Toward one-dimensional turbulence subgrid closure for large-eddy simulation

Randy McDermott, Rod Schmidt,
Alan Kerstein, Phil Smith

CSGF Conference

Washington, D.C.

June 23, 2005

Sandia National Laboratories
Combustion Research Facility

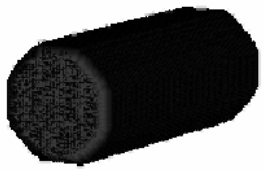
Acknowledgements

- DOE (DE-FG02-97ER25308)
- Krell Institute
- Stas Borodai (U. Utah)
- S. Kumar (U. Utah)
- Z. Gao (U. Utah)

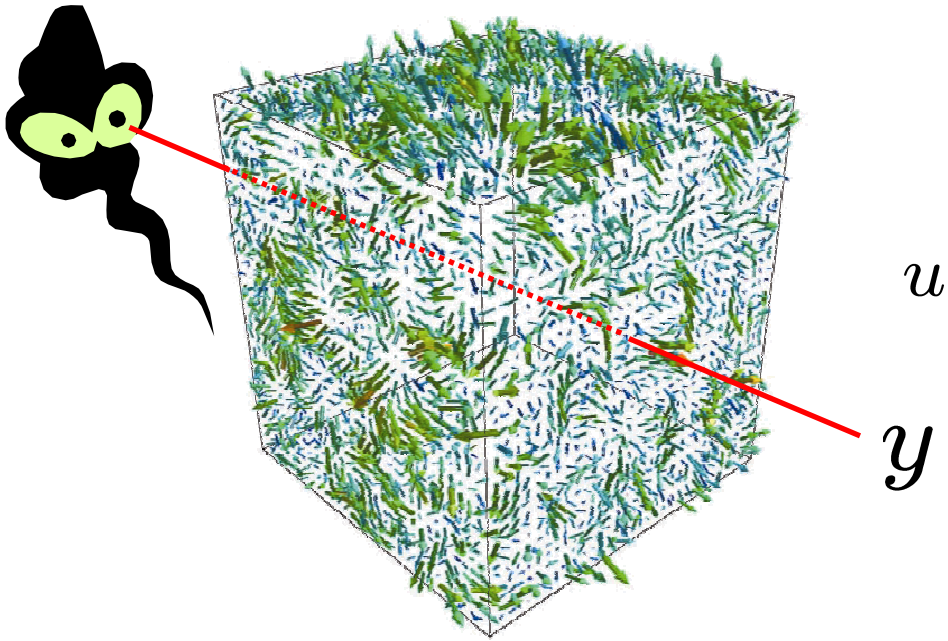
The C-SAFE ASCI problem

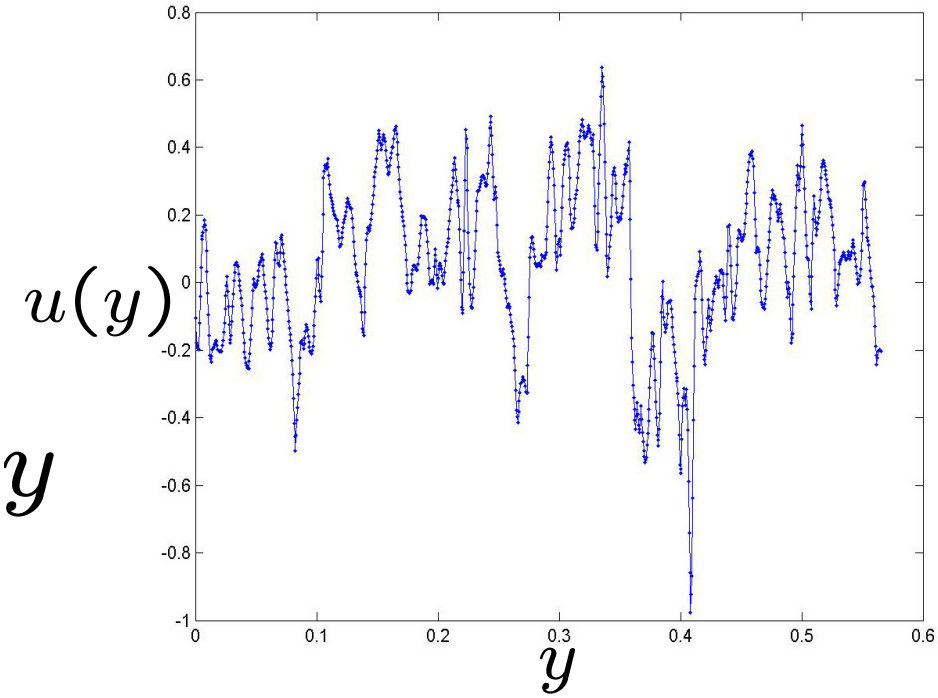
- multi-material
- radiation
- soot
- chemistry
- subgrid heterogeneity
- turbulence
  - subgrid energy production
  - subgrid stresses
  - intermittency
  - backscatter
  - anisotropy

Status: a cylinder in a fire



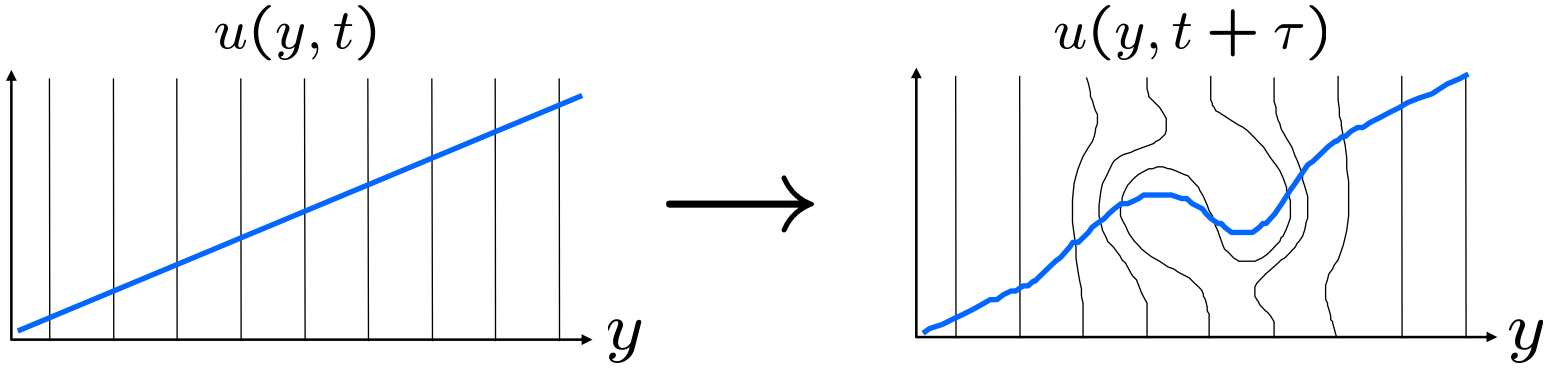
One-dimensional turbulence



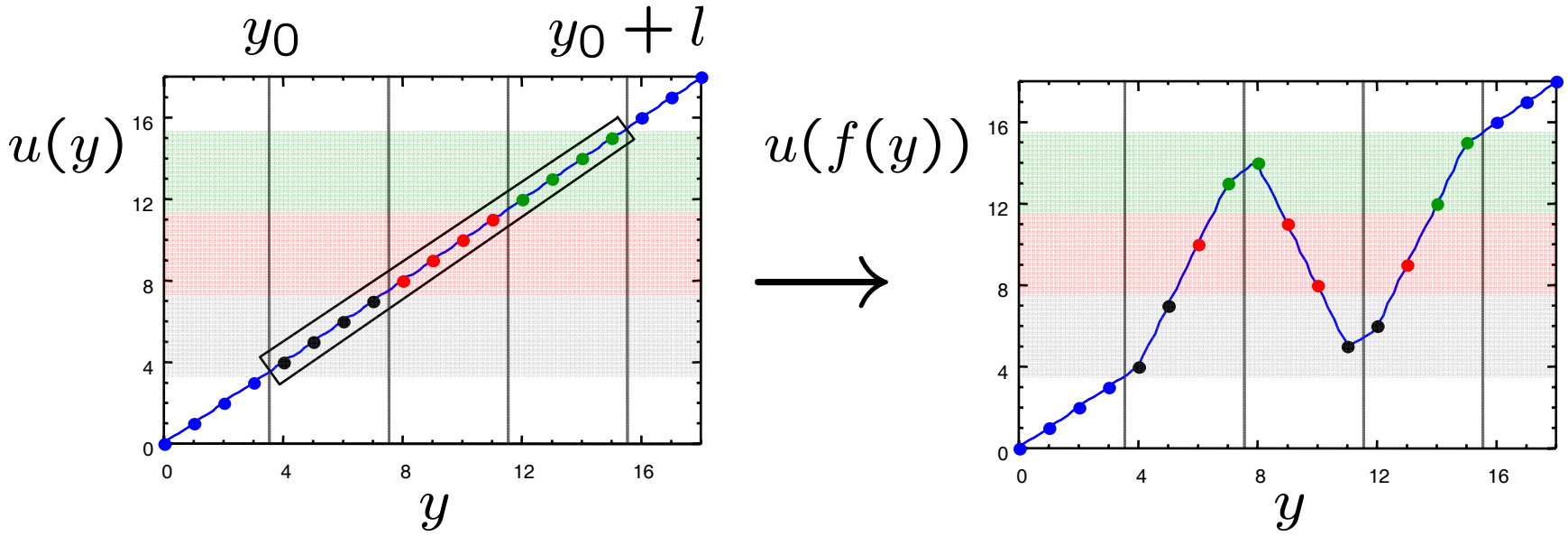


$$\frac{\partial u_i}{\partial t} = \nu \frac{\partial^2 u_i}{\partial y \partial y} + \text{eddy events}$$

The triplet map



$$u(y) \longrightarrow u(f(y)) \qquad f(y) = y_0 + \begin{cases} 3(y-y_0) & \text{for} \quad y_0 \le y \le y_0 + \frac{1}{3}l \\ 2l - 3(y-y_0) & \text{for} \quad y_0 + \frac{1}{3}l \le y \le y_0 + \frac{2}{3}l \\ 3(y-y_0) - 2l & \text{for} \quad y_0 + \frac{2}{3}l \le y \le y_0 + l \\ y - y_0 & \text{otherwise} \end{cases}$$



Eddy sampling: where,when,how big?

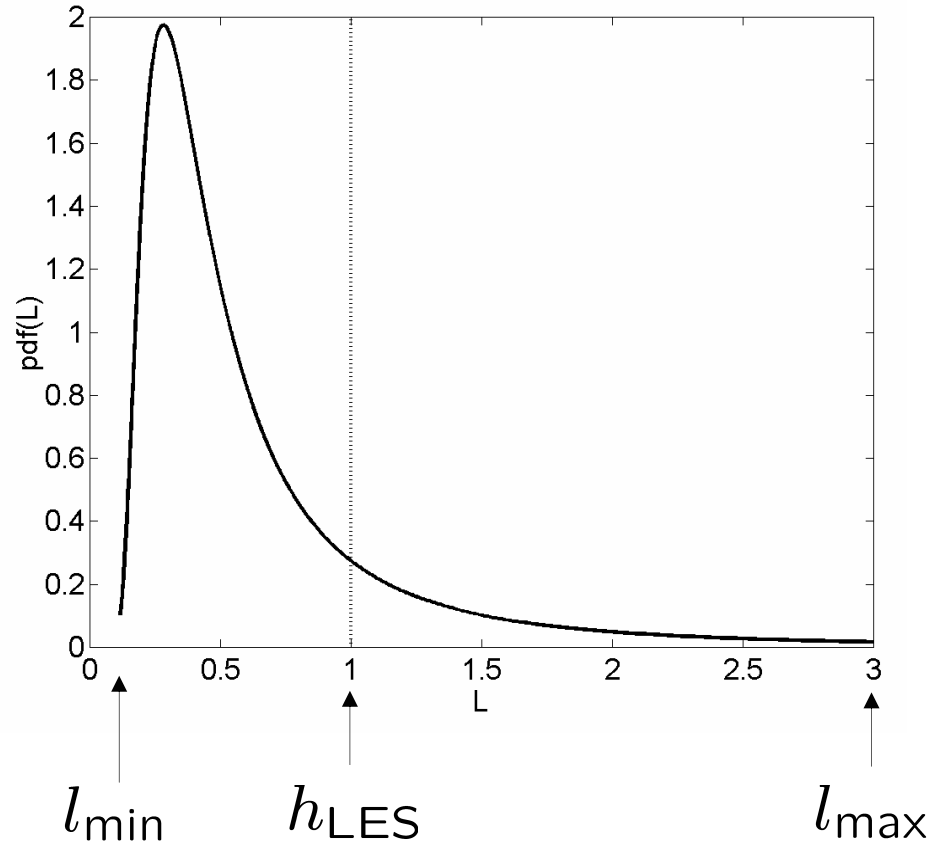
$$\lambda(t; y_0, l) \equiv \frac{1}{l^2 \tau(t; y_0, l)} [=] \frac{\text{events/time}}{\text{position} \times \text{length}}$$

eddy energetics

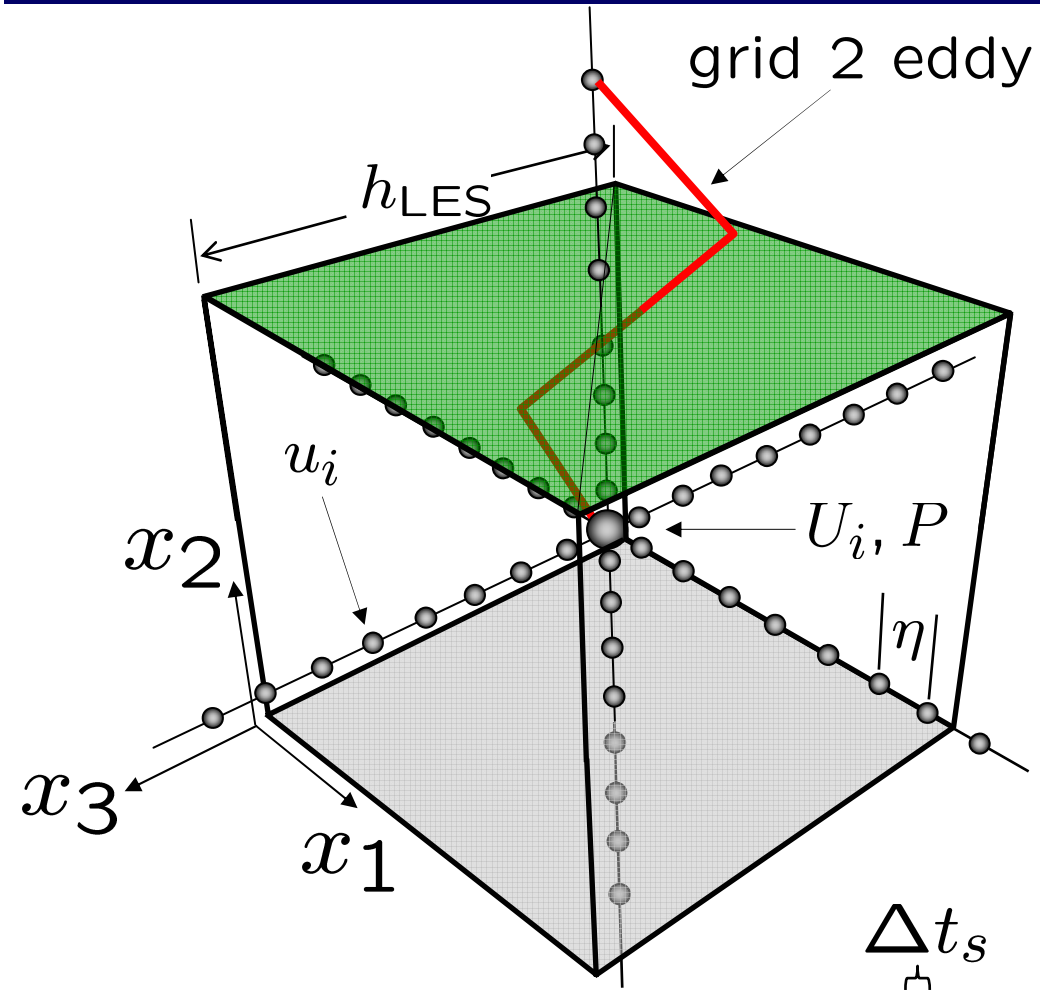
$$\frac{1}{2} m u^2 \sim \frac{1}{2} m \left(\frac{l}{\tau}\right)^2$$

model parameters

$$\frac{1}{\tau} = C \frac{\nu}{l^2} \sqrt{\text{Re}_l^2 - Z^2}$$



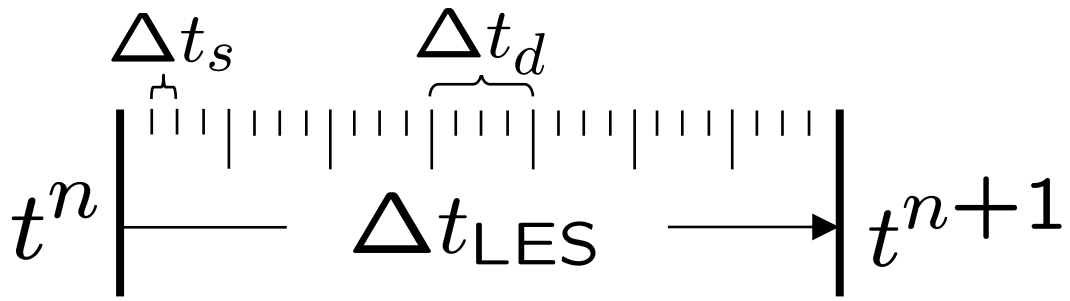
LESODT



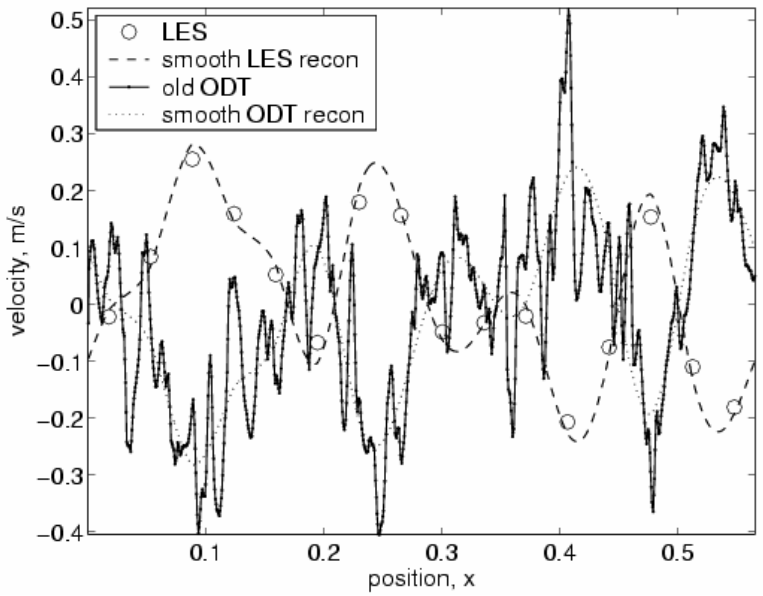
Algorithm:

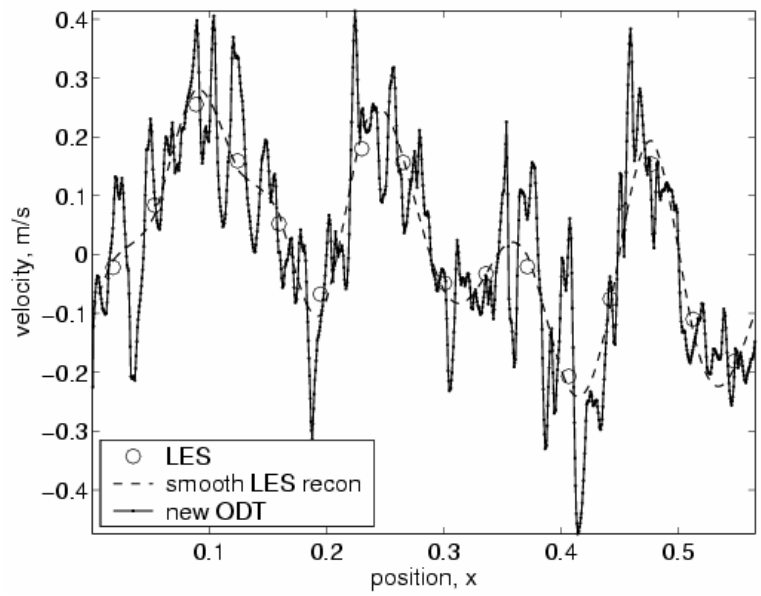
1. $\overline{u}_i^n = U_i^n$
2. Obtain F_i^{ODT}
3. $\dfrac{\mathrm{d}U_i}{\mathrm{d}t} = F_i^{\mathrm{NS}} + F_i^{\mathrm{ODT}}$
4. Reconstruct

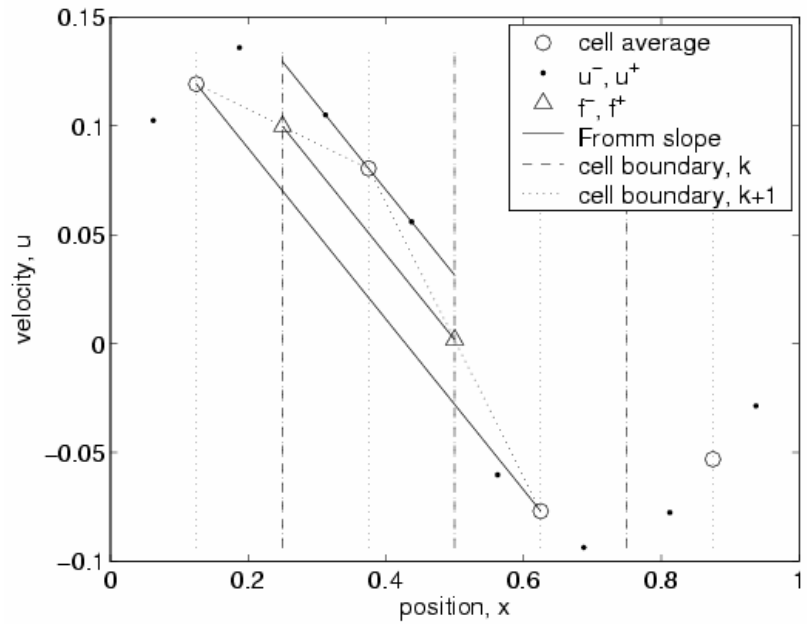
$\overline{u}_i^{n+1} \neq U_i^{n+1} \rightarrow \overline{u}_i^{n+1} = U_i^{n+1}$



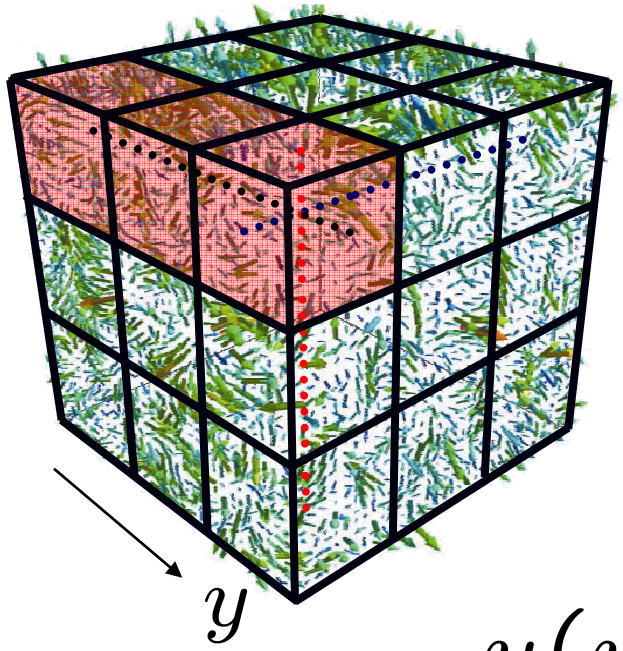
Reconstruction



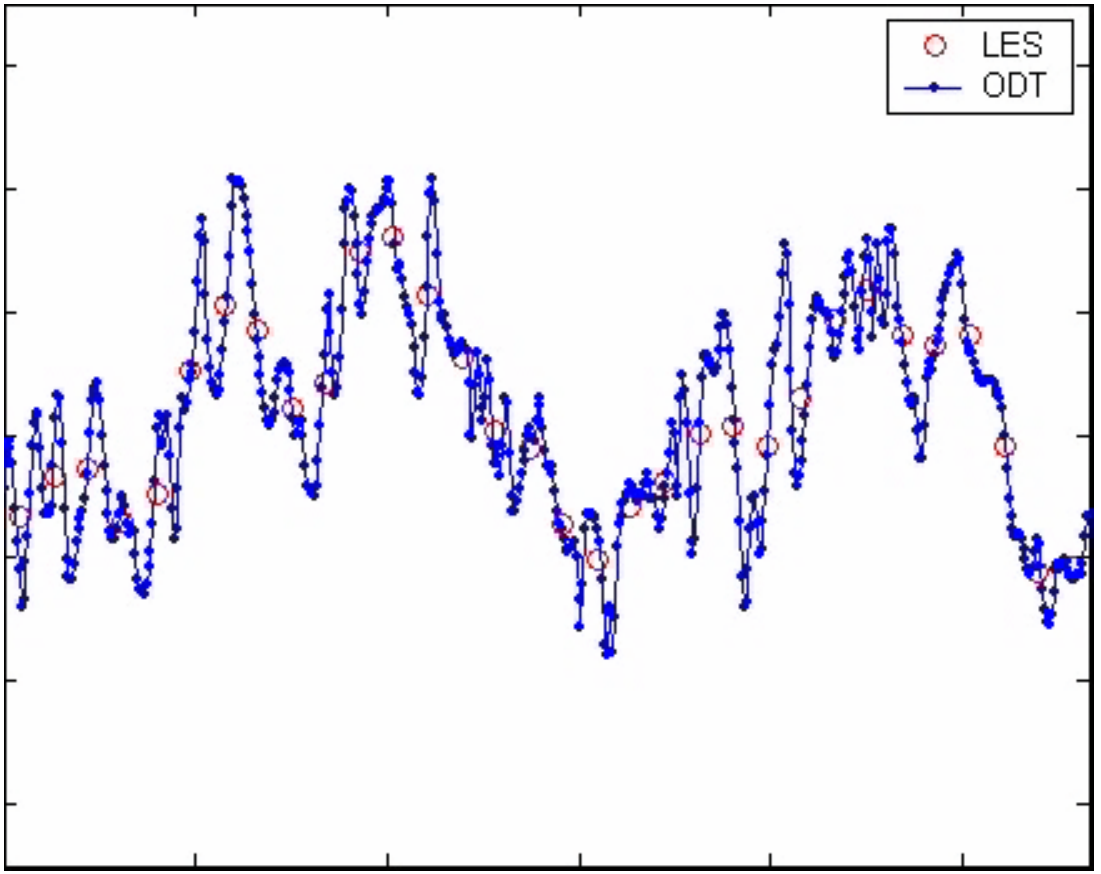




32^3 LES / 512 ODT



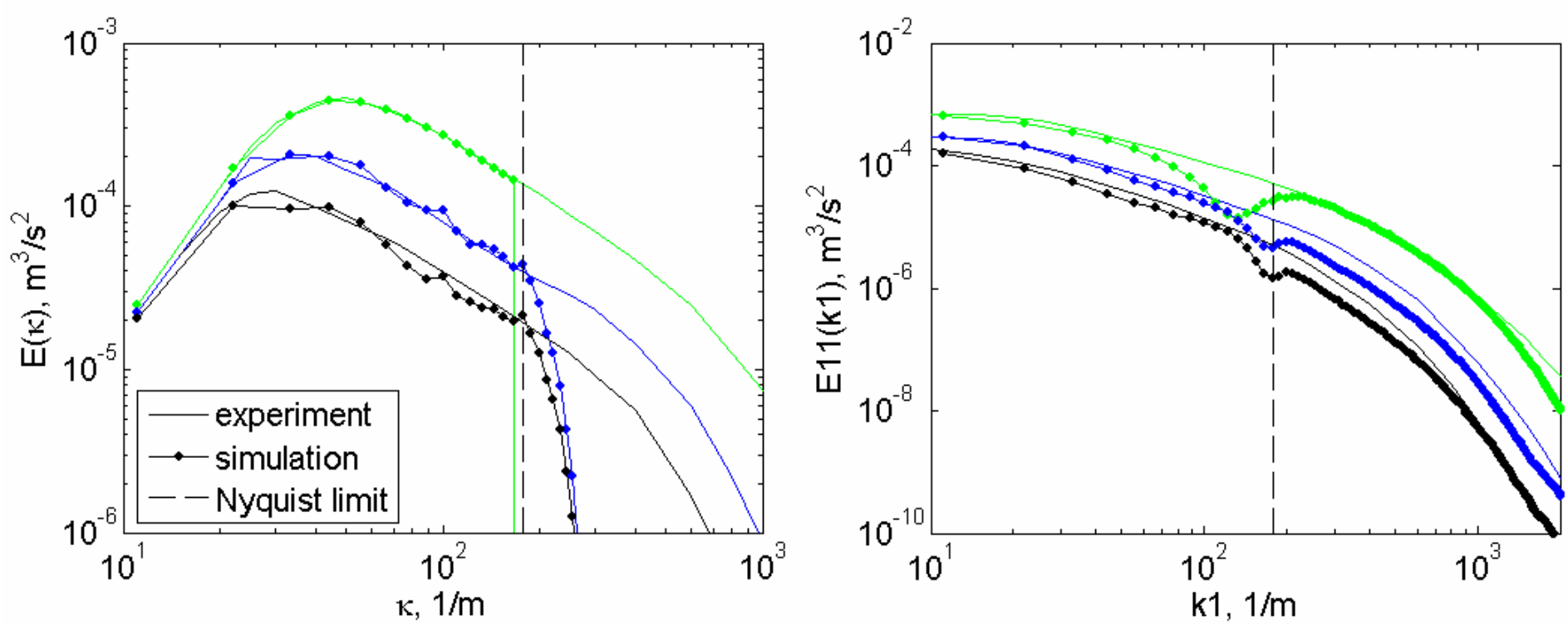
$u(y)$



y

Spectral results

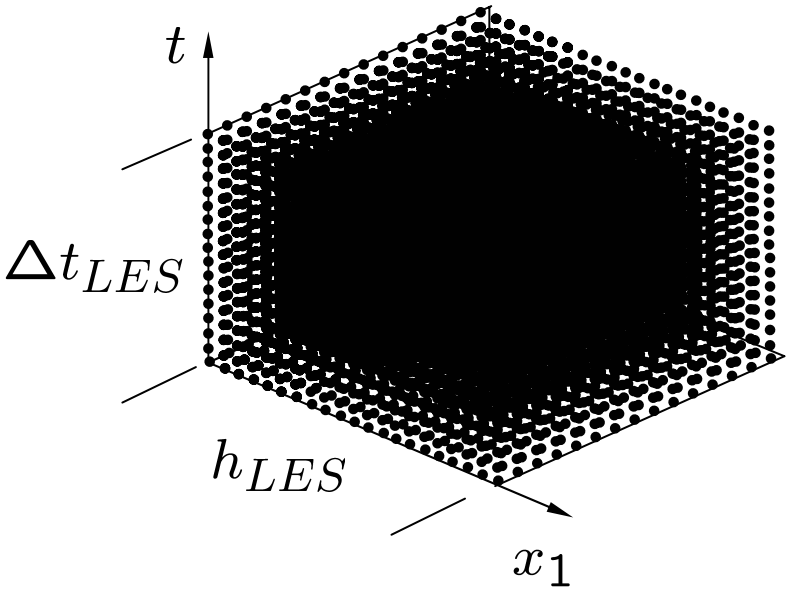
Comte-Bellot and Corrsin (1971)



$$E_{11}(\kappa_1) = \int_{\kappa_1}^{\infty} \frac{E(\kappa)}{\kappa} \left(1 - \frac{\kappa_1^2}{\kappa^2}\right) \, \mathrm{d}\kappa$$

Computational work

DNS



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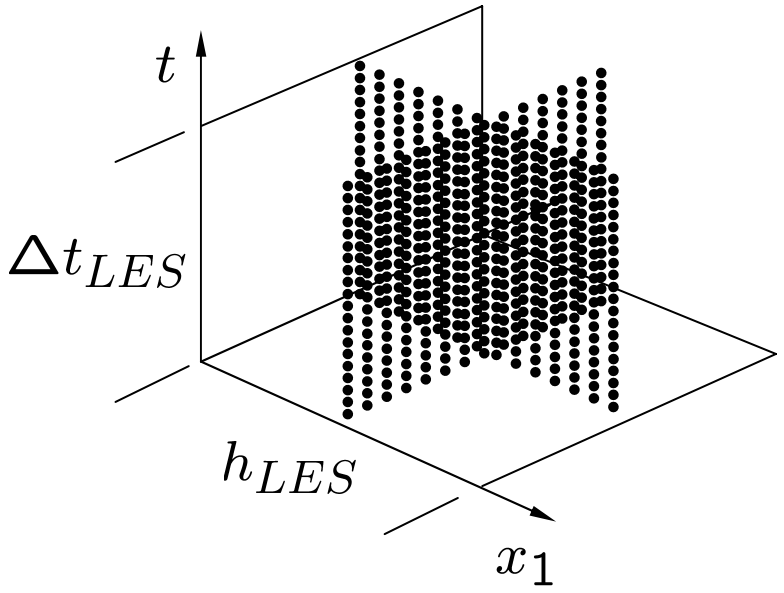
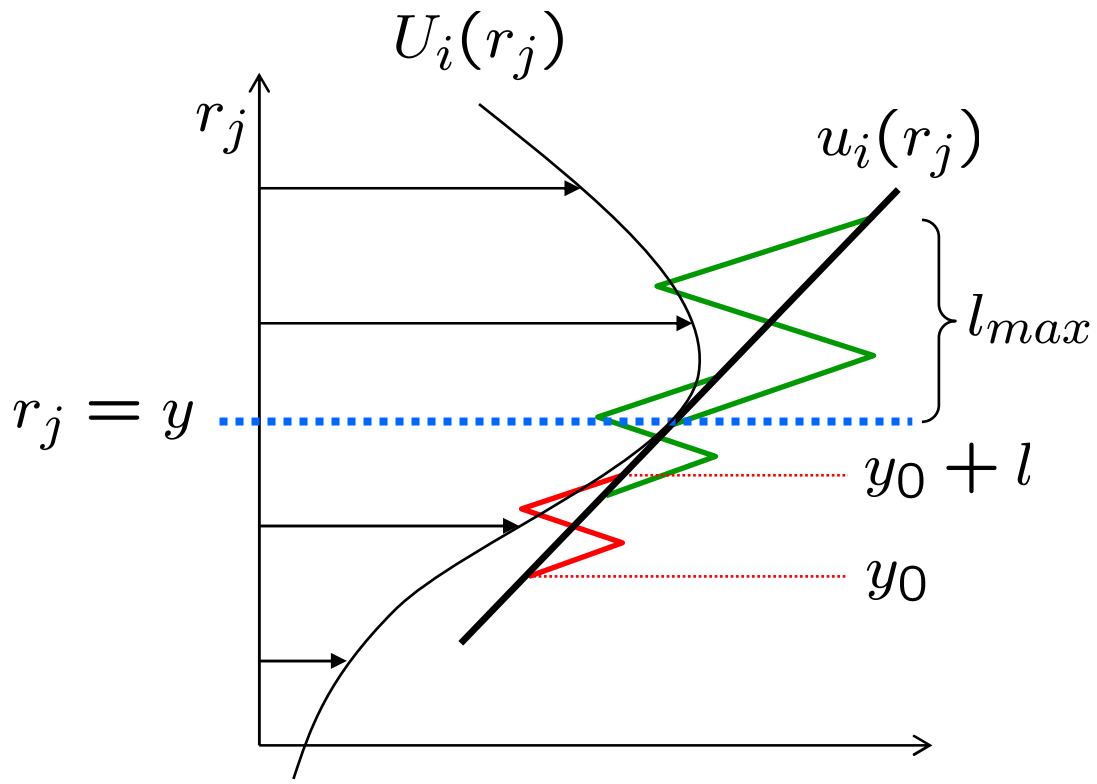


3D space:

$$\sim \left(\mathrm{Re}^{\frac{3}{4}}\right)^4 = \mathrm{Re}^3 \qquad \sim 3\left(\mathrm{Re}^{\frac{3}{4}}\right)^2 = 3\,\mathrm{Re}^{3/2}$$

Ensemble mean closure



$$y_0 \le y \le y_0 + l$$

$$S_{ij}(y) \equiv \partial_r U_i|_{r_j=y}$$

$$\tau_{ij}^{sgs}(y) = -\frac{1}{27}\left(l_{max}^2 - l_{min}^2\right)|S(y)|\,S_{ij}(y)$$

Closing remarks

- Parallel results in progress
- LESODT tool kit (http://www.inscc.utah.edu/~randy)

Questions?

"Physicists come and go, and the problem of turbulence remains."

~ A. Liebchaber (1988)