NEW LES CAPABILITY OF ADREA-HF

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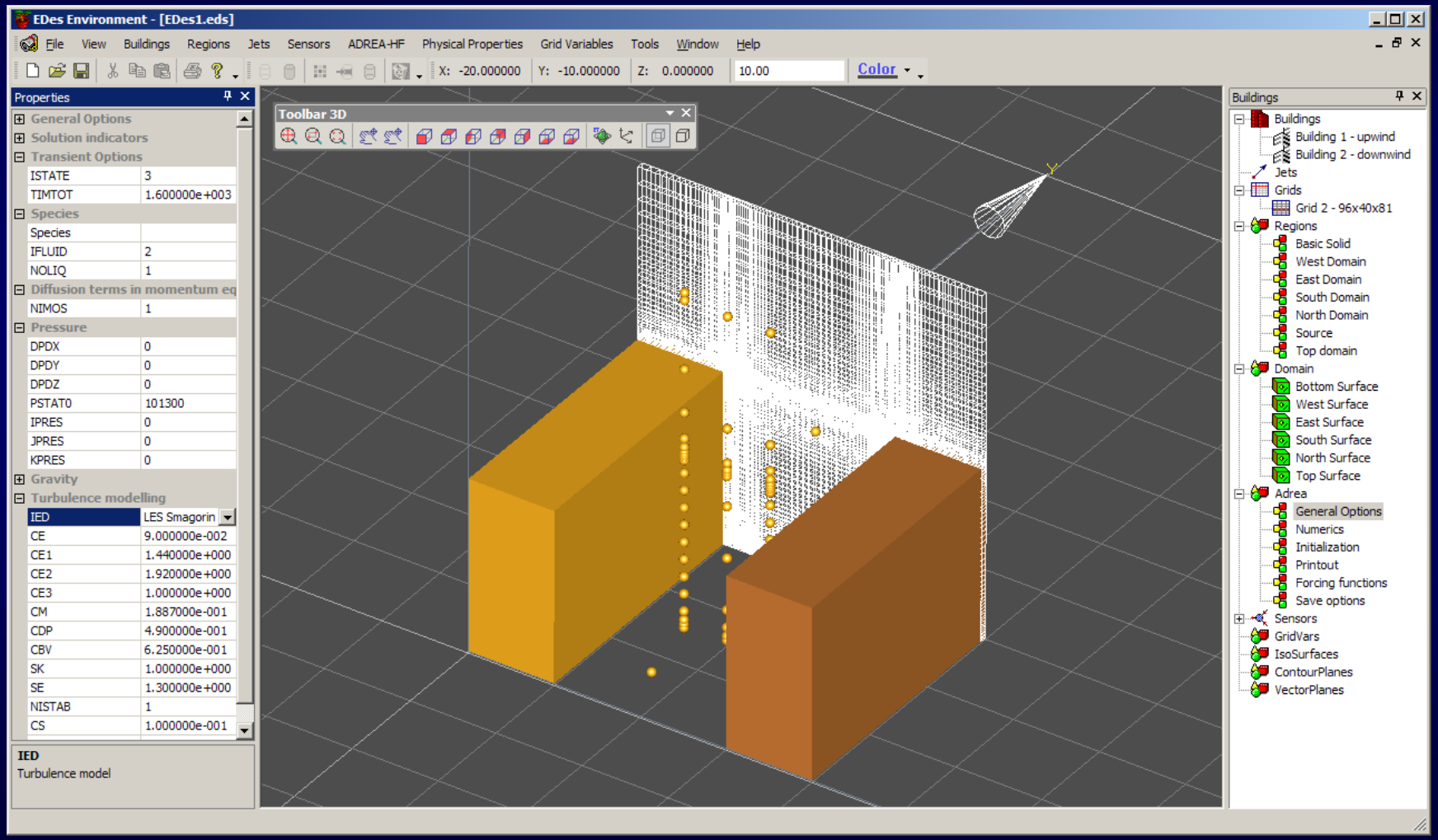
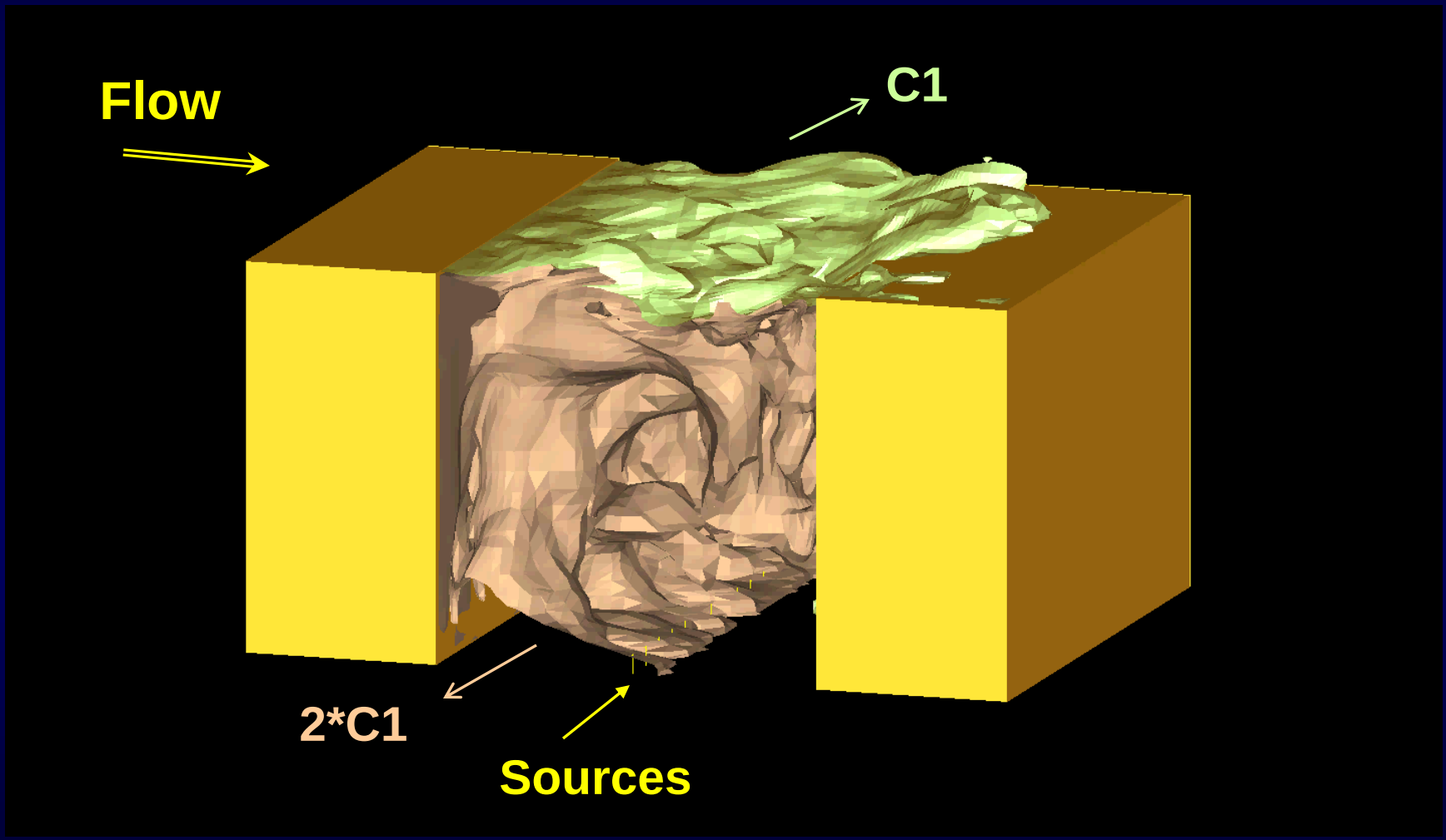
ADREA-HF CFD CODE
Constantly developing

- **Latest additions:**
  - **LES (Large Eddy Simulation)**
  - **Parallel solver**
  - **Arbitrary number of species**
  - **Combustion**
  - **GUI pre and post processor (called EDes)**
- **Advantages:**
  - **Robust, powerful and general**
  - **Specialization in environmental applications**
  - **“ADREA + dispersion”: 29 hits in Scopus**

ADREA-HF CFD CODE
GUI environment for pre and post processing



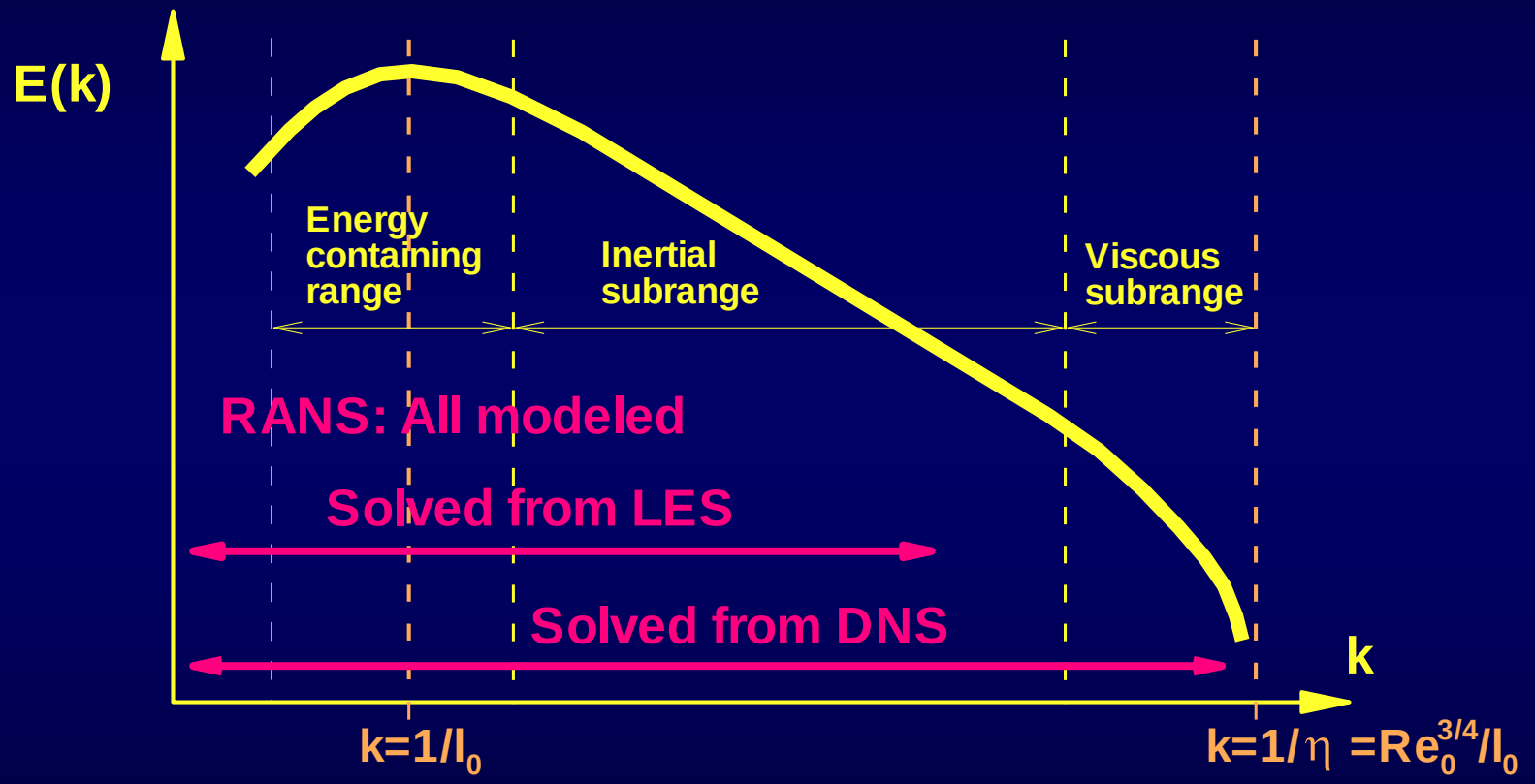
ADREA-HF CFD CODE
Post processing example with ADREA-HF GUI



LARGE EDDY SIMULATION
Between DNS and RANS

- Navier-Stokes math. analysis: impossibly difficult
- DNS: Fully-resolved NS
  - Cost $\propto \underline{Re^{2.75}}$ (for wall-bounded flows $\propto Re^{3.5}$)
- RANS: Time-averaged NS
  - Fast, widely tested, usually accurate "enough"
- LES: Spatially-filtered NS
  - Cost near wall: $\propto \underline{Re^{2.4}}$! (at outer layer $\propto Re^{0.5}$)
  - Converges to DNS. As in DNS, LES needs:
    a) averaging b) demanding boundary conditions
  - Suggested were RANS fails: transient, separated flow

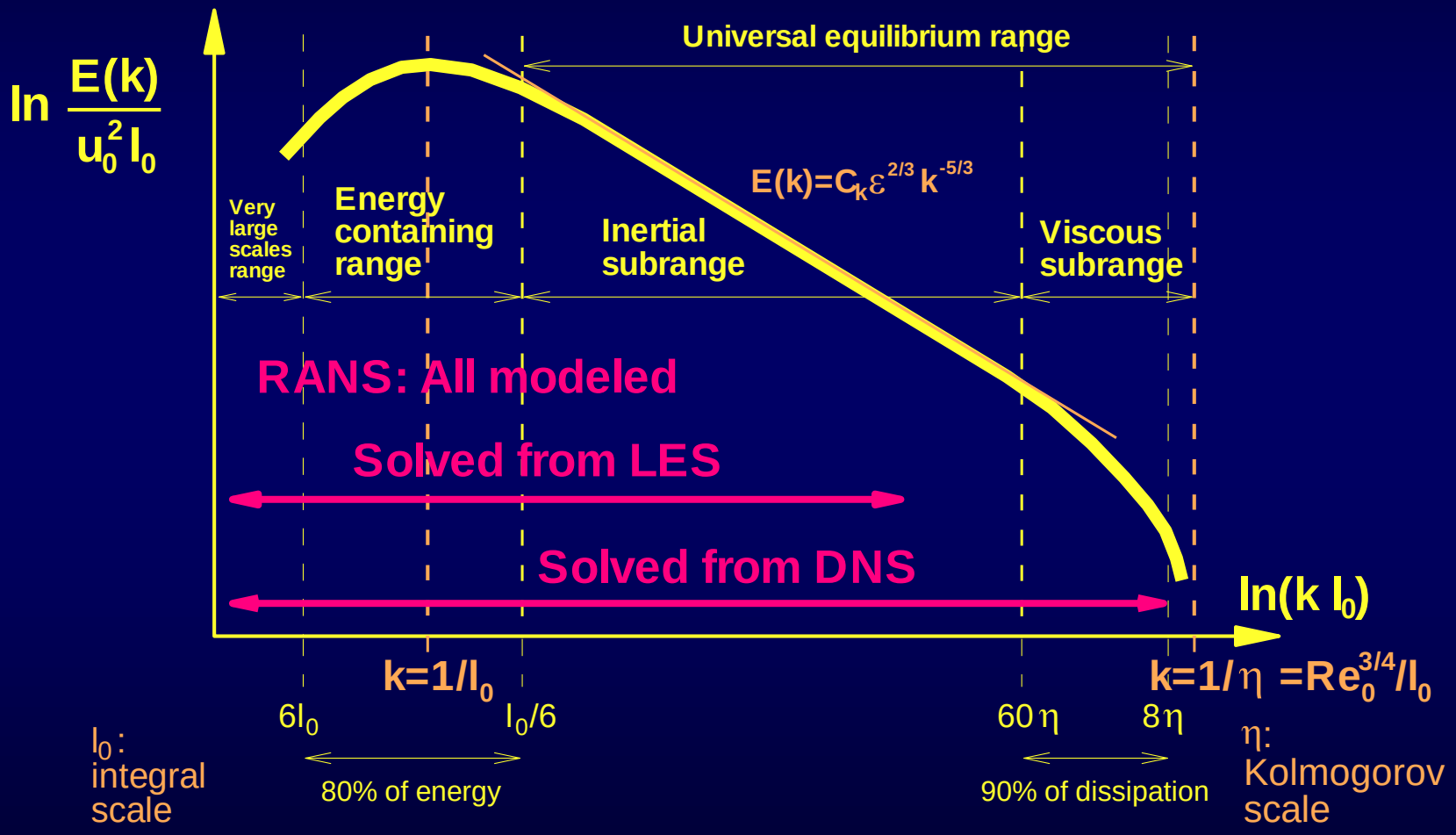
ENERGY CASCADE
LES solves most of the turbulence



l_0: integral scale

η: Kolmogorov scale

ENERGY CASCADE
LES solves most of the turbulence



LES EQUATIONS AT ADREA-HF
Compressible volume-filtered Navier-Stokes

- **Filtered equations:**

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial (\bar{\rho}\tilde{u}_i)}{\partial x_i} = 0$$

$$\frac{\partial (\bar{\rho}\tilde{u}_i)}{\partial t} + \frac{\partial (\bar{\rho}\tilde{u}_i\tilde{u}_j)}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial (\tilde{\tau}_{ij}^{l} + \tau_{ij}^{R})}{\partial x_j}$$

$$\tau_{ij}^{R} = -\bar{\rho}u_i u_j + \bar{\rho}\tilde{u}_i\tilde{u}_j$$

$$\bar{p} = \bar{\rho} r \bar{T}$$

$$\tilde{\tau}_{ij}^{l} + \frac{2}{3}\mu\frac{\partial \tilde{u}_k}{\partial x_k}\delta_{ij} = 2\mu\tilde{S}_{ij}$$

$$\tilde{S}_{ij} = \frac{1}{2}\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right)$$

- **Smagorinsky model of the residual stress tensor**

$$\tau_{ij}^{R} + \frac{1}{3}\tau_{kk}\delta_{ij} = 2\mu_t\tilde{S}_{ij}\ ;\ \mu_t = \bar{\rho}(C_s\Delta)^2\sqrt{2\tilde{S}_{ij}\tilde{S}_{ij}} \qquad \Delta = V^{1/3} \quad \text{Cs=0.1}$$

LES AT ADREA-HF
Numerics

- ADREA/SIMPLER algorithm
- Central differences convection scheme
- Solver: Parallel BiCGstab with parallel Schwarz preconditioner. Speedup with 2 CPUs up to 1.7
- For more:
  - Venetsanos, A. G., E. Papanikolaou and J. G. Bartzis, 2010: The ADREA-HF CFD code for consequence assessment of hydrogen applications. Int. J. Hydrogen Energy, 35, 3908.

LES
Boundary and initial conditions

- Initial conditions should also create turbulence
  - "Vortex generator" may be needed
  - Simpler solution: big over-imposed *disturbance*
- Boundary conditions should also retain turbulence
  - Difficult to do explicitly
  - Simpler solution: *cyclic* BC
- Near wall:
  - Well-resolved LES requires $z^+=1$
  - "Wall-function"-type solutions for coarser grids

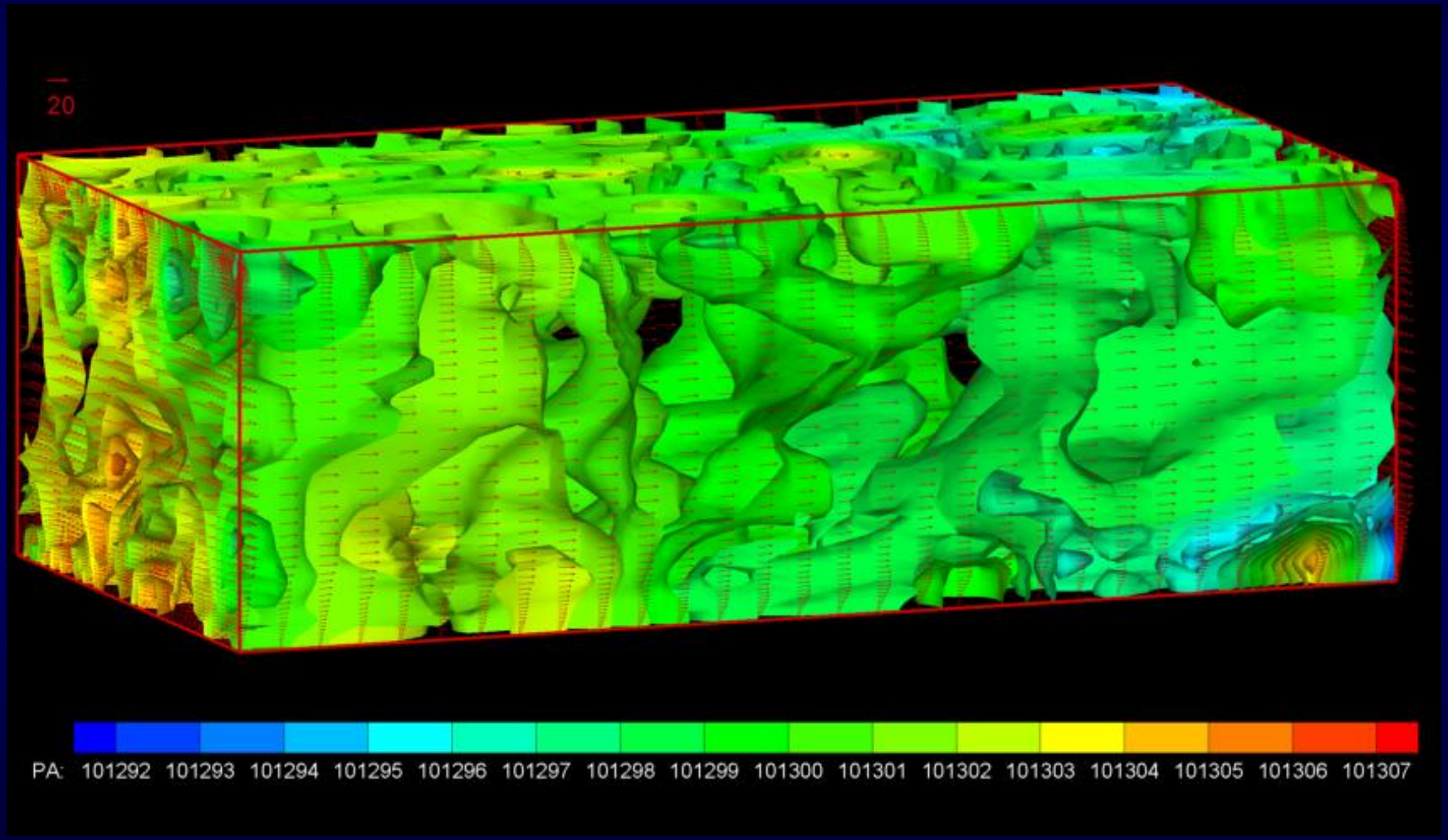
TEST CASES SETUP
a) Channel flow

- **1D fully-developed channel flow: the classic LES test**
  - **DNS of Moser et al, 1999 $Re = 8000$**
  - **90000 cells**
  - **Cyclic BC**
  - **$z^+ = 1$**
  - **$CFL_{max} < 0.3$**
  - **$C_s = 0.065$**
  - **Mass flow correction to control Re**
  - **Time 50s = 160 passes Averaging from 20s**

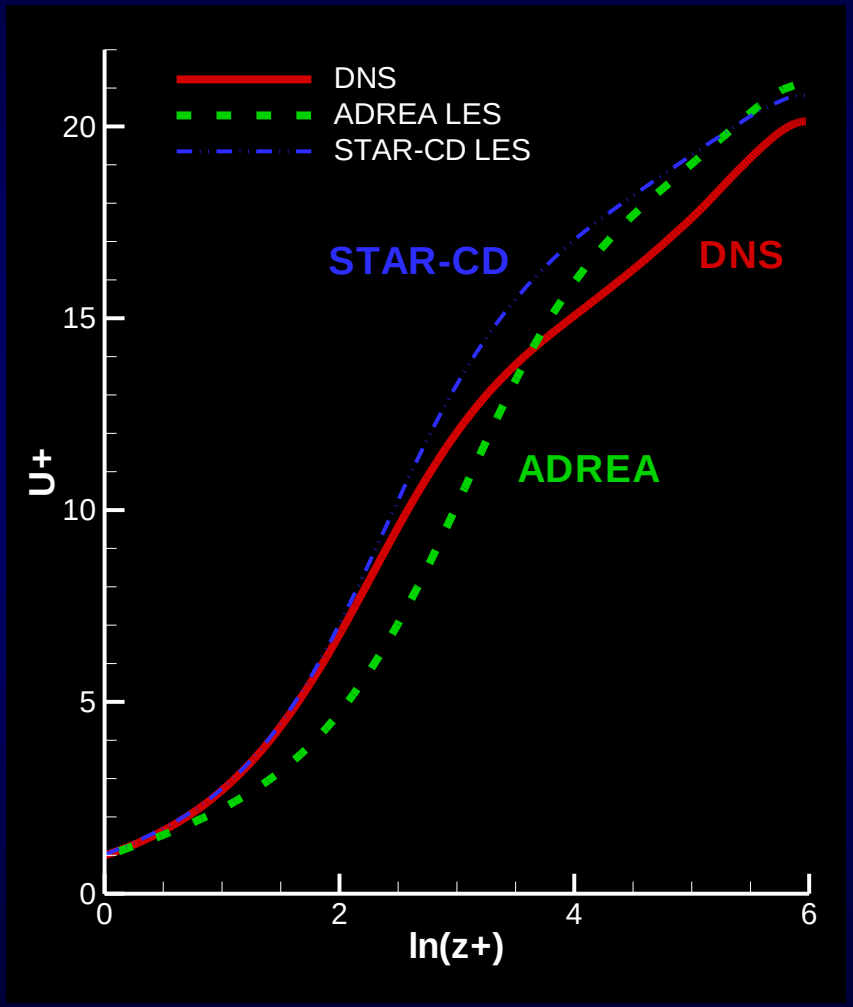
TEST CASES SETUP
b) Street canyon

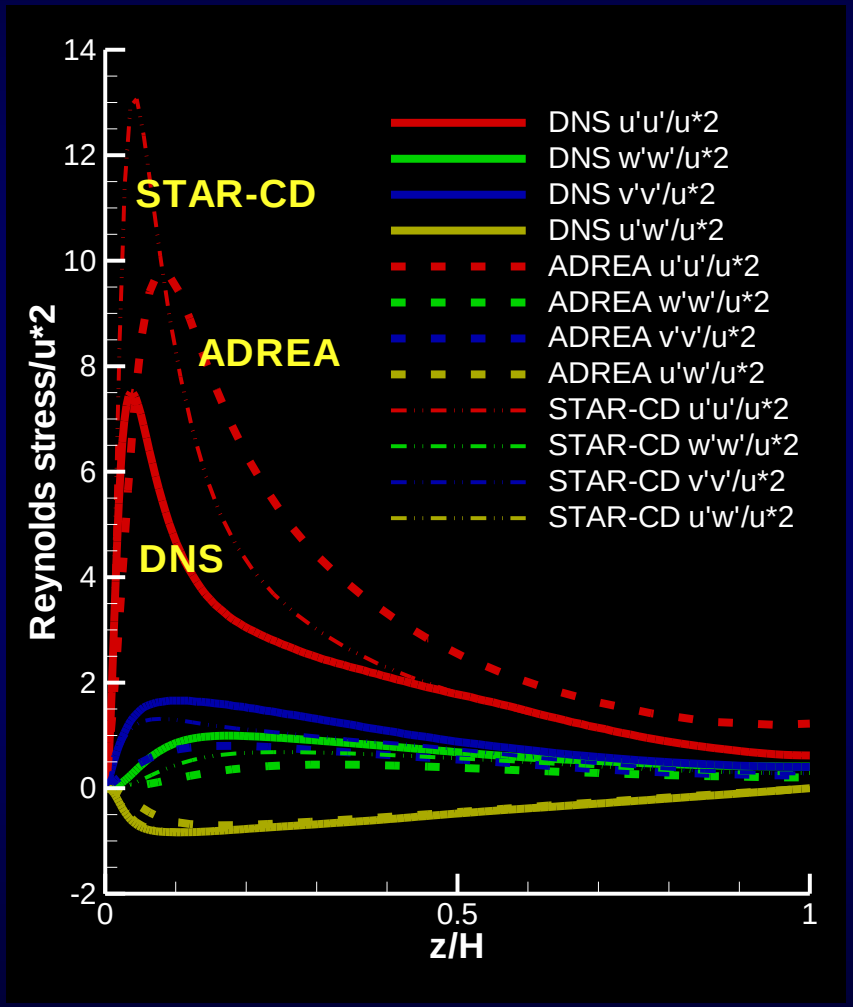
- 2D street canyon: the most basic urban case
  - Water channel of Li et al, 2009 Re = 12000
  - 300000 cells
  - Cyclic BC: sequence of identical canyons
  - $z^+ = 1$
  - Time 1000s = 250H/U Averaging from 400s

FULLY DEVELOPED CHANNEL FLOW
Pressure isosurfaces and velocity vectors

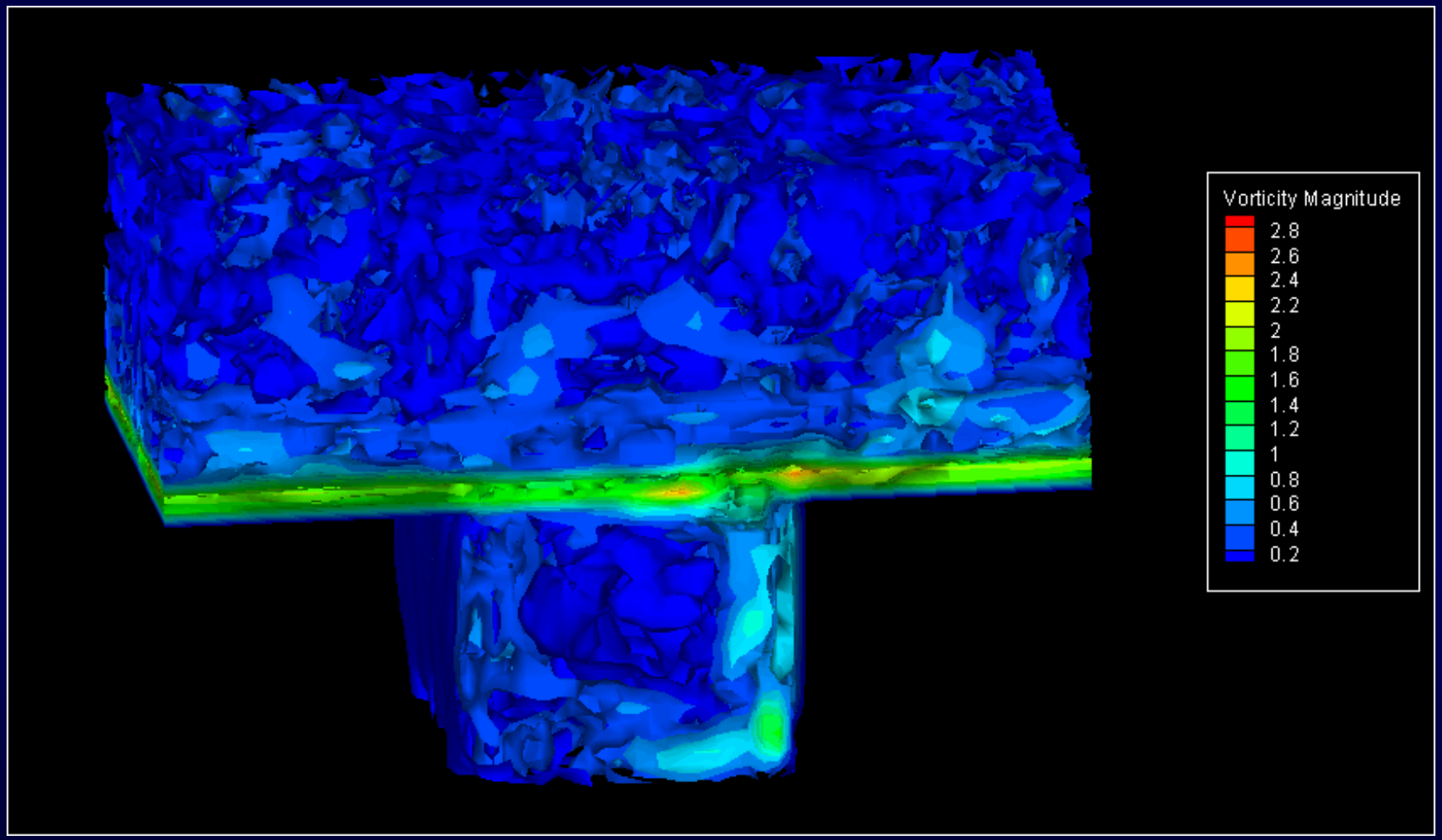


FULLY DEVELOPED CHANNEL FLOW
Comparison with DNS and other LES

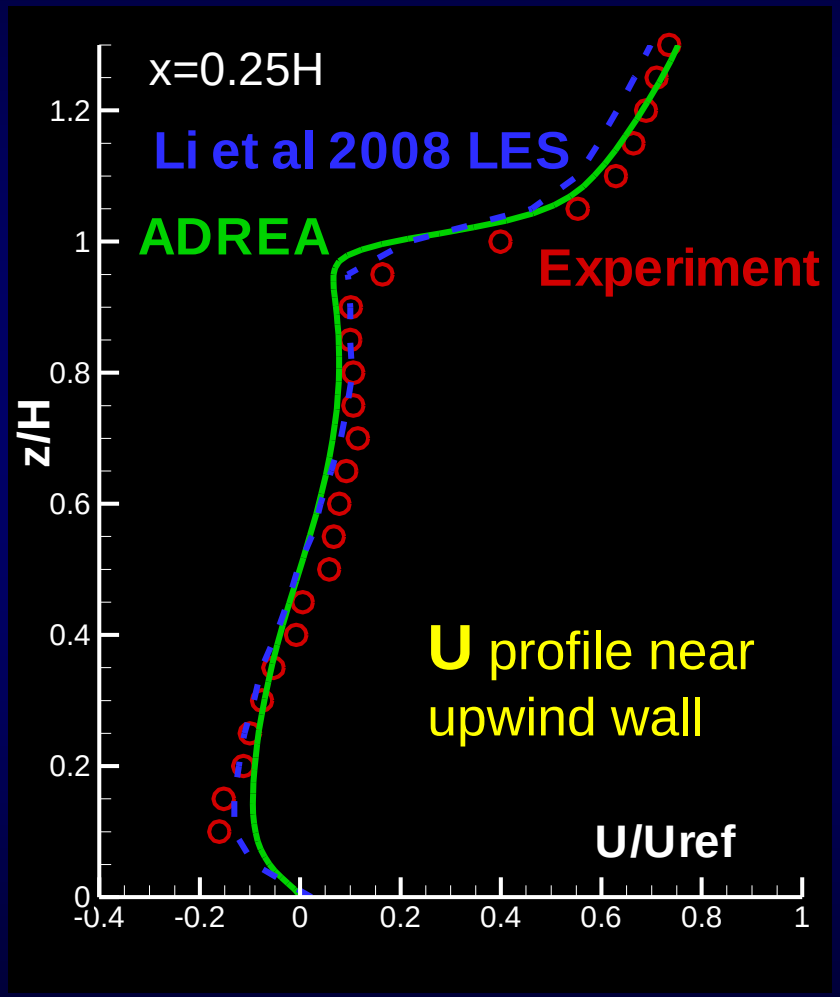


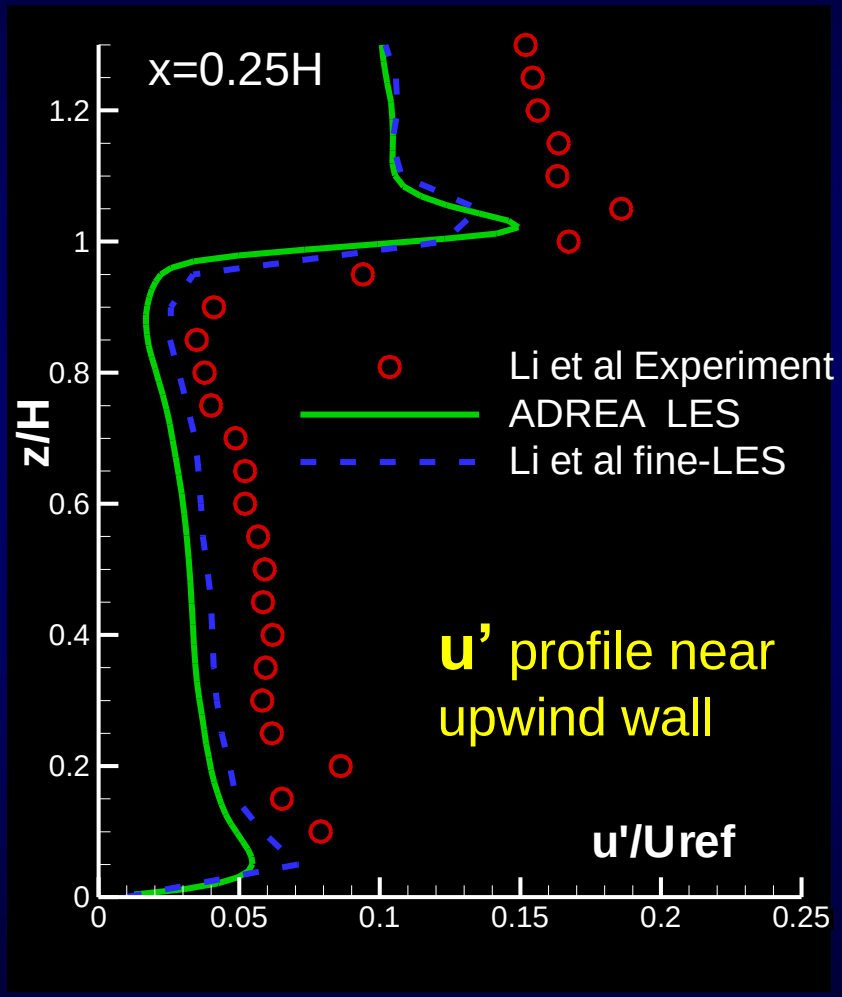


STREET CANYON
Canyon 1: Building width=2H. Real time movie

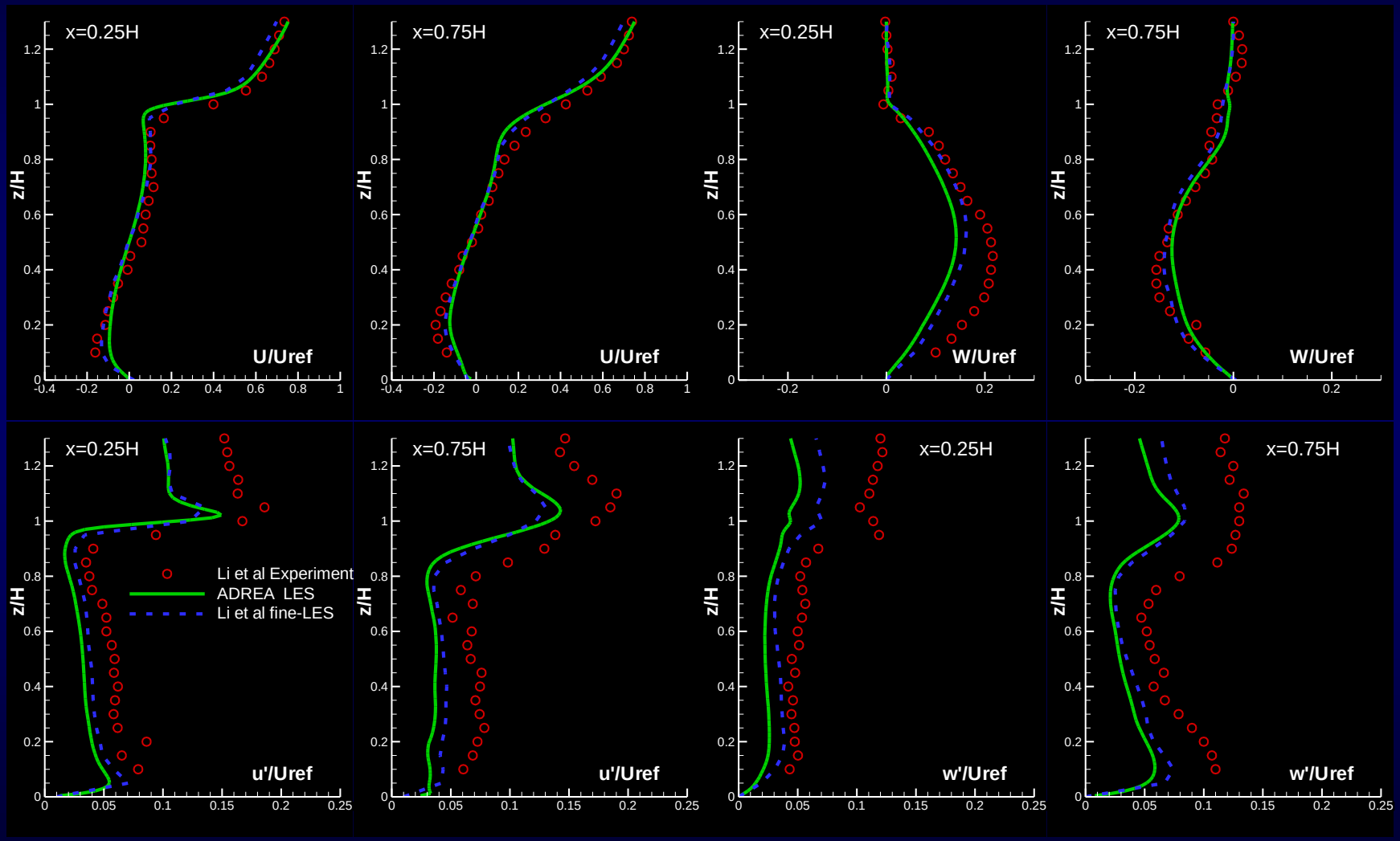


STREET CANYON
Canyon 2: Building =1H. Comparison with exp.





STREET CANYON
Canyon 2: Building =1H. Comparison with exp.



DISCUSSION
LES of ADREA-HF is competitive

- ADREA performs well against exps and other LESs
- Channel: C_s correction needed near wall
- General tendency of Reynolds stresses predicted
- Canyon: Performance very close to fine-grid LES
- Profiles similar shape to experimental ones
- Experiment stronger vortex with more turbulence:
  - In experiment vortex generators were used
  - In experiment 3D effects were present
- RANS (not shown) was also good in these tests

CONCLUSIONS
LES is not for everyday use

- ADREA-HF has now tested LES
- LES is not RANS++
- LES orders of magnitude more expensive than RANS
- Near wall treatment a key point for real-world cases
- What now:
  - Refine ADREA LES
  - Add and test more LES options

THE END
… is also a beginning

For any suggestions:

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