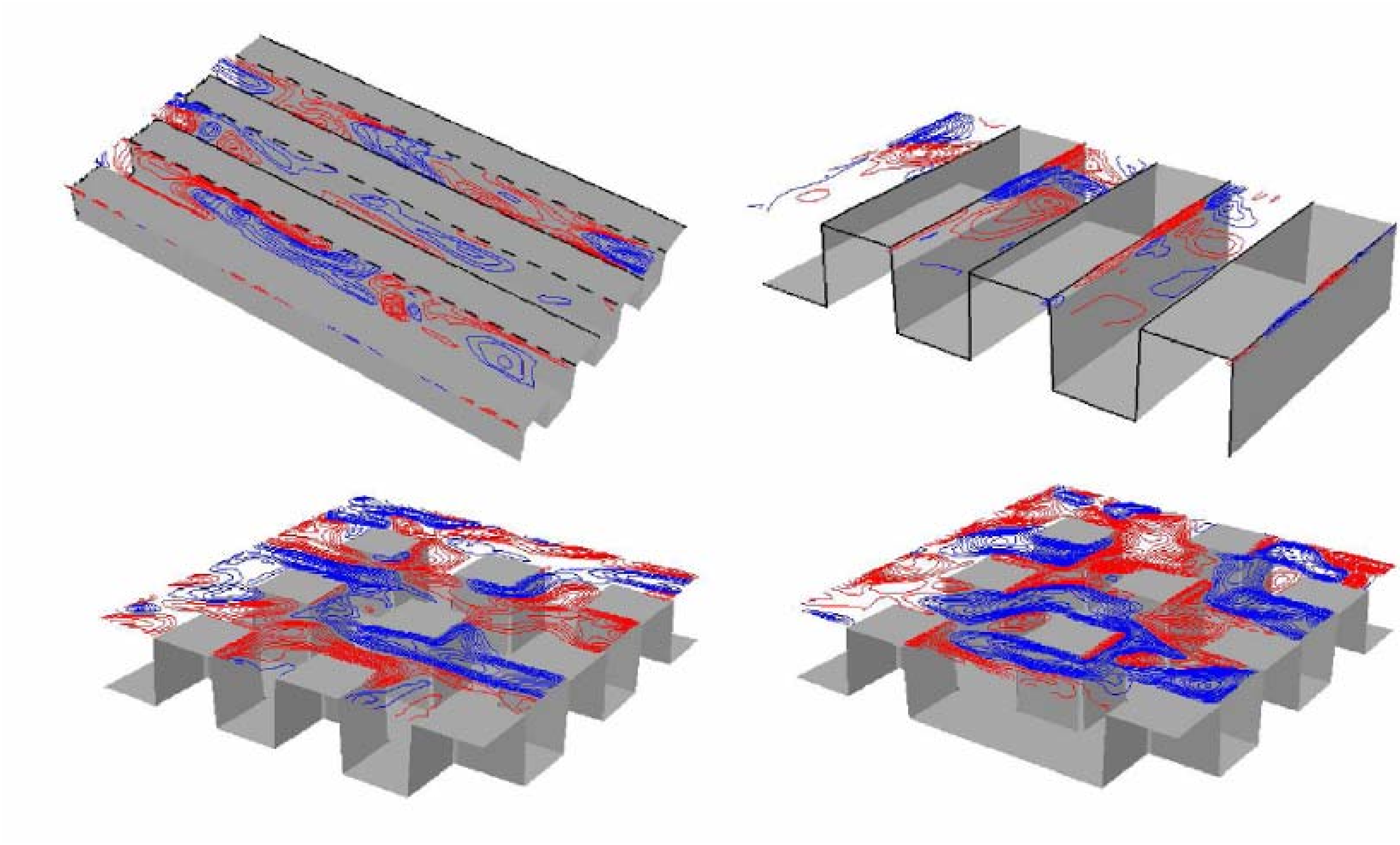


At low A_v/A_s no scaling

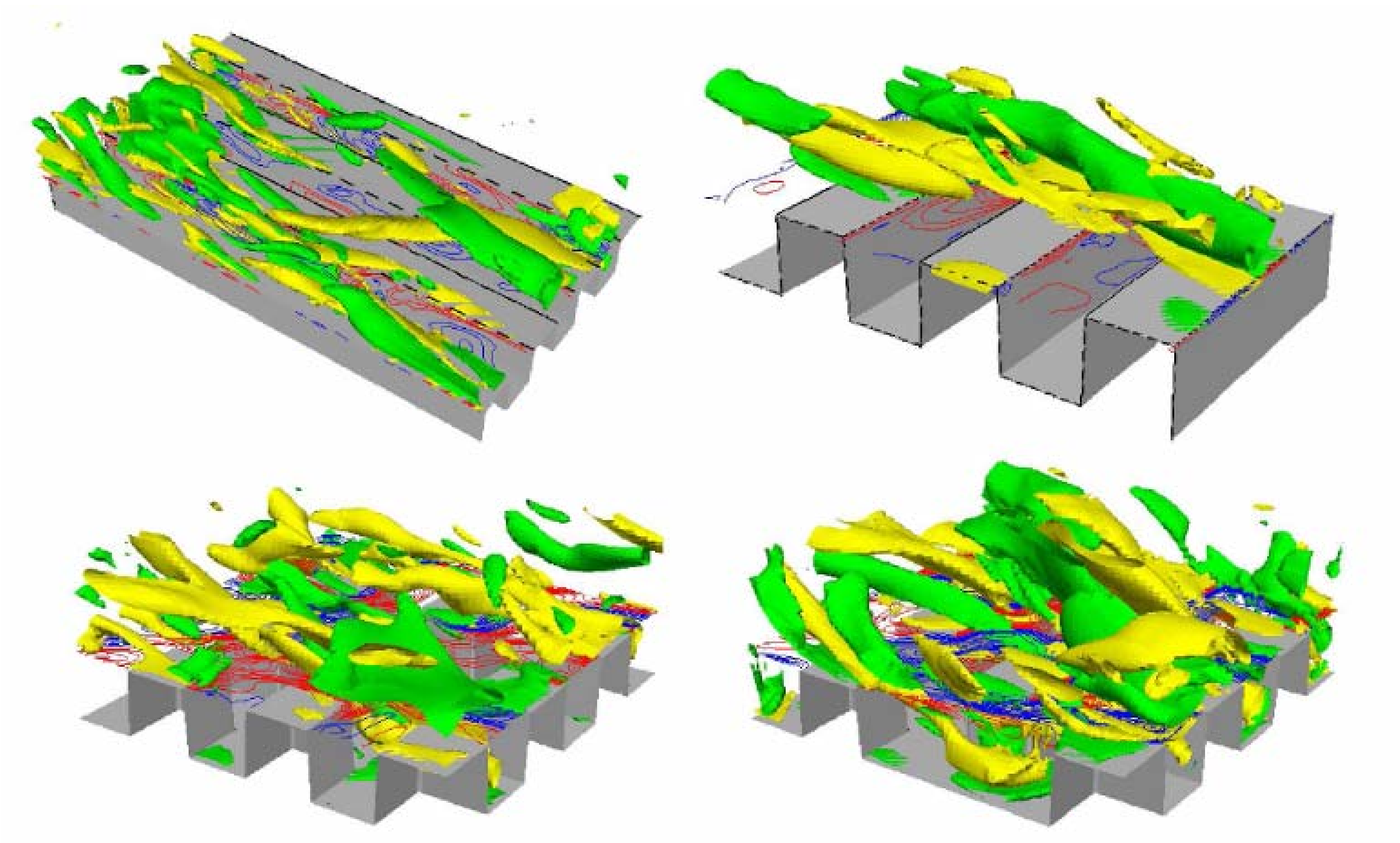
Search for scaling

- Geophysical applications
  - In LES the roughness cannot be described accurately since too many points are required
  - Roughness represented by ad hoc wall b.c.
  - As for smooth walls
  - Comprehension of flow physics at low Re
  - Could lead to find the driving quantities

Normal wall velocity at the crests plane



Streamwise vorticity iso-surfaces superimposed to normal wall velocity at the crests plane

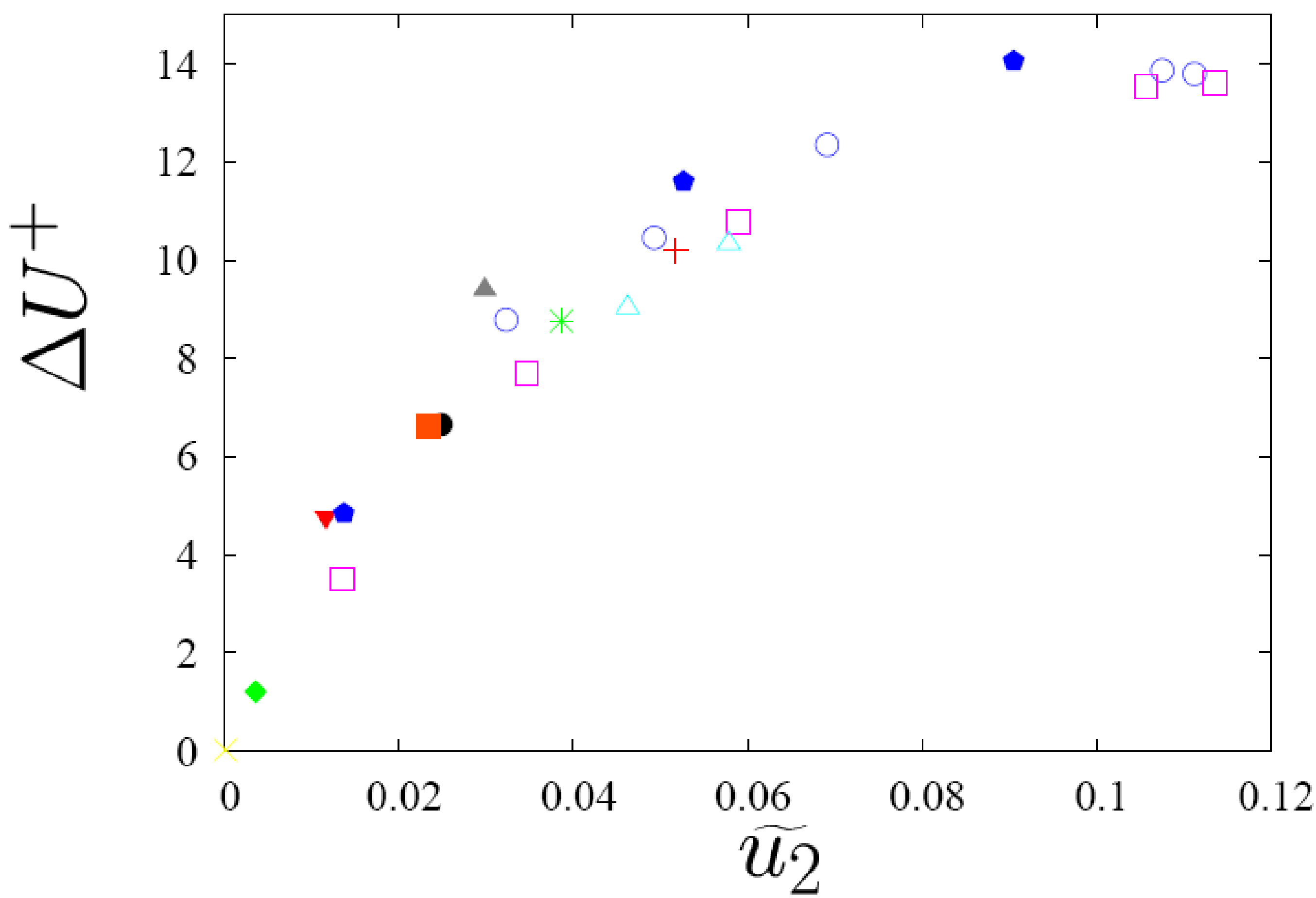


Towards new scaling

- Physics from DNS
  - Independent of roughness on the lower wall
  - Statistics upper wall unchanged
  - To change drag action on walls
  - Isotropy drag increase DISORDER
  - Anisotropy drag decrease ORDER
- Vertical velocity at the interface driving motor
  - Verified by DNS of smooth wall with vertical velocity as B.C. constant in time
  - Useful in laboratory for very high Re
  - Very high Re not affordable today with small clusters
  - Necessity of thousands of processors

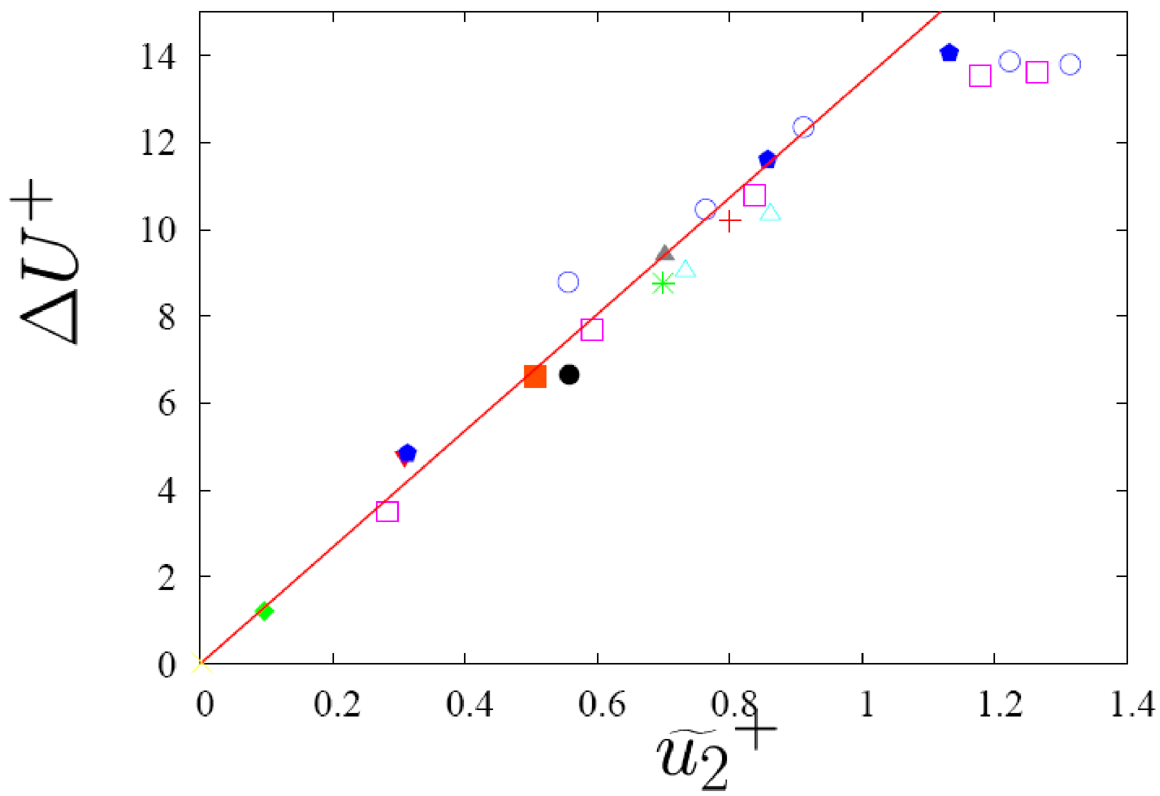
NEW SCALING

u_2' **at interface driving motor**



New Scaling

$$\Delta U^+ = \kappa^{-1} B \widetilde{u_2}^+$$



To be checked at high Reynolds numbers experimentally (need of large Wind Tunnel)

Conclusions

- Roma-Puertorico collaboration
  - From Roma, numerical tools
  - From Puertorico, students
  - To create together a database of basic turbulent flows and give guidelines for applied simulations
- Examples
  - Forced isotropic turbulence + passive scalar to explain clouds formation
  - 3D roughness for a new parameterization in micro-meteorological codes
  - Conjugate heat transfer for distribution of pin-fin cooling

Suggestions from industries and agencies required and appreciated